JYU Dissertations 804

Sami El Geneidy

Integrating Financial, Carbon and Biodiversity Footprint Accounting in Organizations

JYVÄSKYLÄ UNIVERSITY
SCHOOL OF BUSINESS AND ECONOMICS

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Esitetään Jyväskylän yliopiston kauppakorkeakoulun suostumuksella
julkisesti tarkastettavaksi yliopiston vanhassa juhlasalissa S212
kesäkuun 11. päivänä 2024 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Jyväskylä University School of Business and Economics,
in building Seminarium, auditorium S212, on June 11, 2024 at 12 o'clock noon.

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2024

Editors
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Cover photo by Sami El Geneidy.

ISBN 978-952-86-0216-3 (PDF)
URN:ISBN:978-952-86-0216-3
ISSN 2489-9003

Permanent link to this publication: http://urn.fi/URN:ISBN:978-952-86-0216-3

ABSTRACT

El Geneidy, Sami
Integrating financial, carbon and biodiversity footprint accounting in organizations
Jyväskylä: University of Jyväskylä, 2024, 106 p. + original articles
(JYU Dissertations
ISSN 2489-9003; 804)
ISBN 978-952-86-0216-3 (PDF)

Climate change and biodiversity loss are deteriorating the foundations of good life on Earth. Organizations, such as businesses, public institutions and associations, are the basic building blocks of societies. Carbon and biodiversity footprint assessments have been developed to understand the contribution of organizations to climate change and biodiversity loss. The assessment of carbon and biodiversity footprints alone is unlikely to initiate the necessary transformative changes. Financial accounting, a key decision-making tool in organizations, would also need to be transformed to better reflect the reality showcased by environmental accounts.

In this doctoral dissertation I develop the assessment of consumption-based carbon and biodiversity footprints in organizations by testing the methodologies in pilot organizations. In addition, I explore the use of financial accounts in environmental accounting and the possibility for environmental accounts to change the value of financial accounts.

The results indicate that upstream value chain carbon and biodiversity footprints have a high contribution in organizations. Flights, procurement of goods and services and energy consumption are important contributors across organizations. The developed biodiversity footprint methodology can be used to assess the biodiversity footprint of consumption in various contexts. The indicator of biodiversity loss, which I further developed and call the biodiversity equivalent, can be used by organizations to compare value chain biodiversity footprints across the world. Finally, I show that setting a financial value to the carbon and biodiversity footprints with offsetting mechanisms can significantly affect the financial position of an organization.

Comprehensive environmental accounting and its integration to financial accounting can be a necessary initial step towards planetary well-being. However, transformative changes in organizations, and in the society, could benefit from a value-transforming integration of financial and environmental accounting. Value-transforming financial-environmental accounting has the potential to change the structures, decision-making processes, and perhaps even underlying values that guide financial decision-making in organizations and the society.

Keywords: carbon footprint, biodiversity footprint, environmental accounting, financial accounting

TIIVISTELMÄ (ABSTRACT IN FINNISH)

El Geneidy, Sami
Hiili- ja luontojalanjäljen sekä talouskirjanpidon yhdistäminen organisaatioissa
Jyväskylä: Jyväskylän yliopisto, 2024, 106 s. + artikkelit
(JYU Dissertations
ISSN 2489-9003; 804)
ISBN 978-952-86-0216-3 (PDF)

Ilmastonmuutos ja luontokato heikentävät hyvän elämän perusedellytyksiä maapallolla. Organisaatiot, kuten yritykset, julkiset instituutiot ja yhdistykset, ovat yhteiskuntamme peruspilareita. Hiili- ja luontojalanjäljen laskenta on kehitetty, jotta ymmärtäisimme organisaatioiden vaikutuksen ilmastonmuutokseen ja luontokatoon. Hiili- ja luontojalanjäljen laskenta on kuitenkin yksinään riittämätön toimi tarvittavan yhteiskunnallisen muutoksen saavuttamiseksi. Talouskirjanpito on keskeinen päätöksenteon väline organisaatioissa ja se pitäisi muuntaa vastaamaan paremmin ympäristökirjanpidon realiteetteja.

Väitöskirjassani kehitän kulutusperustaista hiili- ja luontojalanjäljen laskentaa testaamalla menetelmiä pilottiorganisaatioissa. Lisäksi tutkin talouskirjanpidon hyödyntämistä osana ympäristökirjanpitoa sekä ympäristökirjanpidon mahdollisuuksia vaikuttaa taloudellisen arvon muutokseen.

Tulokset osoittavat, että arvoketjun rooli tutkittujen organisaatioiden hiili- ja luontojalanjäljessä oli suuri. Esimerkiksi lennot, tavaroiden ja palveluiden hankinta, sekä energiankulutus, ovat merkittäviä hiili- ja luontojalanjäljen aiheuttajia. Kehittämääni luontojalanjäljen laskentamenetelmää voidaan käyttää kulutuksen luontojalanjäljen laskentaan eri konteksteissa. Jatkokehitin aikaisempaan tutkimukseen perustuen mittarin, luontoekvivalentin, jota eri organisaatiot voivat käyttää luontojalanjälkensä laskentaan ja vertailuun ympäri maailman. Lopuksi osoitan, että taloudellisen arvon asettaminen hiili- ja luontojalanjäljelle kompensaatioiden avulla voi vaikuttaa organisaation taloudelliseen asemaan merkittävästi.

Kokonaisvaltainen ympäristökirjanpito ja sen yhdistäminen talouskirjanpitoon voi olla tärkeä ensimmäinen askel kohti planetaarista hyvinvointia. Yhteiskunnallinen kestävyysmurros saattaisi kuitenkin hyötyä laajemmasta taloudellista arvoa muuttavasta ympäristö-taloudellisesta kirjanpidosta. Kirjanpidon murros voi parhaimmillaan mahdollistaa organisaatioiden ja yhteiskunnan rakenteiden, päätöksenteon prosessien ja jopa taloudellista päätöksentekoa ohjaavien arvojen muutoksen.

Asiasanat: hiilijalanjälki, luontojalanjälki, ympäristökirjanpito, ympäristötilinpito, talouskirjanpito

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FOREWORD

When I think about the starting point of this journey, my mind travels back to Naddi village, situated at the foot of the Himalayan mountains in Northern India. I travelled there to do my internship and Master’s thesis in a non-governmental organization called EduCARE India. At that time, I had a completely different idea about what I would like to do there, and I can assure you, it had next to nothing to do with environmental accounting.

I started thinking about interesting topics, and after a while we decided with the head of the organization, known as Mr. B, that perhaps it could be interesting to explore the carbon footprint of the organization. I got excited about the topic and started emerging myself into it. I have a very vivid experience of sitting there on the terrace of my host family with my laptop and reading a report from the Intergovernmental Panel on Climate Change (IPCC). I thought that I had been environmentally conscious before, but what I read completely started to change my mindset. To be quite frank, I started feeling guilty about the fact that I had flown to India to do something I thought was important, while at the same time the very same emissions my travel decision created were devastating lives, human and non-human, around the world. I know, let’s not focus too much on individuals and what I did might have triggered immeasurable positive pathways, but still, the feeling persists. The time I had in India was priceless. I often tend to think that it is useless to dwell on the past, but I find myself often dwelling in this particular past, which makes me both sad and happy at the same time.

I want to thank my host family, especially Reena and Seema, for giving my work purpose, giving me support and taking me into the family with such warm-hearted attitude. Thank you for taking me to collect wood, plough the field, herd the goats and showing me how even during the rainy monsoon season it is possible to light up a fire. I will remember and cherish those moments with the whole family by the fire in the kitchen. I hope I can meet you again one day. I want to thank the other interns and volunteers, especially Rachit, Graham, Gaston, Cléa, Isabel, Malte and Lea. I also want to thank the wonderful Gujarat, Rajkot crew Yash, Karan, Alkesha and Charmi. Special thanks to Yash for hosting me in Rajkot, hope you and the family are well. A huge thanks for all the support with my work and for giving me yet another reason to smile some more to Meg and Shivani. This research would not have been possible without the support from the local community and the organization. Special thanks to Reena, Durjula, Anjali and Shabbu. Gulshan, thank you for providing me support and for the trip to your home, I miss the food I got to taste at your place. Mr. B, thank you for the, dare I say, often long but mind provoking discussions and for giving me the freedom and opportunity to pursue this research in Naddi. Finally, I would like to thank the non-human friends who made my life, writing processes and data collection so much happier: the goat Batman, the sheep Robin, the family goats, and all the lovely office dogs. Many thanks to you all and others, who I could not name here.

I started finalizing my Master's thesis after spending a while back in Finland. My supervisor and to-be doctoral thesis supervisor, Stefan Baumeister, encouraged me, or rather us, to pursue a scientific publication from the thesis data. Already then, I got to know Stefan as an easily approachable and warm-hearted supervisor. With Stefan's care and guidance, we managed to publish the first article of my dissertation.

After graduation I applied for several positions in many kinds of organizations. I even applied for a position in the JYU.Wisdom community as a project coordinator but I ended up on the second place. These kinds of crossroads sometimes make me wonder if things might have been very different if the alternative path would have taken place. However, I didn't stay in Finland for too long and I went off to work in Bonn, Germany for the European Forest Institute (EFI) as an Environmental Management Trainee. In this position I got to assess the carbon footprint of EFI and develop an environmental management programme. Again, this journey proved to be fruitful, and I met many wonderful people who helped me along the way to this dissertation. I'd like to give special thanks to Theresa Frei, Andrew Male and all the great people at the Bonn office for taking me in so warmly. Thank you also those of you who hosted me at the Barcelona and Joensuu offices. Special thanks to Venla, Vilppu and Lenni for hosting me in Joensuu. The time in the European Forest Institute also eventually manifested as the second article of my dissertation. This process was again greatly helped by Stefan's guidance and work towards the article. A warm thanks also to my other co-authors and colleagues: Valentino Marini Govigli, Cleo Orfanidou and Venla Wallius. On my short academic career, this has been one of the most pleasant article-writing processes, and I think it's mainly because of the kind dedication you took to contribute to the article, thank you.

At the end of my stay in Bonn, I was contacted by Janne S. Kotiaho. Janne offered me a position at the University of Jyväskylä to work with the carbon (and eventually biodiversity) footprint assessment of the university. He later told me that he got interested by my writings in Twitter. I find this quite amusing and often use it as anecdotal evidence that perhaps social media is not all bad. This project, called Sustainability for JYU, was perhaps the final push to starting my journey as a doctoral researcher. I remember the initial discussions in Janne's office with me, Janne and the students Veera Vainio, Diego Alvarez Franco and Elli Latva-Hakuni. Soon after starting the work I learned that I would enjoy working together with Janne. His direct and compassionate style is something I admire up to this date. Furthermore, I learned that researchers do not have to be hidden in their chambers. They can and should speak out loud and this vision of impactful research inspired and motivated me to eventually start the doctoral dissertation.

Even though the pandemic soon took its place in the daily lives of people, I found my time in Sustainability for JYU to be very pleasant. Although, I have to admit that I feel sorry for my partner Ilona who was trying to finalize her Master's thesis when the pandemic hit and we lived together in a studio apartment. This meant us suddenly spending a lot of time in the same space and I was of course often in Teams and she had to find focus for writing. Nowadays we think back at this time with proper amusement, as horrible as it was for Ilona.

I'd like to thank the whole Sustainability for JYU team: Diego, Stefan, Panu, Ulla, Teea, Elli, Marileena, Liia-Maria, Veera and Janne. Thank you for giving me support, what I do currently, would not have been possible without your bright minds. I'd also like to thank the people in the administration of the University of Jyväskylä for giving your time to the project, especially Ulla Helimo, Viivi Aumanen, Tarja Keihäsvuori, Sari Särkioja, Vesa Kupari and many more. Special thanks also to Vesa for keeping the discussion going and being so active in taking the sustainability discussions to the university investment world. Also many thanks to my co-authors who helped draft the manuscript and preprint about the Sustainability for JYU project: Stefan, Maiju and Janne.

During the Sustainability for JYU project I also met for the first time the people from Green Carbon: Matti Toivonen and Kimmo Koistinen. Especially with Matti we've had many intriguing discussions about carbon and biodiversity footprint assessments, mixed with thoughts about how all this could be combined with financial accounting practices. The discussions have been inspiring. But more than that, I would like to thank Green Carbon, and Matti and Kimmo, for making my doctoral dissertation a reality. My research would not have been possible without funding from Green Carbon. I thank your for putting your trust in me and for giving me the chance to develop my research. Working together with a company that operates "on the field" has given my research a sense of purpose, a feeling that it will be useful and used by others. Thank you and all others at Green Carbon who made this possible.

The Sustainability for JYU group eventually evolved into something else: The Biodiversity Footprint Team. The research group has been evolving and expanding throughout the years, and I currently feel happy that it has gained a more solid standing with many bright minds involved in thinking how we can measure biodiversity footprints and how can we stop biodiversity loss. People often ask me, what do I like about my work. One of the first things that come to my mind is the research group. The whole group is a lovely bunch of people and we've already had so many great discussions, exhausting and mind-boggling brainstorming sessions, and much more. I'd like to thank the current team members Jani, Maiju, Krista, Veera, Laura O. and Laura H., Essi P. and Essi J., Silja, Jaakko, Eetu, Aija, Juho, Ulla, Brayshna, Charlotte and Janne.

I'd also like to thank the many funders of this group who have certainly contributed to making my doctoral dissertation a reality as well: The Finnish Innovation Fund Sitra, S Group, Nokia, City of Tampere, Ministry of the Environment, University of Turku, The Finnish Academy of Science and Letters, Traficom and the Student Union of the University of Jyväskylä. Special thanks to Lasse Miettinen from Sitra for the intriguing discussions and Satu Kuoppamäki and Nina Elomaa from S Group for placing your trust on our research group among one of the first organizations.

Another group that has been giving so much to this work, is the BOOST for biodiversity offsets research consortium. My work would not have been possible without the support and inputs from you all, thank you. The research consortium and consequently my work has received generous funding from the Academy of Finland Strategic Research Council (Kotiaho 345267).

The School of Resource Wisdom, JYU.Wisdom, has been one of the saviours of my work at the university. A few weeks ago, from the time I am writing this foreword, there was a Wisdom Futures event. I had so much work on my plate at that time that I wondered whether I would have the energy to join the event. I nevertheless decided to join and what a good decision it was. I gained so much energy when I remembered that I am surrounded with such a lovely and open-minded community. This feeling has persisted throughout the years. My third article in the dissertation, which is a book chapter, was made possible by the enthusiastic and active people in the Wisdom community. I would like to give special thanks to all of you who gave comments and to the editors of the book: Merja Elo, Jonne Hytönen, Sanna Karkulehto, Teea Kortetmäki, Mikael Puurtinen and Miikka Salo. Special thanks to Miikka for the detailed and constructive feedback and for helping us evolve the chapter to a different level. Thank you, Janne, for your support and inputs in the writing process, it was a blast.

Yet another group that I find truly amazing is the corporate environmental management research group. Even though I haven't been able to give much to the group during recent years, I just want you to know that you have given me so much more. The kind-hearted spirit and sheer joy and friendliness in this group is something that I find extremely empowering. Thank you all.

I have also had the pleasure of having a steering group with highly experienced people. I'd like to thank Hanna-Leena Pesonen, Janne Peljo and Matti Toivonen for giving me valuable inputs and advice on the research topic and how to apply it in the society. Thank you for your patience and trust.

I would also like to thank Francesca Verones and Anne Quarshie for giving me important and constructive feedback on the dissertation manuscript. Likewise, I would like to thank Hanna-Leena Pesonen and Tiina Onkila for their constructive feedback about the manuscript. A final professional thanks to both of my supervisors Stefan and Janne. You have truly inspired me throughout the journey. You both are compassionate, brave and bright people. I have learned a lot from you and I'm sure I will learn a lot more. I think it tells a lot about you that I'd rather think of you two as my good colleagues, rather than being some distant supervisors. Thank you for being who you are.

Finally, I would like to give some thanks to family and friends. A huge thanks to all my friends around the world (mainly in Jyväskylä and Turku) who have kept their interest at what I am doing despite my difficulties in sometimes giving credit to my own work. I appreciate the kind support you have given me. Thanks to my family: my mother and father "äiti" and "baba", my brothers Rami and Ramzi, and all other relatives. You amaze me with how supportive you have been towards this journey.

Ilona, my partner in life. I guess it would be cheesy to say that this work would not have been possible without you. But so it is and will be. This dissertation feels quite small compared to everything we have been through. Often times I have felt that were it not for your enthusiasm and support, I might not have finished this work. You always encouraged me to be who I am, and at the same time, gently pushed me to think about my own well-being and who I want to be. Thank you for giving me and us a loving and warm home.

Searching for myself
Lost in the sea of science
Oh, what a journey

Jyväskylä, Kortepohja 27.5.2024
Sami El Geneidy

ORIGINAL PAPERS

I. El Geneidy, S., & Baumeister, S. (2019). The Carbon Footprint of Volunteer Tourism. European Journal of Tourism, Hospitality and Recreation, 9(2), 15–25. https://doi.org/10.2478/ejthr-2019-0010

II. El Geneidy, S., Baumeister, S., Govigli, V. M., Orfanidou, T., & Wallius, V. (2021). The carbon footprint of a knowledge organization and emission scenarios for a post-COVID-19 world. Environmental Impact Assessment Review, 91, 106645. https://doi.org/10.1016/j.eiar.2021.106645

III. El Geneidy, S., & Kotiaho, J. S. (2023). A planetary well-being accounting system for organizations. In M. Elo, J. Hytönen, S. Karkulehto, T. Kortetmäki, J. S. Kotiaho, M. Puurtinen, & M. Salo (Eds.), Interdisciplinary Perspectives on Planetary Well-Being. Routledge. https://doi.org/10.4324/9781003334002

IV. El Geneidy, S., Baumeister, S., Peura, M., & Kotiaho, J. S. (2023). Value-transforming financial, carbon and biodiversity footprint accounting. arXiv:2309.14186. [econ.GN] https://doi.org/10.48550/arXiv.2309.14186

Contributions of the candidate and co-authors to the articles

I. Sami El Geneidy was responsible for conceptualization, data collection and analysis, and methodology. Stefan Baumeister was involved in conceptualization, data analysis and methodology. Both authors contributed to writing the original draft.

II. Sami El Geneidy was responsible for the conceptualization, data collection and analysis, methodology and writing the original draft. Stefan Baumeister was involved in the conceptualization, data analysis, methodology and writing the original draft. Valentino Marini Govigli, Timokleia Orfanidou and Venla Wallius helped with conceptualization and writing and editing introduction, results and discussion. Valentino Marini Govigli conducted the statistical analyses.

III. Sami El Geneidy was responsible for the conceptualization and writing the original draft. Janne S. Kotiaho was involved in conceptualization, editing and writing introduction and conclusions.

IV. Sami El Geneidy was responsible for the conceptualization, data collection and analysis, methodology and writing the original draft. Stefan Baumeister helped with editing and conceptualization. Maiju Peura was involved in data analysis and methodology. Janne S. Kotiaho was involved in conceptualization, methodology and editing.

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1 INTRODUCTION

1.1 Biodiversity loss and climate change nexus

Nature and functional ecosystems are vital for human existence and good quality of life. Global biodiversity loss, in other words the reduction of undomesticated life on Earth, is altering the productivity and sustainability of Earth's ecosystems (Díaz et al., 2019; Hooper et al., 2012). Humanity's impact on terrestrial, freshwater and marine ecosystems have exposed more species to the risk of extinction than ever before in human history: 70% of land surfaces have been altered, 66% of ocean areas are under cumulative impacts, over 85% of wetland areas have been lost and 77% of rivers (longer than 1000 km) are no longer free flowing (Díaz et al., 2019; IPBES, 2019).

Biodiversity loss is directly driven by human land and sea use, direct exploitation of nature, climate change, pollution and invasive alien species (IPBES, 2019). In recent history land and sea use change, and direct exploitation of nature have been the most important drivers of biodiversity loss, while climate change has been argued to take a lesser role (Jaureguiberry et al., 2022). However, during the next century climate change might become one of the leading drivers of biodiversity loss (Román-Palacios & Wiens, 2020; Trisos et al., 2020; Urban, 2015).

Greenhouse gas (GHG) emissions from human activities have caused climate change where the Earth's surface temperature has risen by 1.1°C in 2011-2020 when compared to temperature levels in 1850-1900 (IPCC, 2023). During 2010-2019 humanity emitted more GHG emissions on average annually than ever before (IPCC, 2023). Apart from increasing projected impacts during the next century, climate change has already had widespread impacts on the atmosphere, ocean, cryosphere and biosphere (IPCC, 2023). Adverse impacts have piled up unequally around the globe and have affected especially "vulnerable communities who have historically contributed the least to current climate change" (IPCC, 2023). It has been assessed that rich countries rely on a net appropriation of resources from the global South, and that the value of this appropriation is over $10 trillion per year (Hickel et al., 2022). Household carbon footprints within nations and regions around the world also show largely unequal distribution between rich and poor households (Chancel, 2022; Ivanova & Wood, 2020; Wiedenhofer et al., 2017). Because it is both globally and regionally the rich that have caused most of the climate change and biodiversity loss, and because the poor generally tend to suffer the consequences, the climate change and biodiversity loss nexus is also an issue of social justice.

Global treaties and policies have been made to address biodiversity loss and climate change. The Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC) came into force in 1993 and 1994 after the Earth Summit in Rio in 1992 (CBD, 2023; UNFCCC, 2023). The main goals of CBD are "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (CBD, 2011). The ultimate aim of the UNFCCC is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UN, 1992).

In the years to follow countries committed to reducing their biodiversity impacts and GHG emissions in the Strategic Plan for Biodiversity (including the Aichi Biodiversity Targets) and Kyoto Protocol (CBD, 2020b; UN, 1998). Later, the Kyoto Protocol was succeeded by the Paris Agreement, which is a legally binding treaty signed by 196 nations of the world (United Nations, 2015). In the Paris Agreement world's countries agreed to limit global warming well below 2°C and pursue efforts to limit warming to 1.5°C above pre-industrial levels (United Nations, 2015). Finally, the Kunming-Montreal Global Biodiversity Framework was adopted in 2022 (CBD, 2022). Some of the main goals of the framework are the restoration of 30% of degraded ecosystems by 2030, conservation and ecologically representative management of 30% of ecosystems by 2030, stopping the extinction of known threatened species and reducing extinction risk tenfold by 2050 (CBD, 2022). On the global arena, we are yet to see the fluent integration of climate and biodiversity treaties, even though expert communities have started to join forces (IPCC, 2023; Pörtner et al., 2021).

One of the suggested overarching goals that could incorporate aspects from both climate change and biodiversity loss is planetary well-being (Elo et al., 2023; Kortetmäki et al., 2021). Kortetmäki et al. (2021) define planetary well-being as follows:

> "a state in which the integrity of Earth system and ecosystem processes remains unimpaired to a degree that lineages [e.g. species] can persist to the future as parts of ecosystems, and organisms (human and nonhuman) can realise their typical characteristics and capacities".

While the current treaties, especially in the context of climate change, have largely focused on sustaining human well-being, the concept of planetary well-being encompasses and recognizes both human and nonhuman well-being (Elo et al., 2023; Kortetmäki et al., 2021). Planetary well-being recognizes that organisms, human and non-human, have the right "to exist, to have their needs satisfied, and to realize their typical characteristics and capacities" (Elo et al., 2023; Kortetmäki et al., 2021). The concept looks at well-being from a systemic perspective, in the sense that human and nonhuman well-being are reliant on the integrity of the Earth system and ecosystem processes.

Because climate change and biodiversity loss are intertwined, with a need for joint solutions (Pörtner et al., 2021), I argue that planetary well-being encompasses the nature of this relationship well. Achieving planetary well-being ultimately requires that biodiversity loss and climate change are stopped. But to stop them, a shift is needed in how human well-being and its relation to nonhuman well-being is viewed. Indeed, ultimately the goal of tackling climate change and biodiversity loss is to preserve life on the planet and as planetary well-being would do just that, planetary well-being could serve as an overarching goal for humanity.

Despite the global treaties, efforts to halt biodiversity loss and climate change have been modest and largely inadequate (Díaz et al., 2019; IPBES, 2019; IPCC, 2023; UNEP, 2023). During 2011-2020 none of the Aichi Biodiversity Targets, aimed to tackle biodiversity loss, were fully met (CBD, 2020a; Díaz et al., 2019). Currently GHG emissions continue to rise and it has been estimated that with current policies the world is heading towards global warming of 2.9°C (UNEP, 2023). Even if current pledges were implemented, warming would be reduced to only around 2.5°C (UNEP, 2023) with unpredictable consequences to all life on Earth, including human societies and other nature (IPCC, 2023). Over three million years have passed since global surface temperatures were sustained at or above 2.5°C above pre-industrial levels (IPCC, 2023).

In the future, climate change can be a major driver of biodiversity loss (Román-Palacios & Wiens, 2020; Trisos et al., 2020; Urban, 2015) but at the same time biodiversity loss can already significantly hinder effective climate action (Pörtner et al., 2021). It has also been shown that actions to stop biodiversity loss can generally benefit climate action (Girardin et al., 2021; Shin et al., 2022). Biodiversity loss and climate change are fundamentally intertwined and it means that to solve both crises, integrated solutions are required (Pörtner et al., 2021).

It has been estimated that in 2007 around 40% of the global biodiversity impacts were caused by food consumption, while transport and production of goods caused 11% each, housing and services 6% each and other sectors 26% (Wilting et al., 2017). Another study found that in 2015 food consumption contributed to 51% of the total global biodiversity impacts, followed by shelter (20%), services (16%), manufactured products (9%), clothing and footwear (3%) and mobility (1%) (Bjelle et al., 2021). In terms of climate change, energy, industry, transportation and buildings were responsible for around 79% of global emissions in 2019, while approximately 22% was caused by agriculture, forestry and other land use (IPCC, 2023).

The underlining causes for both biodiversity loss and climate change are the production activities by humanity, sustained by increasing amounts of consumption (IPBES, 2019; IPCC, 2023). In essence it can be said that the producer produces the environmental impact and the consumer initiates it (Peters & Hertwich, 2008). The distinction between production- and consumption-based impacts has been especially prevalent in discussions around national GHG emission inventories (Franzen & Mader, 2018; Karakaya et al., 2019; Peters & Hertwich, 2008). There, production-based emissions refer to the emissions produced within the nation's borders, while consumption-based emissions take into account the trade of the nation, including imports and excluding exports (Peters & Hertwich, 2008). A similar logic can be applied to organizations (see e.g. Ozawa-Meida et al., 2013; Peters, 2010). For example, a mining company might produce a land use impact while harvesting minerals and a factory uses the minerals to produce a product. The factory might then produce GHG emissions in the production process and further along the value chain there might be an organization who eventually uses the product produced by the factory, thus initiating the GHG emissions and consequently the land use by the mining company. From a production-based perspective one would only be interested in the direct environmental impacts of an organization, but a consumption-based approach includes all environmental impacts created along its value chain. In this dissertation I focus on consumption-based climate and biodiversity impacts of organizations.

1.2 The role of organizations in the biodiversity loss and climate change nexus

Humans have largely organized their everyday lives and economics of societies through organizations. An organization can be defined as "a group of people who work together in an organized way for a shared purpose" (Cambridge Dictionary, 2023). Thus, an organization can be for example a public institution, a private enterprise, or an association. Organizations often provide the premises of production and consumption, making them important elements of how we operate our lives. Considering for example the abovementioned sectors of global environmental impacts: Food is produced by farmers or farming companies and generally distributed through associations and corporations. Transportation is organized not only by individual citizens, but by logistics organizations and public transportation companies, and the underlying infrastructure is often built by governments, also a type of organization. Energy is often provided by an energy company. Housing and the materials are in many cases provided for example by a mining or a forestry organization.

Because organizations are key elements of our everyday lives and societies, it can be assumed that much of our production and consumption activities, and related environmental impacts, are also happening through organizations. It has been estimated that only the direct emissions of around 9000 companies contributed to over 38% (13 gigatonnes CO_2e) of global GHG emissions in 2021 (CDP, 2022). To understand the contribution of organizations to climate change and biodiversity loss, and to create efficient strategies to tackle the two crises, we need to be able to empirically measure organizations' negative environmental impacts. However, before the tools of measurement are presented, the wider theory of change in organizations needs to be explored to understand how changes towards sustainability are justified and expected to take place.

1.3 Managing the nexus in organizations through environmental accounting

Environmental accounting has been developed to make visible the impacts an organization has on the environment (Bracci & Maran, 2013; Schaltegger & Burritt, 2000; Unerman et al., 2018). Carbon and biodiversity footprint assessments are examples of environmental accounting tools used to investigate the (negative) climate and biodiversity impacts of organizations (R. Chen et al., 2021; Crenna et al., 2020; Damiani et al., 2023; Marques et al., 2017; Peters, 2010; Shi & Yin, 2021; Wiedmann & Minx, 2007). The indicator of carbon footprint is the carbon dioxide equivalent (CO_2e) that measures the amount of greenhouse gas emissions caused for example by an organization's operations (WBCSD & WRI, 2012; Wiedmann & Minx, 2007). Biodiversity footprints in turn have differing indicators from regional to global species loss (Crenna et al., 2020; Damiani et al., 2023; Lammerant et al., 2022; Marquardt et al., 2019; Sanyé-Mengual et al., 2023). However, generally it can be said that biodiversity footprints are focused on measuring the amount and consequences of the direct drivers of biodiversity loss.

The measurement of carbon and biodiversity footprints can be seen as a necessary precondition to monitoring, mitigation and offsetting of impacts, if organizations wish to reach net zero emissions (Fankhauser et al., 2022) or no net loss of biodiversity (Moilanen & Kotiaho, 2018; ten Kate et al., 2004). As Doran (1981) put it in the context of writing management's goals and objectives: any objective should be Specific, Measurable, Assignable, Realistic and Time-related (SMART). In this doctoral dissertation I support the development of at least the first two qualities of a smart objective by providing management examples of how carbon and biodiversity footprints can be measured for specific consumption categories in organizations.

Even though measurement can be a crucial first step in managing the biodiversity loss and climate change nexus, current trends of global emissions and biodiversity loss indicate that measurement of carbon, and in the future biodiversity, footprints, i.e. conventional environmental accounting, might not be enough. The use of environmental accounts has remained small in decision-making, which has been dominated by another accounting system, financial accounting (Bracci & Maran, 2013; Maas et al., 2016; Saravanamuthu, 2004; Schaltegger & Burritt, 2000; Tregidga & Laine, 2021; Veldman & Jansson, 2020)

1.4 Aim and research questions

The overall aim of my doctoral dissertation is to develop the methodologies of carbon and biodiversity footprint assessment in organizations. In addition, I aim to develop pathways for consistent reporting, mitigation and offsetting of carbon and biodiversity footprints in organizations. To achieve the objective, in Articles 1, 2 and 4 I focus on how organizations can assess, mitigate and offset their consumption-based carbon and biodiversity footprints. I used three different types of organizations from different parts of the world as living labs, to assess their carbon and biodiversity footprints. The biodiversity footprint methodology I have created in Article 4 is a methodological contribution, created by synthesizing previous research and databases. In Article 3 I focus on understanding what is the role of financial and environmental accounting in reaching planetary well-being. Finally, I discuss can the integration of financial and environmental accounting serve as a technical response to catalyse transformative change in organizations. The research questions (RQ) of the dissertation are:

- RQ1: How can organizations assess, mitigate and offset their consumption-based carbon and biodiversity footprints?
- RQ2: What is the role of financial and environmental accounting in reaching planetary well-being?
- RQ3: Can integration of financial and environmental accounting serve as a technical response to catalyse transformative change in organizations?

2 THEORETICAL FOUNDATIONS

2.1 Theoretical positioning

A theory can be described as "a formal statement of the rules on which a subject of study is based or of ideas that are suggested to explain a fact or event or, more generally, an opinion or explanation" (Cambridge Dictionary, 2024). Several theories have been developed to understand the role and motives of organizations, and perhaps more commonly corporations, in addressing climate change, biodiversity loss and other environmental issues. Since in this dissertation I focus on methodology development of environmental accounting and how it might drive change in organizations, I explored suitable theories to answer questions such as: Why organizations engage in environmental accounting? What kind of changes take place in organizations and what can be the role of environmental accounting in facilitating those changes? What is transformative change in organizations and what is the role of environmental accounting in relation to transformative change? Exploring the theories will give way to further analysis and discussion on the implications of how the carbon and biodiversity footprint methodologies I have developed and tested might or might not drive transformative organizational change.

2.1.1 Why organizations engage in environmental accounting? Perspectives from stakeholder and legitimacy theories

One of the widely developed and discussed theories in understanding why organizations engage in environmental accounting and reporting is the stakeholder theory (Freeman, 2010; Freeman et al., 2020; Friedman & Miles, 2002; Laplume et al., 2008). The stakeholder theory cannot be exhaustively defined, but its essence could be summarized as the understanding that an organization has relationships with groups that are influenced by the organization but also have an influence on the key objectives of the organization (Harrison et al., 2019). In order for a manager to achieve the goals of an organization, they would have to understand how the relationships with the different groups, so called stakeholders, can be managed (Freeman, 2010; Harrison et al., 2019). Again, the notion of who and what can be included as a stakeholder varies, but examples of the stakeholders of an organization are employees, management, customers, suppliers, shareholders and policymakers (Harrison et al., 2019), or even nonhuman nature (Driscoll & Starik, 2004; Laine, 2010; Starik, 1995).

While the role of nonhuman nature as a stakeholder has been contested (Laine, 2010; Phillips & Reichart, 2000), nature and functional ecosystems are vital for the long-term economic viability of any organization (Dasgupta, 2021; IPBES, 2019; Pörtner et al., 2021; World Economic Forum, 2020, 2023). The World Economic Forum (2020) assessed that $44 trillion of economic value generation in the world is moderately or highly dependent on nature. Another assessment showed that around $7.2 trillion of the world's largest listed companies' enterprise value was exposed to unmanaged biodiversity risk (Carvalho et al., 2023). Irrespective of whether nature can be accounted for as a stakeholder, organizations need to recognize and manage their impacts on the environment to halt biodiversity loss and climate change. Thus, I support and utilize the overall concept of stakeholder theory to argue that environmental accounting can be used to provide information to (and about) stakeholders, on what kind of impacts the organization has on the environment.

Legitimacy theory can also be used to explain why organizations engage in environmental accounting and reporting (N. Brown & Deegan, 1998; Deegan, 2002, 2019; Mousa & Hassan, 2015). According to legitimacy theory, organizations are not inherently accepted by the society, but they only exist when "the society 'confers' upon the organization the 'state' of legitimacy"(Deegan, 2002). The legitimacy of an organization is connected to the idea of a social contract between an organization and the society, and has been characterized as follows:

> "Any social institution - and business is no exception - operates in society via a social contract, expressed or implied, whereby its survival and growth are based on: 1) the delivery of some socially desirable ends to society in general, and 2) the distribution of economic, social, or political benefits to groups from which it derives its power." (Shocker & Sethi, 1973, p. 67)

Therefore, the legitimacy theory proposes that if this social contract between an organization and the society is broken, the organization loses its legitimacy and cannot exist in the society (Deegan, 2002; Mousa & Hassan, 2015). However, it should be noted that the concept of legitimacy and how it is perceived and recognized by organizations and the society can vary (Deegan, 2002, 2019). Organizations can also manipulate and influence the perception of legitimacy, for example in how and when they provide environmental disclosures (Deegan, 2002; Hummel & Schlick, 2016).

The contribution of my dissertation can be seen as an enabler or hindrance of legitimacy for organizations, depending on how carbon and biodiversity footprints of organizations are perceived. Organizations assessing and reporting their carbon and biodiversity footprints to stakeholders can be seen to uphold their legitimacy by complying with the regulatory framework or even providing more disclosures than necessary, while on the other hand for example unsuccessful mitigation of footprints could be a hindrance to future legitimacy. The stakeholder and legitimacy theories both provide the necessary context for understanding why organizations engage in environmental accounting and who organizations report their environmental impacts to.

2.1.2 What kind of changes can environmental accounting drive in organizations? Perspectives from organizational change theories

While stakeholder and legitimacy theories can be used to understand why organizations engage in environmental accounting, they do not theorize whether changes take place in organizations due to environmental accounting or not. Furthermore, to understand the role of environmental accounting in driving change in organizations, one first needs to understand how changes are proposed to take place in organizations.

A widely discussed model of organizational change was proposed by Laughlin in the early 1990s (1991), building up especially on the work of Greenwood and Hinings (1988). Laughlin (1991) first conceptualizes the structure of an organization around three distinct and interconnected levels: sub-systems (tangible organizational elements), design archetype (organization structure, decision processes and communication systems) and interpretative schemes (beliefs, values and norms) (Figure 1).

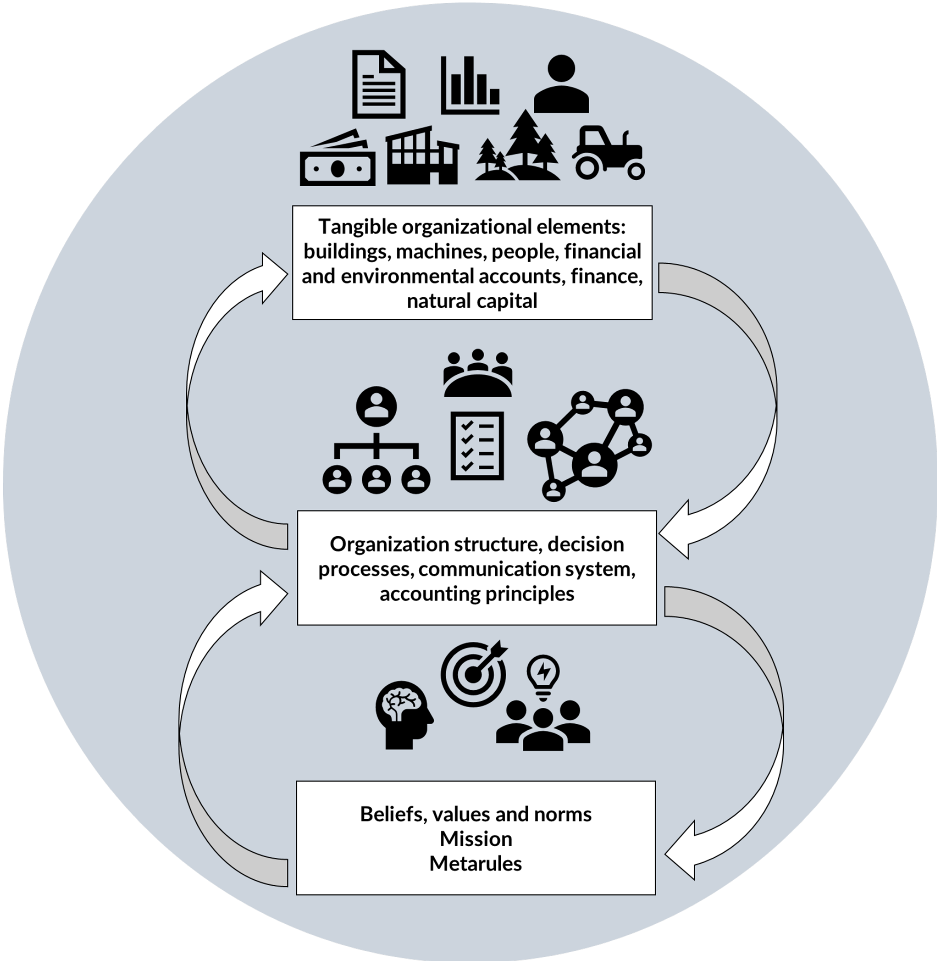

Figure 1: A model of an organization (adapted from Laughlin (1991)).

The sub-systems contain the tangible elements of the organization, such as buildings, machines and people, and their behaviour (Laughlin, 1991). In the context of my dissertation, sub-systems could also be interpreted to include the financial and environmental accounts of the organization, which are tangible reports of the organization's financial and environmental implications. In addition, sub-systems could also include the natural capital of the organization, that is, the natural assets such as land and freshwater resources owned or directly influenced by the organization (Dasgupta, 2021).

The design archetype contains less tangible elements such as the organization structure, management and communication systems, and decision processes, which guide the development of the sub-systems but are in turn manifested by a set of values and beliefs (Greenwood & Hinings, 1988, 1993; Laughlin, 1991). The financial and environmental accounting practices and principles could be seen to belong to the design archetype, as the practices themselves are intangible elements of the organization which are manifested as the financial and environmental accounts of the organization, while they are in turn influenced by the values and beliefs at the heart of the organization.

Finally, the most intangible level of the organization are the interpretative schemes, which can be subdivided into three levels: 1) beliefs, values and norms, 2) mission or purpose and 3) metarules (i.e. the paradigms that give direction to other levels) (Laughlin, 1991; Ranson et al., 1980). The interpretative schemes can also be understood as the "culture" or "ideology" of the organization (Laughlin, 1991). Even though financial and environmental accounting might seem to be systems that are somehow "value-free", it is indeed our values, beliefs and norms that construct the reality of how we want environmental and financial accounting to operate (Hines, 1988).

The three levels of the organization interact with each other in a state of balance and coherence (Laughlin, 1991). Laughlin (1991, p. 213) continues to explain that the state of balance and coherence should not be interpreted as a state in which no conflicts exist, rather, "at some level, there will be certain characteristics which bind the organization together and make it a coherent whole". With these elements of the organization, it is possible to start uncovering how changes take place in organizations and what is the role of environmental accounting in those changes.

Based on the model of an organization, Laughlin (1991) theorizes how changes take place in organizations. Changes in organizations are expected to take place after some sort "disturbance, jolt or kick" shifts the balance of some or many of the three elements of an organization (described above) (Laughlin, 1991). It is important to note that an underlying assumption made in the theory is that organizations have an inert state where no changes occur (Gray et al., 1995; Laughlin, 1991). Thus, the change can be assumed to lead to "some other balanced state around which a new level of inertia can set in" (Laughlin, 1991, p. 213). However, as Gray et al. (1995) point out, it is not at all clear whether or not such a state of inertia and balance really exists in organizations that are more or less under constant influence and change.

Laughlin (1991) categorizes changes in organizations into two classes: first order and second order changes, which can also be called organizational transitions and transformations. To root the concepts of organizational change better with upcoming concepts of transformative change and with contemporary language, I will refer to organizational transition as incremental change and organizational transformation as transformative change (following the footsteps of Mitchell et al. (2012)). Generally speaking incremental changes are not expected to affect the beliefs, values and norms of the organization, while transformative changes are expected to affect or initiate from the beliefs, values and norms of the organization (Laughlin, 1991). However, it is important to note that it has been argued that a clear distinction between incremental and transformative change does not necessarily exist, rather, they are cumulative processes of the same continuum, where smaller incremental changes might pave the path towards larger transformative changes (Contrafatto & Burns, 2013; Garcia-Torea et al., 2023; Mitchell et al., 2012).

Incremental changes can further be classified into "rebuttal" and "reorientation" depending on how the organization responds to the disturbance

(Laughlin, 1991). In rebuttal the organization faces only minor changes in its structure, decision processes or other design archetype elements, as it aims to revert the change to achieve a similar state before the disturbance (Gray et al., 1995; Laughlin, 1991; Tilt, 2006). In reorientation the disturbance is not rebutted but the organization internalizes the disturbance to reorient its structure, decision processes or other design archetype elements (Gray et al., 1995; Laughlin, 1991; Tilt, 2006). This in turn might affect the tangible organizational elements, such as the buildings, people or reported accounts but does not affect the heart of the organization, i.e. its beliefs, values and norms (Gray et al., 1995; Laughlin, 1991; Tilt, 2006). In other words, reorientation could be understood as something where change occurs but the underlying intentions that guide decision-making remain the same.

Transformative changes can further be classified into “colonisation” and “evolution” depending on how the organization responds to the disturbance (Laughlin, 1991). In colonisation a change is forced upon the organization, which affects the structure, decision processes or other design archetype elements so that the organization shifts to a new state where both the tangible elements and underlying values, beliefs and norms are changed (Gray et al., 1995; Laughlin, 1991; Tilt, 2006). In evolution on the other hand, the change is freely chosen by the organization, which leads first to a shift in the underlying values, beliefs and norms and consequently the structure, decision processes and other design archetype elements, and tangible organizational elements (Gray et al., 1995; Laughlin, 1991; Tilt, 2006).

Next, the links between organizational change and environmental accounting and reporting will be explored to understand what is known about the role of environmental accounting in driving change in organizations. Garcia-Torea et al. (2023) provide an extensive overview of how sustainability accounting and reporting (broadly including aspects from social and environmental accounting) has or has not been found to drive organizational change. They found two streams of evidence: sustainability accounting and reporting can drive organizational change, but the change can often be of a “limited nature”, or it can even inhibit sustainable organizational change. In the latter case, researchers have argued that sustainability accounting and reporting is often used to defend the dominant perspectives of the organization (J. Brown & Dillard, 2014; Dey, 2007; Garcia-Torea et al., 2023; Tregidga et al., 2014). A more substantive change was exhibited by sustainability accounting and reporting practices that were incorporated in internal decision-making (e.g. Gunarathne & Lee, 2015; Narayanan & Boyce, 2019; Passetti et al., 2018), which connects to Laughlin’s (1991) idea of evolutionary change where change is accepted and initiated by the organization itself (Garcia-Torea et al., 2023). However, as Garcia-Torea et al. (2023) point out, mandatory or integrated reporting, whether it is internally or externally initiated, has also been argued to drive organizational change (Cerbone & Maroun, 2020; Leong & Hazelton, 2019). At the critical end of the discussion, Garcia-Torea et al. (2023) find that sustainability accounting and reporting has been argued to be “prone to the capture by dominant actors and perspectives in organizations to defend and reinforce their hegemonic position" (J. Brown & Dillard, 2014; Tregidga et al., 2014).

Coming back to the concepts of organizational change, Tilt (2006) provided an interesting framework employing the organizational change theory (Laughlin, 1991) with the concepts of voluntary environmental disclosure, i.e. environmental accounting and reporting (Gray et al., 1995). Tilt (2006) argued that the relationship between environmental activities and voluntary reporting could be used to conceptualize what kind of environmental reporting drives incremental and transformative changes. Later in the dissertation I employ and adapt Tilt's framework to discuss, what could be the role of the presented methodological advances in environmental accounting, and more specifically carbon and biodiversity footprint assessments, to drive transformative changes in organizations. Here I adapt Tilt's framework and apply it in the context of environmental accounting, which can be understood as a form of environmental disclosure (Figure 2).

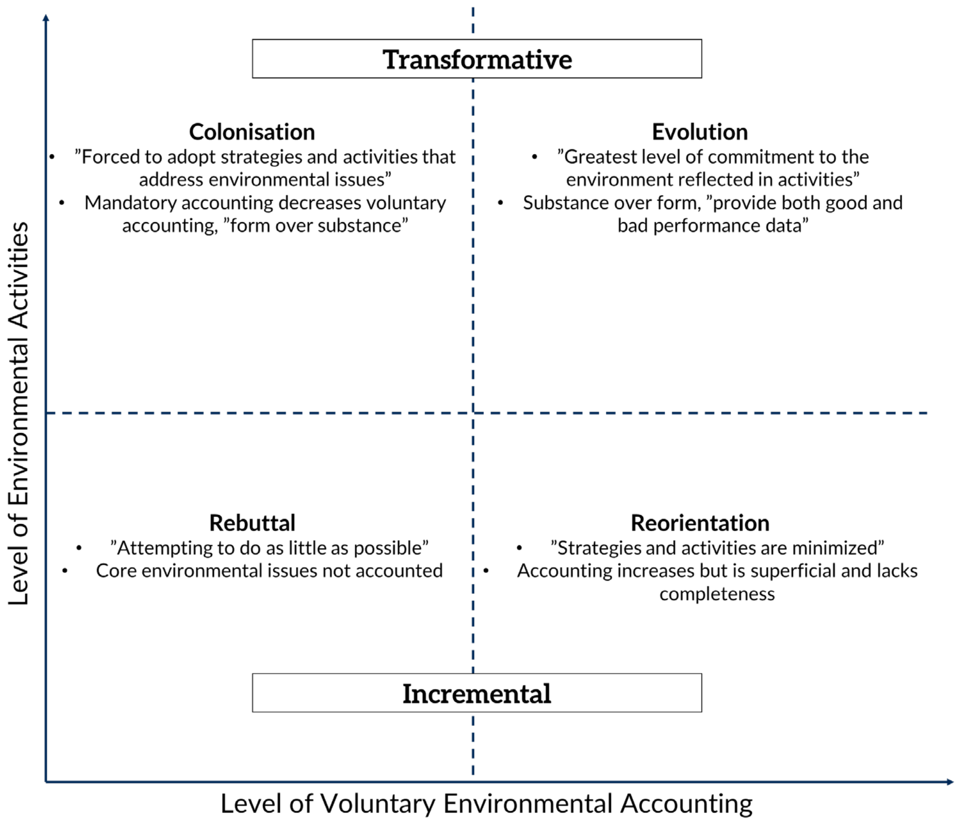

Figure 2: Linking organizational change and environmental activities with environmental accounting (or reporting) (adapted from Tilt (2006) and based on Laughlin (1991) and Gray et al. (1995)).

I will also look at the issue from the perspective of the society, in which all organizations are embedded. Thus, I will next explain how the organizational change theories could be connected to the concept of transformative change from a societal perspective in the context of sustainability science.

2.1.3 Connecting organizational and societal aspects of transformative change

It has been argued that transformative changes are needed to halt biodiversity loss and climate change (Díaz et al., 2019; IPCC, 2023). Transformative change in this context has been defined as:

> "A system-wide change that requires more than technological change through consideration of social and economic factors that, with technology, can bring about rapid change at scale." (IPCC, 2018)

Even though pathways towards transformative changes have been analysed (IPBES, 2019; IPCC, 2023), it is not clear how transformations could come about (O'Brien & Sygna, 2013). Synthesizing and adapting previous discussion from Sharma (namely Sharma, 2007), O'Brien and Sygna (2013) conceptualize the breadth and depth of sustainability transformations of societies in three spheres: practical, political and personal.

The practical sphere is the core of the transformation and entails the behaviours and technical solutions (O'Brien & Sygna, 2013; Sharma, 2007). O'Brien and Sygna (2013) argue that most attention has focused on this sphere, and it is also here where numbers and indicators are measured. They continue by analysing that this is also the sphere where "the line between business-as-usual and transformation is easily blurred", because practical solutions, without considering wider systems and structures, can create new problems (O'Brien & Sygna, 2013). Similarly, Meadows (1999) discussed how leverage points can be used to transform systems. They also conclude that constants, parameters and numbers can be one of the least effective leverage points that do not necessarily initiate transformative change (Meadows, 1999). However, parameters can facilitate transformative change if they are ambitious enough to influence some of the other leverage points, such as by creating positive feedback loops (Meadows, 1999).

The second sphere of transformation is the political sphere, which "represents the systems and structures that define the constraints and possibilities under which practical transformations take place" (O'Brien & Sygna, 2013). The political sphere includes economic, political, legal, social and cultural systems that define the rules of the game (O'Brien & Sygna, 2013; Sharma, 2007).

The third sphere is the personal sphere, where "the transformation of individual and collective beliefs, values and worldviews occur" (O'Brien & Sygna, 2013). The personal sphere has been argued to have more powerful consequences than the other spheres, because changes in worldviews can change the perspective of how people see the underlying political structures and what is possible to change (Meadows, 1999; O'Brien & Sygna, 2013).

When comparing the organizational change frameworks by Laughlin (1991) and Tilt (2006) to the transformative change framework by O'Brien & Sygna (2013) and Sharma (2007), some interesting connections can be found from the organizational to the societal level. For example, it seems that the three spheres of the transformative change framework are similar to the three elements of the organization (sub-systems, design archetype, interpretative schemes) in Laughlin's framework (Figure 3).

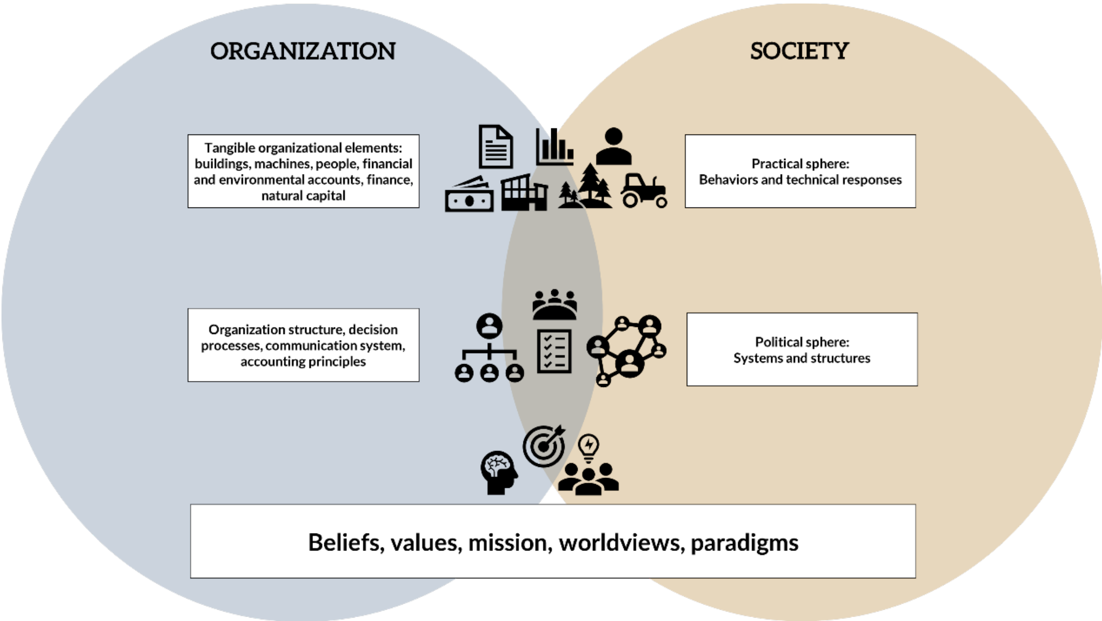

Figure 3: Illustration of the conceptual interconnectedness of organizational and societal models of transformative change (adapted from Laughlin (1991) and O'Brien & Sygna (2013)).

Furthermore, both frameworks argue that the most transformative changes happen at the personal level, when beliefs, values and norms are influenced (Laughlin, 1991; O'Brien & Sygna, 2013). Building up on the framework of Tilt (2006) presented in Figure 2, I aim to conceptualize how organizational and societal changes might be interconnected in the context of environmental accounting and transformative changes (Figure 4). The model I propose aims to illustrate that increasing levels of environmental accounting and reporting associated with increasing environmental activities can be associated with Laughlin's representation of transformative change both in the organizational and societal perspective, which are in constant interaction with each other.

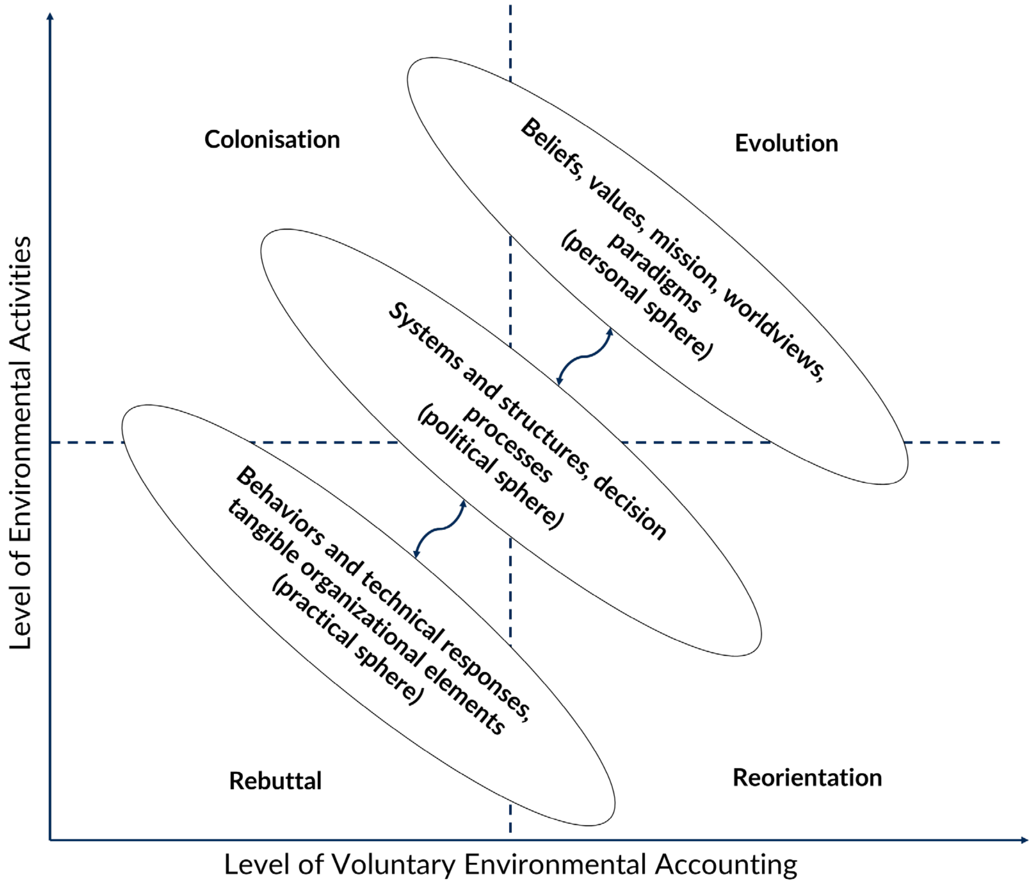

Figure 4: Illustration of the positioning of the organization's and society's elements of transformative change in the context of environmental accounting and activities, and pathways of organizational change (adapted from Laughlin (1991), O'Brien & Sygna (2013) and Tilt (2006)).

2.2 Conceptual background

2.2.1 Environmental accounting

Organizations and other entities use environmental accounting (sometimes referred to as environmental management accounting, sustainability management accounting or sustainability accounting) to understand their environmental impacts, or how changes in the environment might affect their operations (Bracci & Maran, 2013; Russell et al., 2017; Schaltegger & Burritt, 2000; Unerman et al., 2018). For example, an organization might collect environmental accounts that include how much greenhouse gases it produces annually or what kind of ecosystem assets, such as forest land, it has and how changes in that asset might affect its financial performance. The motives behind environmental accounting differ from reputation and cost management to enhancing societal and environmental well-being (Schaltegger & Burritt, 2018).

Russell et al. (2017) explored the history of environmental accounting research and found out that before the 1990s the focus was on introducing environmental impacts to traditional accounting systems. The aim was to identify, measure, count and monetize environmental impacts. However, during the years, research around the integration of financial and environmental accounting has dwindled (Russell et al., 2017; Unerman et al., 2018), although other streams of research especially around the practical implementation of environmental accounting has been on the rise (Nicholls, 2020; Russell et al., 2017; Shi & Yin, 2021).

Several standards and frameworks exist to guide the collection and reporting of environmental accounts in organizations, such as the Sustainability Reporting Standards of the Global Reporting Initiative (GRI, 2023) and the International Financial Reporting Standards' Sustainability Disclosure Standard (IFRS, 2022). Some standards provide guidance for specific dimensions of environmental accounting, for example the Greenhouse Gas Protocol (WBCSD & WRI, 2012) or the Natural Capital Protocol (Capitals Coalition, 2016). In addition, the International Integrated Reporting Framework (IIRC, 2021) has developed a framework that combines financial, social and environmental accounts under the same report.

To conduct environmental accounting, methods are needed to assess environmental impacts of organizations. There are multiple levels in which environmental impact assessments can be conducted in organizations, but perhaps the two most prominent methods for assessing consumption-based environmental impacts are life cycle assessment (LCA), environmentally extended input-output assessment (EEIO) and the combination of these two, also called hybrid-LCA or hybrid EEIO-LCA (R. H. Crawford et al., 2018; Marques et al., 2017; Peters, 2010). After the methods are introduced, I will discuss how they can be used to assess the negative climate and biodiversity impacts of organizations, i.e., their carbon and biodiversity footprints.

2.2.1.1 Life cycle assessment

Life cycle assessment (LCA) is a method for quantitatively assessing the environmental impacts of goods and services throughout their value chain, from the harvesting of raw materials to end use, re-use and disposal, i.e. "from cradle to grave" (Finkbeiner et al., 2006; Guinée et al., 2011; Hellweg & Milà i Canals, 2014; International Organization for Standardization, 2006a, 2006b). This means that in typical LCA studies, the environmental impacts of the studied process are investigated from raw material extraction to use and disposal phases. LCA can be used to answer multiple questions, such as: What is the environmental impact of a product? Which processes in the value chain have the largest impact on the environment? Is the environmental impact of product A larger or smaller than product B? What is the relative magnitude of different environmental impacts (e.g., carbon footprint vs. biodiversity footprint) in the production process? How can one efficiently mitigate the environmental impacts of production and consumption? To answer these questions, LCAs are generally conducted through four steps: 1) goal and scope definition, 2) inventory analysis, 3) life-cycle impact assessment, and 4) interpretation of results (M. A. Curran, 2013; Hellweg & Milà i Canals, 2014; International Organization for Standardization, 2006a).

In the first phase crucial steps include clearly defining the goal of the study and setting the system boundaries and a functional unit (M. A. Curran, 2013; Hellweg & Milà i Canals, 2014). System boundaries refer to the scope of the analysis and what is included and excluded. For example, the LCA of a plant-based food product might include the cultivation of crops, transportation, processing and disposal, but might exclude for example the production of the transportation equipment. The functional unit is the unit that the impacts are compared against. In the example, the functional unit could be one kilogram of finished food product or one item of the sold product.

The second phase assesses all the inputs and outputs in different processes of the life cycle and collects them to a single inventory of the whole life cycle system. The inputs and outputs refer to different types of resources and emissions collected and created during the life cycle of the studied system. There are a multitude of different databases that have collected information about the inputs and outputs of different products and services and that can be used for further analyses (see e.g. https://nexus.openlca.org/). One of the most commonly used databases is the ecoivent (Wernet et al., 2016).

The third phase is where the total environmental impacts are assessed based on the collected inventory of inputs and outputs. During this stage of life cycle impact assessment (LCIA) the resources and emissions identified in the inventory analysis are grouped, for example according to what kind of impact on the environment they have. Common categories include for example climate change, ecotoxicity and human toxicity, land stress and eutrophication (Hellweg & Milà i Canals, 2014). For example, different GHG emissions can be collected under the climate change or carbon footprint category and summed up as the global warming potential expressed as carbon dioxide equivalents (explained in detail in section 2.2.2). These types of LCIA impacts can be referred to as midpoint impacts (Huijbregts et al., 2017). Midpoint impacts generally describe the amount of land use, GHG emissions, pollutants and other environmental impacts. It is also possible to further calculate the consequences these environmental impacts might have for example on human health, ecosystems and resource availability, i.e. endpoint impacts (Hellweg & Milà i Canals, 2014; Huijbregts et al., 2017). In the context of my dissertation, the carbon footprint would be an example of a midpoint indicator and the biodiversity footprint of an endpoint indicator. Many different LCIA methods exist that compile information of different LCIA indicators. A widely used LCIA method is the ReCiPe, containing around 17 midpoint and three endpoint impact categories (Huijbregts et al., 2017).

The fourth and final step of LCA is the interpretation of results, where the inventory analysis and the LCIA are assessed to answer the objectives set in the first phase. The interpretation phase can also be seen as a cross-cutting and iterative phase of an LCA (Guinée et al., 2011). In fact, an LCA is generally a circular process where different steps are continuously improved based on knowledge created during the process (M. A. Curran, 2013).

An LCA can be conducted on multiple levels from individual products to product groups and from individual citizens to whole nations (Hellweg & Milà i Canals, 2014), but is perhaps most commonly used to assess product specific environmental impacts (Guinée et al., 2011; Hellweg & Milà i Canals, 2014). Computer software, such as openLCA or SimaPro, can be used to conduct LCAs and facilitate the use of LCA databases and LCIA methods.

2.2.1.2 Environmentally extended input-output analysis

Compiling all the needed information for a traditional LCA can be time-consuming and technically difficult, especially when the complexity of a product's composition and supply chains grows. Environmentally extended input-output analysis (EEIO or EEIOA) is a method that can be used to complement LCAs and are generally used to assess environmental impacts of large entities such as nations and regions, but also organizations (Marques et al., 2017; Moran et al., 2016; Munksgaard et al., 2005; Peters, 2010).

The basic idea of an input-output assessment is to analyse how much economic inputs a sector of the economy needs to produce its products and services and how much outputs a sector provides to other economic sectors and to final demand (Kitzes, 2013; Leontief, 1970; R. E. Miller & Blair, 2009). An EEIO analysis then adds the inputs from the environment (such as minerals and other materials) and the outputs to the environment caused by the activities of the economic sectors (such as greenhouse gas emissions or land use) (Kitzes, 2013; Leontief, 1970; R. E. Miller & Blair, 2009; Schaffartzik et al., 2014). Ultimately this approach then allows the assessment of environmental impacts based on monetary consumption. One could for example assess what kind of carbon footprint is associated with the production or consumption of IT supplies with a value of 1 000 euros. EEIO databases based on material flows (such as material tonnes) have also been developed (Merciai & Schmidt, 2018). In addition, many EEIO databases contain information about the global economy and are multi-regional (MR EEIO), making it possible to assess the embodied environmental impacts of product sectors that are traded between nations (Kitzes, 2013; Lenzen et al., 2013; Stadler et al., 2018). Even though organizations generally utilize readymade EEIO databases without the need to fully understand the construction of an EEIO dataset, I will use examples from existing papers to demonstrate how a simplified EEIO dataset works, to bring clarity to the complexity of EEIO analyses.

Consider a simplified three-sector economy consisting of wood, paper and book production and consumption (modified example from Leontief, 1970 and Schaffartzik et al., 2014). The inputs and outputs each sector need and provide are presented in Table 1. The values in the cells represent the economic value each sector uses as inputs and creates as outputs to other sectors or uses internally. In addition, the use of products and services from each sector as final demand is presented. Final demand refers to the consumption of the finished products by households, government and businesses and the total output of a sector is the sum of the outputs it has created for other economic sectors and to final demand (Kitzes, 2013). The associated carbon dioxide (CO_2) emissions produced by each economic sector are also known. The emission information could be produced directly by national measurement, the organizations of the industry, LCA studies or other modelling (Stadler et al., 2018). This is a figurative example but for clarity, made up units are provided in the examples.

From the example one can see for instance that to produce the total amount of paper for the economy (310 €), 90 euros worth of inputs from the wood sector, 10 euros worth of inputs from the paper sector and 5 euros worth of inputs from the book sector were needed. On the other hand, no inputs from the wood sector were directly needed to produce books. Furthermore, the example shows that 50 kg CO_2 emissions were associated with the production of wood. The organizations within an economic sector also trade goods and services, which is why for example the wood sector produces 85 € worth of outputs to itself. In addition, it is not only the upstream economic sectors (primary producers) that produce goods and services for the downstream economic sectors, but also the other way around. Thus, in the example the book sector provides 5 euros worth of inputs to the paper sector.

Table 1: A simplified model of a three-sector economy. Modified from Leontief, 1970 and Schaffartzik et al., 2014.

Outputs → / Inputs ↓	Wood	Paper	Books	Final demand	Total output
Wood	85 €	90 €	0 €	20 €	195 €
Paper	10 €	10 €	90 €	200 €	310 €
Books	5 €	5 €	20 €	500 €	530 €
CO_2 emissions	50 kg CO_2	50 kg CO_2	10 kg CO_2		110 kg CO_2

Further operations are needed if one is to understand, for example, how much paper is needed to produce one unit of books for final demand (the rationale behind the mathematical operations is not covered in this dissertation and can be further explored for example in Kitzes, 2013; Leontief, 1970; Miller & Blair, 2009; Schaffartzik et al., 2014). In the context of assessing environmental footprints, one could be especially interested in assessing how much CO_2 emissions are created per each economic unit spent on books. To answer these questions, a matrix of technical coefficients can be calculated, as shown in Equation 1:

$$A = Z \times \hat{x}^{-1} \text{ (Eq. 1)}$$

where A is the matrix of technical coefficients, Z represents the interindustry flows and emissions and $\hat{x}^{-1}$ is the diagonalized inverse of total outputs in Table 1. The results of the technical coefficient matrix are shown in Table 2. From this table one can derive that 0.17 units of paper and 0.02 units of CO_2 emissions were needed to produce one unit of books. The matrix of technical coefficients shows the direct inputs of needed to produce one unit's worth of output to final demand and direct emissions caused by one unit of expenditure per economic sector.

Table 2: The matrix of technical coefficients. Modified from Leontief, 1970 and Schaffartzik et al., 2014.

Inputs \ Outputs	Wood	Paper	Books
Wood	0.44 €	0.29 €	0.00 €
Paper	0.05 €	0.03 €	0.17 €
Books	0.03 €	0.02 €	0.04 €
CO_2 emissions	0.26 kg CO_2	0.16 kg CO_2	0.02 kg CO_2

Again, no direct inputs from the wood sector were needed to produce things in the book sector. However, one might logically assume that to produce books, paper was needed, and to produce paper wood was needed, indicating that there should be an indirect relationship between the wood and book sectors both in economic and environmental terms.

To take into account both direct and indirect economic and environmental inputs and outputs, a mathematical operation known as the Leontief inverse (Leontief, 1970) can be conducted to the matrix. The Leontief inverse can be calculated with Equation 2:

$$M = (I - A)^{-1} \text{ (Eq. 2)}$$

where M is the total requirements matrix, I is an identity matrix and A is the previously calculated matrix of technical coefficients. The results of this operation can be seen in Table 3. The results of the total requirements matrix show the direct and indirect inputs needed to produce one unit's worth of output to final demand and direct and indirect emissions caused by one unit of expenditure per economic sector. Now the indirect role of the wood sector in the production of books is visible: 0.10 units of wood was indirectly needed to produce one unit of books. Consequently, the emissions for each sector are also higher than in Table 2, because indirect emissions associated with indirect economic inputs are also taken into account on top of the direct emissions caused by each sector.

Table 3: The total requirements matrix. Modified from Leontief, 1970 and Schaffartzik et al., 2014.

Inputs ↓ / Outputs →	Wood	Paper	Books
Wood	1.83 €	0.55 €	0.10 €
Paper	0.11 €	1.07 €	0.19 €
Books	0.05 €	0.03 €	1.04 €
CO_2 emissions	0.49 kg CO_2	0.31 kg CO_2	0.07 kg CO_2

In principle these CO_2 emission factors could now be used to calculate the emissions of production and consumption in a comprehensive manner. Assuming that the numbers in the example would be realistic (which they are not), one could for example calculate that if a person would consume 100 euros worth of books, the total direct and indirect emissions associated with that consumption would be:

$$0.07\ kg\ CO_2\ /\ € \times 100\ € = 7\ kg\ CO_2 \quad \text{(Eq. 3)}$$

This is the essence of how EEIO-based environmental impact factors work. I have merely scratched the surface with the examples and adding multi-regionality, imports and exports, amount of environmental indicators and physical inputs and outputs make the operations much more complex than it might seem (Lenzen et al., 2013; Merciai & Schmidt, 2018; Stadler et al., 2018).

While it is generally more cost- and time-efficient to conduct holistic assessments of environmental footprints through EEIO analyses, one of their major limitations is the relatively low resolution of data (Kitzes, 2013; Marques et al., 2017; Peters, 2010). EEIO methodologies are generally unable to distinguish between different products of the same sector (Stadler et al., 2018). Therefore, it can be difficult to compare alternative consumption patterns such as changing to books that consume less paper than conventional books or books that consume recycled paper instead of virgin paper. Furthermore, when EEIO databases are used to assess environmental impacts of the monetary consumption of goods and services in organizations, they can be sensitive to changes in pricing. Even though inflation and tax levels can be taken into account to adjust prices (El Geneidy et al., 2023b), changes in pricing can affect results, for example if a product that causes less impact on the environment is priced higher than the one with a higher impact. To complement the strengths of both LCA and EEIO methods, hybrid-LCAs provide a viable option.

2.2.1.3 Hybrid-LCA

Hybrid-LCA is a method that combines the use of LCA and EEIO analyses to minimise the limitations of both (R. H. Crawford, 2008; R. H. Crawford et al., 2018; Nakamura & Nansai, 2016; Suh et al., 2004). LCAs are generally more granular and accurate, looking at individual products and services and the individual stages of their life cycle, whereas EEIO analyses deliver a comprehensive coverage of the economy and multi-regionality. There is a whole spectrum of methodological approaches on how the hybridization of methods can be conducted: in some cases the LCA could be complemented with certain EEIO based analyses, while in other cases EEIO data could be complemented with LCA data, shifting the emphasis of the methodological choice (R. H. Crawford et al., 2018). One of the challenges of hybrid-LCA is that the LCA and EEIO databases sometimes appear to yield different environmental footprint results for the same sector (Steubing et al., 2022).

2.2.2 Carbon and biodiversity footprint assessment

Organizations can assess their negative impacts on climate and biodiversity with the abovementioned environmental accounting methodologies paired with data about their production and consumption. The negative impacts organizations have on climate and biodiversity can be called carbon and biodiversity footprints but are sometimes also referred to as climate and biodiversity impacts, climate and nature footprints or simply emissions. It seems that the term "footprint" has been more closely related to the EEIO community than the LCA community and does not have a distinct definition in literature (Fang et al., 2016; Lenzen, 2014; Marques et al., 2017). I refer to the term footprint broadly as the negative environmental impacts caused by all consumption activities. In turn, positive environmental impacts can be referred to as handprints, although the concept is still in its infancy (Grönman et al., 2019; Pajula et al., 2021) Next, I will go through the concepts of carbon and biodiversity footprints and present research that has already been done especially in the context of organizations' footprints. The methodological background of the carbon and biodiversity footprint assessments I have used in the dissertation are examined more carefully in section 3.

Carbon and biodiversity footprints are indicators used to measure the amount of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions (R. Chen et al., 2021; Peters, 2010; Shi & Yin, 2021; Wiedmann & Minx, 2007), and the amount of biodiversity loss (Crenna et al., 2020; Damiani et al., 2023; Marques et al., 2017), caused by a product's life cycle processes (Asselin et al., 2020; Hellweg & Milà i Canals, 2014), individuals and households (Bjelle et al., 2021; Chancel, 2022), regions and nations (Ivanova et al., 2017; Wilting et al., 2020) or organizations (Bull et al., 2022; El Geneidy, Baumeister, et al., 2021; El Geneidy et al., 2023b; Larsen et al., 2013; Pokkinen et al., 2024; Thurston & Eckelman, 2011).

Carbon footprints are generally expressed as carbon dioxide equivalents (CO_2e), which means that all GHG emissions included in the assessment are converted into CO_2e based on their global warming potential (WBCSD & WRI, 2012; Weidema et al., 2008; Wiedmann & Minx, 2007). Whereas carbon footprint has a more uniform metric of measurement, biodiversity footprint has several different indicators (covered in detail in section **Error! Reference source not found.**) depending on how the impact on biodiversity is measured and what level of biodiversity is considered (Damiani et al., 2023; Lammerant et al., 2022; Marquardt et al., 2019; Marques et al., 2017; Sanyé-Mengual et al., 2023).

A common factor across different biodiversity footprint methods is that they generally measure what is the response of biodiversity to a driver of biodiversity loss (land and sea use, overexploitation of natural resources, climate change, pollution and invasive alien species) (Damiani et al., 2023; IPBES, 2019; Lammerant et al., 2022). For example, a biodiversity footprint could measure how much land use is caused by the production of a food product and how the land use affects biodiversity (Kyttä et al., 2023). In fact, the drivers of biodiversity loss could be seen as midpoint indicators in LCA terminology. Biodiversity footprint is thus an endpoint indicator, indicating consequences that midpoint indicators have on biodiversity, while carbon footprint is a midpoint indicator that simply reflects how much GHG emissions are created by an activity (Huijbregts et al., 2017). Thus, a carbon footprint assessment is actually an intermediate step of a biodiversity footprint assessment. Different biodiversity footprint methodologies cover a different number of the drivers of biodiversity loss (midpoint indicators) (Damiani et al., 2023; Lammerant et al., 2022; Sanyé-Mengual et al., 2023).

In organizations, carbon and biodiversity footprints are used to assess the whole set of operations it might have from direct use of fuel or other natural resources used for operations, purchased energy and consumed goods and services. In the scientific literature, organizations' carbon footprint assessments seem to focus largely on academic institutions (El Geneidy, Alvarez Franco, et al., 2021; El Geneidy, Baumeister, et al., 2021; Larsen et al., 2013; Letete et al., 2011; Ozawa-Meida et al., 2013; Thurston & Eckelman, 2011). A systematic literature review scoped case studies around indirect (scope 3) carbon footprint assessments and found out that around 26% of the sample was focused on universities and only 6% on corporations, while the rest were industry-specific or city and nation level assessments (Hettler & Graf-Vlachy, 2023). In the case of biodiversity footprints, scientific literature still only has few assessments focused on organizations (Bull et al., 2022; El Geneidy et al., 2023b; Taylor et al., 2023) but more assessments have been published in reports (El Geneidy, Alvarez Franco, et al., 2021; Lammerant et al., 2022; Peura et al., 2023; Pokkinen et al., 2023, 2024; Pykäläinen et al., 2024).

A wide variety of standards and guidelines exist that guide carbon footprint assessments in organizations (Gao et al., 2014; Robinson et al., 2018), but assessments still lack comparability due to differences in system boundary setting and methods, especially in terms of value chains (Klaaßen & Stoll, 2021). Fewer standards and guidelines exist for biodiversity footprint assessments of organizations, but many are being developed (Taskforce on Nature-related Financial Disclosures, 2023; The Science Based Targets Network, 2023; UNEP-WCMC et al., 2022; Value Balancing Alliance et al., 2023).

The different dimensions of the carbon footprint have been defined as "scopes", depending on what activities of the organization they cover (WBCSD & WRI, 2012). Scope 1 refers to the impacts created directly by the organization, such as combustion of fossil fuels or driving company-owned vehicles. Scope 2 refers to the indirect impacts created by purchased energy, namely heat and electricity. Scope 3 refers to all other indirect impacts, such as impacts embedded in purchased goods and services, business travel, investments and so on. Scope 3 emissions can be further divided into upstream and downstream impacts (WBCSD & WRI, 2012). Upstream impacts basically relate to the production of goods and services flowing into the organization and downstream impacts to the goods and services flowing out of the organization, i.e., their use and disposal. It has been assessed that the role of scope 3 impacts, especially in terms of carbon footprint, can be highly significant in different organizations and industries (El Geneidy, Baumeister, et al., 2021; Hertwich & Wood, 2018; Matthews et al., 2008; Peters, 2010; M. Schmidt et al., 2022).

There are not as widely used standards in the field of biodiversity footprint, but the Science Based Targets Network has defined the "scopes" of biodiversity footprint assessment as upstream, direct and downstream impacts, embedding scope 2 impacts to upstream and direct impacts (Science Based Targets Network, 2023). Building up on the work of the GHG Protocol and the Science Based Targets for Nature (SBTN), I illustrate how carbon and biodiversity footprints could fit into the same framework and show the relevant activities in the value chain and direct operations from the viewpoint of an organization (Figure 5). I have used the distinction used by the SBTN framework and embedded energy purchases (scope 2) into upstream impacts. The list of activities upstream and downstream of the value chain is not exhaustive but provide certain examples. The direct operations of the organization and the organizations and individuals in the upstream and downstream of the value chain cause climate change in the form of GHGs and biodiversity loss in the form of the different drivers of biodiversity loss. The interaction between climate change and biodiversity loss creates the nexus (nature-climate nexus) that was discussed in section 1.1.

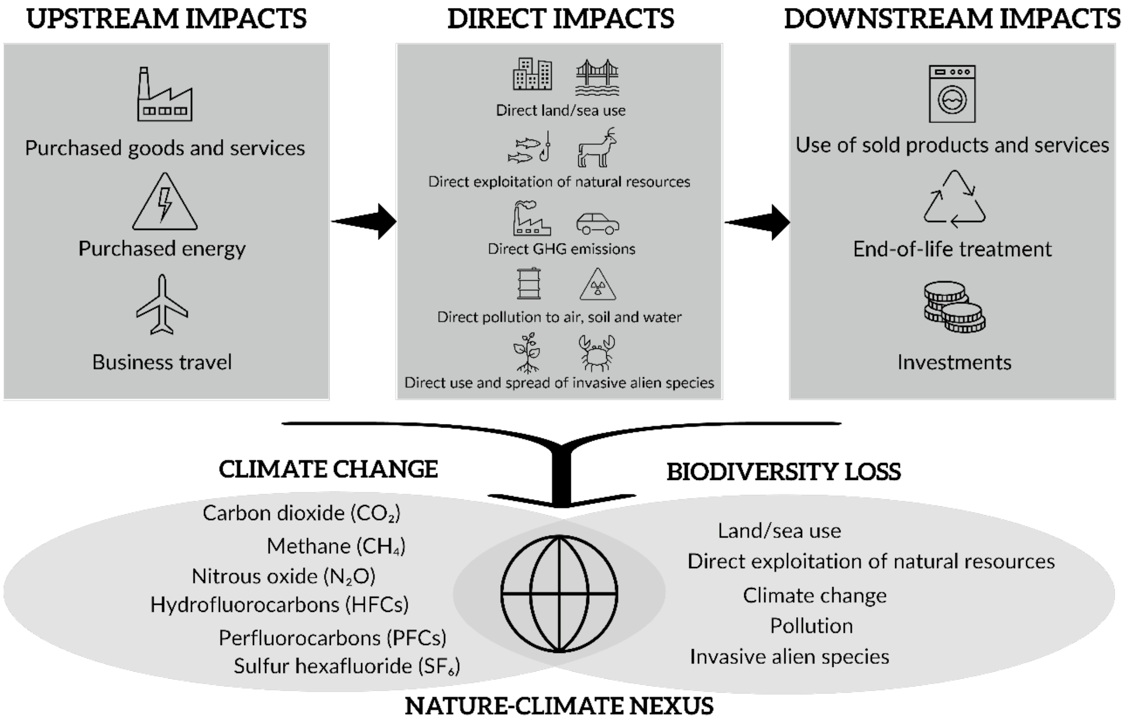

Figure 5: The dimensions of carbon and biodiversity footprint assessment from the viewpoint of an organization. Inspired by the GHG Protocol and the SBTN framework (Science Based Targets Network, 2023; WBCSD & WRI, 2012).

2.2.3 Biodiversity footprint indicators

Biodiversity (i.e. biological diversity) refers to the variability among all living organisms in terrestrial, marine and other aquatic ecosystems, including the genetic, species and ecosystem diversity (Díaz et al., 2015). Thus, to measure the negative impacts an activity has on biodiversity, one needs to understand how it affects genetic, species and ecosystem diversity. Current indicators mostly focus on negative impacts on species diversity (Crenna et al., 2020; Damiani et al., 2023; Lammerant et al., 2022), probably at least partly due to lack of data on other aspects of biodiversity. However, it has also been proposed that measuring and stopping species extinctions should be one of the most important goals in global conservation policy (Rounsevell et al., 2020), and thus the focus on species diversity may be justified.

Potentially disappeared fraction of species (PDF) is an indicator of biodiversity loss that accounts for the fraction of species that are potentially lost if the driver of biodiversity loss (e.g. land use) continues over time (Goedkoop & Spriensma, 2001; Scherer et al., 2023; Verones et al., 2017, 2020). PDF values range from 0 to 1, meaning that an activity that causes 0 PDF indicates that 0 % of the species are in risk of going extinct, while for example 0.1 PDF would mean that 10 % of the species are in risk of going extinct (Verones et al., 2020). The basic building blocks of the indicator are species area relationship models (SAR), geographic ranges of species, vulnerability of species to the drivers of biodiversity loss and extinction risk classification of species (Goedkoop & Spriensma, 2001; Scherer et al., 2023; Verones et al., 2017, 2020).

PDF has two types: regional and global PDF. The regional PDF indicates the potential for species to disappear regionally, while the global PDF indicates the potential global extinction of species (Verones et al., 2017, 2020). It has been argued that the global PDF is an important indicator because regionally lost species can be recovered if they are not endemic, while globally lost species cannot (Verones et al., 2017, 2020). Furthermore, addressing biodiversity loss as a global issue makes it possible to compare biodiversity footprints in different geographical locations, which could be important for decision-making and reporting in organizations and their stakeholders, such as investors (El Geneidy et al., 2023b). Nevertheless, it has been argued that there might be a need to look at both regional and global species loss to cover the different functions of biodiversity better (Verones et al., 2020), even though stopping global biodiversity loss could benefit from a unified indicator (Rounsevell et al., 2020). Furthermore, regional and global species loss indicators might result in slightly different outcomes (Marquardt et al., 2019). From the drivers of biodiversity loss, global PDF impact factors currently cover for example land use, water stress, climate change, pollution and ecotoxicity (Verones, 2021; Verones et al., 2020). Impacts to terrestrial and freshwater ecosystems are covered most comprehensively, while pollution is currently the only driver considered in marine ecosystems (Verones, 2021; Verones et al., 2020).

Other indicators of biodiversity loss include for example the mean species abundance (MSA) and habitat hectare. MSA indicates the average abundance, richness or geographic extent of species relative to a hypothetical pristine state of nature (Alkemade et al., 2009). Similar to PDF, MSA ranges from 0 to 1, but here the value 1 means that the ecosystem is in its pristine state, while 0 means that all species have been lost. MSA does not take into account the global vulnerability of species, making it a regional indicator of biodiversity loss (Marquardt et al., 2019). Contrary to the species-based metrics like PDF and MSA, the habitat hectare indicates the quality and condition of an ecosystem (Parkes et al., 2003; Vainio et al., 2024).

2.2.4 Carbon and biodiversity footprint mitigation

To stop climate change and biodiversity loss, organizations need to mitigate their carbon and biodiversity footprints. The mitigation of carbon and biodiversity footprints is highly context-specific, depending for example on the type of the organization's production and consumption activities. Nevertheless, some common guidelines and trends can be observed from the scientific literature of carbon and biodiversity footprint mitigation. Carbon and biodiversity footprints can be mitigated by reducing the amount of greenhouse gas emissions or other drivers of biodiversity loss such as land use and pollution. The reduction can be achieved by shifting modes of consumption and production to ones that have less impact or by reducing the total amount of consumption and production. I will cover a handful of mitigation actions in four key sectors of consumption in organizations: energy, transportation, food and other goods and services.

Fossil fuels have a high carbon footprint and reducing the amount of fossil energy is therefore a key aspect in mitigating the carbon footprint of energy consumption in organizations (IEA, 2023; IPCC, 2022; UNECE, 2022). While focus should be on reducing total energy use, shifting towards low-impact, in some cases renewable, energy sources, such as solar, wind, hydro and nuclear power, can reduce the carbon footprint of energy use in organizations (IPCC, 2022; UNECE, 2022). Many renewables seem to host a fairly good potential in mitigating other midpoint indicators, such as pollution and land use, which could indicate co-benefits between carbon and biodiversity footprint mitigation options (IPCC, 2022; UNECE, 2022). However, some trade-offs have been identified, especially in terms of bioenergy but also other renewables, which should be taken into account when shifting energy consumption in organizations (Rehbein et al., 2020; Santangeli, Di Minin, et al., 2016; Santangeli, Toivonen, et al., 2016; Vainio et al., 2024). Overall, it seems that more research on biodiversity footprint mitigation potential of different energy sources is needed.

Mitigating the carbon footprint of transportation is in a way similar to reducing the footprints of energy use: the key is to cut down fossil fuel consumption (Baumeister, 2019; IPCC, 2022; Jenu et al., 2021). In international travel, emissions can be reduced by switching flights to land-based transportation modes or for example by reducing the number of stopovers (Baumeister, 2017; IPCC, 2022; Jenu et al., 2021). In domestic travel, emissions can be reduced by switching private vehicle use and short-haul flights to land-based public transportation modes, and by switching fossil fuel based transportation modes to electric ones with low-impact electricity sources (Baumeister, 2019; IPCC, 2022; Jenu et al., 2021). Research on the biodiversity footprint of transportation remains scant, but some early examples seem to be pointing to the importance of reducing the amount of flying and other energy intensive transportation modes (Bull et al., 2022; El Geneidy et al., 2023b; IPCC, 2022). It seems that caution should again be exercised especially when shifting to biofuel based transportation modes (IPCC, 2022). Besides the shift in transportation modes, avoiding to travel in the first place, and thus reducing total consumption, hosts mitigation potential as well (Bull et al., 2022; El Geneidy, Alvarez Franco, et al., 2021; El Geneidy, Baumeister, et al., 2021).

Shifting from animal-based food, especially from ruminant animals, to plant-based food consumption has a significant mitigation potential both in terms of carbon and biodiversity footprints, and across a variety of midpoint environmental indicators (Clark et al., 2022; Crenna et al., 2019; Forslund et al., 2022; IPCC, 2022; Poore & Nemecek, 2018; Taylor et al., 2023). Organizations that consume or produce food services could thus aim to reduce the share of animal-based food products to mitigate their carbon and biodiversity footprints in unison. Reducing food loss and waste also has some potential (Forslund et al., 2022; IPCC, 2022; Taylor et al., 2023). Other measures could also include for example sustainable sourcing of food by giving attention to the practices in supply chains or sourcing certified products (Taylor et al., 2023).

Other goods and services organizations consume might include for example different supplies and machinery, such as computers and other IT supplies, paper and miscellaneous office products, and all kinds of supporting services such as maintenance, health and financial services. Due to the variety of different goods and services, it remains difficult to give generalized mitigation recommendations. Solutions of circular economy might provide some mitigation potential for the wider society (Cantzler et al., 2020; Forslund et al., 2022), and from an organization's perspective this might mean for example avoiding the consumption of goods and services in the first place, reusing and recycling, increasing the lifespan of goods, such as IT supplies, and demanding information and similar actions from suppliers regarding carbon and biodiversity footprints.

2.2.5 Carbon and biodiversity offsetting

Human activities and consequently organizations will always have negative environmental impacts. Thus, it is virtually impossible for any organization to completely eradicate their absolute total carbon and biodiversity footprints. As part of their climate and biodiversity strategies to reach carbon neutrality, net zero, carbon negative, no net loss of biodiversity loss, net positive impact or nature positive operations, many organizations now seek to offset the residual carbon and biodiversity footprints that they cannot immediately avoid or mitigate. Offsetting in the context of biodiversity is generally seen as a part of a hierarchical structure of the so-called mitigation hierarchy, where impacts are first avoided, then reduced and offset, and finally restored (Broekhoff et al., 2019; Moilanen & Kotiaho, 2021; Phalan et al., 2018).

Carbon neutrality or net zero refers to a state where emissions have reached net zero, i.e., the greenhouse gas emissions are in balance with sinks, removals or reduction activities that mitigate the amount of greenhouse gases in the atmosphere or reduce the amount of further emissions (Allen et al., 2020; Broekhoff et al., 2019; DEFRA, 2009; Fankhauser et al., 2022; Helppi et al., 2023). Similarly, no net loss of biodiversity loss refers to a state where negative biodiversity impacts are in balance with activities that conserve or restore the state of biodiversity (BBOP, 2012; Maron et al., 2018; Moilanen & Kotiaho, 2018; ten Kate et al., 2004). In both cases, the state of neutral impacts can be seen as a temporary point in time that is followed by net negative state in terms of climate impact (Peters & Geden, 2017) or net positive state in terms of biodiversity impact (Moilanen & Kotiaho, 2021). I propose that organizations could use the overarching concept of net zero impact to bring both climate and biodiversity targets under the same umbrella.

Carbon and biodiversity offsets are operational tools used to reach net zero impact by supporting the reduction and storage of emissions, or the conservation and restoration of nature, somewhere else than in the operations of the organization (Allen et al., 2020; BBOP, 2012; Broekhoff et al., 2019; Moilanen & Kotiaho, 2018). Organizations could for example offset the carbon footprint of their flights by acquiring carbon credits that certify the reduction or storage of emissions in projects that support the installation of renewable energy, afforestation or mineralisation of emissions (Allen et al., 2020; Broekhoff et al., 2019). Biodiversity offsetting one the other hand has perhaps more traditionally been used in urban planning, for example by offsetting the impacts of land use by conserving or restoring land elsewhere (Hanson & Olsson, 2023). While the nature of carbon and biodiversity offsets differ for example in the sense that biodiversity offsets are at least traditionally more strictly bound by the type and target of the impact (Moilanen & Kotiaho, 2018), the criteria for science-based offsets have many similarities, such as additionality, permanence, effectiveness and adequate measurement (Allen et al., 2020; Broekhoff et al., 2019; Moilanen & Kotiaho, 2018).

Carbon and biodiversity offsets alike have faced an abundance of criticism, that is mostly targeted at existing offsetting schemes and how they have failed to deliver quality offsetting (Broekhoff et al., 2019; Cames et al., 2016; M. Curran et al., 2014; Gibbons et al., 2018). However, some critique has also been given to the very concept of offsetting (Anderson, 2012; Becken & Mackey, 2017; Spash, 2015). In the context of organizations offsetting schemes, one issue might be that the markets are largely unregulated and voluntary offsetting does not provide organizations with enough guidance. More stringent and carefully considered regulation could advance the development and uptake of science-based carbon and biodiversity offsets that truly deliver what they promise (Koehler, 2007; Kujala et al., 2022; Wu & Babcock, 1999).

2.2.6 Integrating financial and environmental accounting

Even though especially carbon footprints, but also some types of biodiversity footprints, have been assessed at different levels for a fairly long time, we have not bended the curves of global emissions and biodiversity loss. The current situation seems to point to the fact that environmental accounting in its current state might not be adequate to facilitate transformative change. Indeed, research has shown that environmental accounting is still its own separate part in organizations and it's use has remained small in decision-making (Bracci & Maran, 2013; Maas et al., 2016; Saravanamuthu, 2004; Tregidga & Laine, 2021; Veldman & Jansson, 2020).

On the other hand, financial accounting has succeeded in providing organizations and their stakeholders, such as investors, with concise information to support and guide decision-making (Bracci & Maran, 2013; Hines, 1988; Saravanamuthu, 2004; Schaltegger & Burritt, 2000; Veldman & Jansson, 2020). According to the International Accounting Standards Board the objective of financial reporting is to provide financial information to management, investors, regulators and the general public (International Accounting Standards Board, 2018). Financial accounting is often perceived as an objective information management system, but it defines the performance, profit, loss and other key operational figures that directly influence the operational capability of an organization (Hines, 1988). Financial accounting and management accounting have been identified to hold significant power in shaping the operations of organizations, what is taken into account and what is valued (Burchell et al., 1980; P. Miller & Power, 2013), while simultaneously ignoring the value of the environment and impacts on it (Gray, 1992; Maunders & Burritt, 1991; Milne, 1996; Nedopil, 2023). Tregidga and Laine (2021) argue that one of the reasons for inadequate response to urgent environmental crises has been that environmental accounting has a long-term focus, while conventional financial accounting has a short-term focus. They suggest that the society should transition towards a model where financial accounting has a long-term perspective and environmental accounting a short-term perspective so that societies could respond to the urgent ecological crises at hand. The long-term nature of current environmental accounting, they argue, does not adequately communicate urgency to short-term financial decisions.

To address the issues of financial and environmental accounting, a stronger merger between the two might be necessary. Some examples exist of the integration of financial and environmental accounting on a conceptual (Maas et al., 2016; Nicholls, 2020; Veldman & Jansson, 2020) and practical level (Alvarez et al., 2014; Houdet et al., 2020; Larsen et al., 2013; Thurston & Eckelman, 2011). Environmental management accounting (EMA) has traditionally been used to measure environmental information and related direct costs, earnings and savings, leaving out indirect economic consequences of environmental impacts outside the traditional boundaries of the organization (Burritt et al., 2002; Jasch, 2003; Jasinski et al., 2015; Schaltegger & Burritt, 2000). Taking the monetisation of environmental impacts a step further, full cost accounting (FCA, also called full environmental cost accounting, total cost accounting and total cost assessment) has attempted to not only value the direct environmental impacts but also the indirect environmental consequences that might happen elsewhere to stakeholders that were not responsible for the environmental impact (Bebbington et al., 2001; Jasinski et al., 2015). Another similar system is called the environmental profit and loss accounting, where the purpose is to report alongside financial information the estimated indirect profit and loss associated with environmental impacts (Arena et al., 2015; Jørgensen et al., 2014; J. H. Schmidt & de Saxcé, 2016).

Nevertheless, despite all the abovementioned examples, scholarly initiatives at creating value-transforming integration of financial and environmental accounting seem to have diminished (Russell et al., 2017). Monetising environmental impacts has also received a fair amount of critique ranging from concerns over appropriation and capitalisation of common resources such as forests, rivers and the atmosphere to concern over the exhaustion of other types of values over financial ones (Russell et al., 2017). It has also been argued that economic valuation of nature is generally resisted because of its inability to take into account questions of social and environmental justice (Matulis, 2014). In this dissertation I aim to light up the discussion on a theoretical and practical level around the value-transforming integration of financial and environmental accounting in organizations.

3 RESEARCH APPROACH

3.1 Ontology and epistemology

To understand what kind of scientific methodologies were applied in my dissertation and why, I will briefly analyse the ontological and epistemological foundations of the chosen research approach. Ontology explains how a researcher views reality, while epistemology explains what is the relationship between the investigated reality and the researcher (Healy & Perry, 2000). There are roughly four scientific paradigms: positivism, realism, critical theory and constructivism (Guba & Lincoln, 1994; Healy & Perry, 2000). These paradigms address issues of ontology and epistemology from a different perspective. I will mainly present and analyse the positivist and realist approaches as they are most relevant for the contents of my dissertation. Briefly it can be summarized that critical theory explains reality as something that is mended by values, such as cultural, social and economic values, while constructivism explains that instead of a one mended reality there can be multiple "constructed" realities (Healy & Perry, 2000). In both approaches the findings of the researcher are considered to be subjective, i.e. value mediated or even created (Healy & Perry, 2000). For a broader overview of what is considered to be included in each paradigm, see e.g. Healy & Perry (2000) and Guba & Lincoln (1994).

Positivism assumes that "reality is real and apprehensible" and that the findings of the research can be objectively true, independent facts (Healy & Perry, 2000). Due to the technical nature of the methodologies of my dissertation, it could be assumed that I mostly employ a positivist approach, i.e. I measure carbon and biodiversity footprints of consumption and assume that the findings reflect the reality as objectively as possible. At the same time the realist paradigm also offers some interesting viewpoints to be considered in the context of this dissertation. Realism also considers that the reality can be grasped scientifically but that it is "only imperfectly and probabilistically apprehensible" and that the findings can be objectively, but only probably, true (Healy & Perry, 2000). Considering that the models I have used in this dissertation are only best estimations of for example what kind of biodiversity impacts different economic activities have, rather than actual on-site measurements of biodiversity impacts, one could also argue that my dissertation follows a realist approach as well.

It has also been argued that the different scientific paradigms explain whether a research is theory-building or theory-testing research, where theory-building puts more emphasis on meaning and theory-testing more emphasis on measurement (Healy & Perry, 2000) (Figure 6). In this sense, it could be argued that this research has a closer link to theory-testing research. However, considering that the research articles themselves do not have the clear intention of testing specific scientific theories, but they develop and test methodologies of carbon and biodiversity footprint assessment, the focus of my dissertation might not even be in theory-testing. In fact, the focus of my research might be in methodological development that in the future can be used to test existing theories, especially in the field of how organizations impact biodiversity and how that is taken into account for example in accounting and management practices (Figure 6).

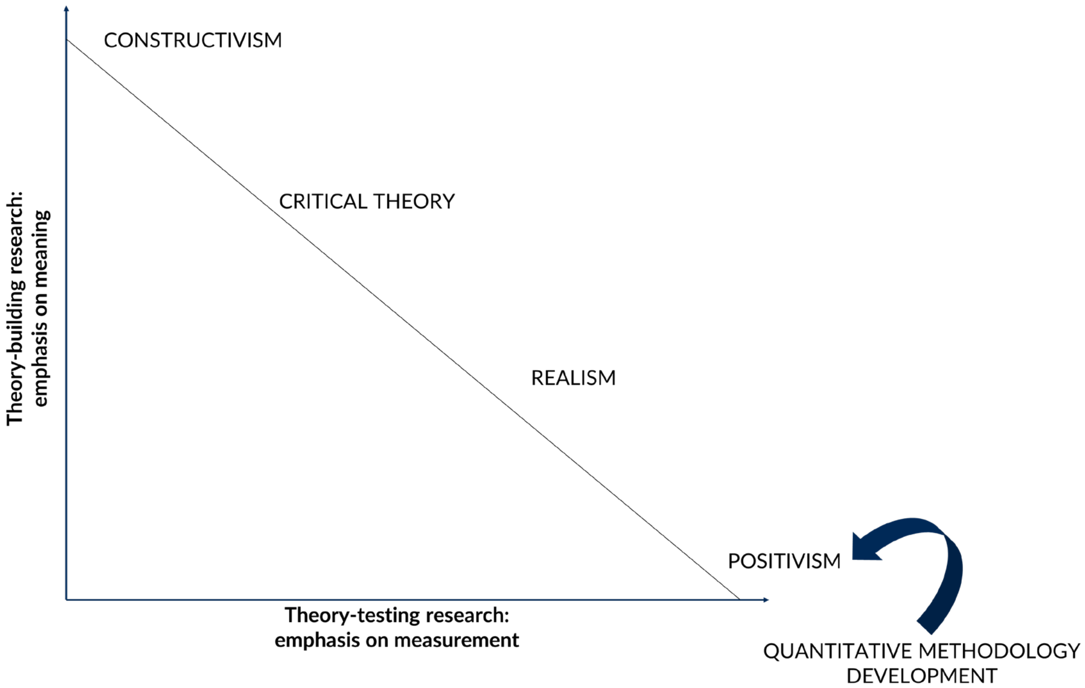

Figure 6: Positioning quantitative methodology development in relation with the paradigms of science using theory-building and theory-testing research as illustrative dimensions (adapted from Healy & Perry, 2000).

3.2 Methodology

Methodology refers to the techniques that are used to understand the reality (Healy & Perry, 2000). I mainly employed empirical quantitative methods by assessing the carbon and biodiversity footprints of consumption, with the exception of Article 3 which was more conceptual work and is discussed at the end of this section. Although the assessment of carbon and biodiversity footprints have differences, they do share many of the basic steps (Figure 7).

First, the amount and type of consumption needs to be identified, whether it is monetary consumption of a product or service in euros (€), kilograms (kg) of food consumed or megawatt hours (MWh) of energy. Second, the amount of driver of biodiversity loss or climate change needs to be identified for that specific type of consumption. The drivers of biodiversity loss are identified separately for each ecosystem type: terrestrial, freshwater and marine ecosystems. While, the second step would be enough for a carbon footprint assessment, in biodiversity footprint assessment additional steps are required to translate the drivers of biodiversity loss to actual biodiversity loss. The third step in the biodiversity footprint assessment is to identify the geographical location of the driver of biodiversity loss, because nature is location specific. In the fourth phase, one needs to identify the response of biodiversity to the drivers of biodiversity loss in the specific geographical locations.

After these steps the biodiversity impact factors and emissions factors are available, which can be multiplied with the amount of consumption to derive the carbon and biodiversity footprints. The biodiversity footprint is initially calculated separately for three ecosystem types. As a final step in the biodiversity footprint assessment, different ecosystem types can be merged with ecosystem specific weights that are based on the assessed species richness of different ecosystem types (Román-Palacios et al., 2022) to derive a single biodiversity footprint value. Next, the employed methods and data sources I have used in the articles will be briefly explained in more detail. A thorough examination of each methodology can be found from the original papers.

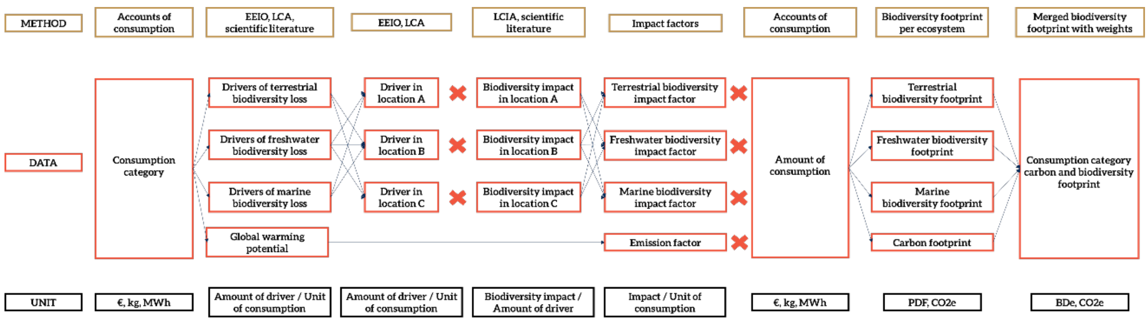

Figure 7: The overall model of calculating consumption-based carbon and biodiversity footprints (adapted from Article 4 and Pokkinen et al., 2024).

To assess the amount and type of consumption, I utilised different accounts of consumption in the research articles. In Article 1, data was collected on-site between June and November 2018 in an Indian non-governmental organization (NGO). Consumption data was collected through interviews, observations, electricity bills, waste analysis and travel accounts. Several assumptions were made to cover gaps in the collected data. For example, the travel accounts only indicated the country of origin for the studied volunteer tourists. Thus, for example in the case of United States and Canada I had to estimate the average travel distance from major airports in the East and West coasts of the countries. Furthermore, not all information could be gathered for the whole year for example in terms of electricity consumption and product use, in which case I had to assume that the consumption is distributed equally around the year.

In Article 2, the data was collected from a multinational knowledge organization that had five offices in Europe and additional project offices in Asia. The data for the study was mainly from the year 2018 and some additional data was collected from the year 2020 to analyse the impact of the COVID-19 pandemic on the carbon footprint of the organization. As data sources, I utilised energy bills and energy provider data, financial accounts, travel agency data and a travel survey. I conducted the travel survey to gain data about the employees' commuting emissions, travel behaviour and opinions. Furthermore, the survey data was analysed with two linear regression models to assess the extent to which sociological characteristics affect travel and transport choices and emissions.

In Article 4, the collected data consisted of the financial accounts of the University of Jyväskylä, paired with additional consumption data about travel and energy use. The financial account dataset included University purchases for 123 different expense categories from 2019 to 2021. The financial accounts were received from the University administration.

To assess the carbon footprints, per unit of consumption and the drivers of biodiversity loss a hybrid-LCA model was applied in all three articles. To assess the carbon footprints of non-monetary consumption (such as energy use, travel and food consumption) I used scientific literature, expert reports, direct information from service providers or LCA database ecoinvent (version 3.4) (Wernet et al., 2016) paired with the software openLCA (Ciroth, 2007; GreenDelta, 2023).

I assessed the carbon footprints and drivers of biodiversity loss of monetary consumption with the EEIO database EXIOBASE (versions 2.2, 3.4 and 3.8.2) (Stadler et al., 2018, 2021). EXIOBASE is an environmentally extended multi-regional input-output (EE MRIO) database (Stadler et al., 2018). It contains data for 44 countries, five rest of the world regions and 200 product categories. In addition to the carbon footprint, I was able to extract information on land use (occupation, 17 different sub-categories), direct exploitation of natural resources in terms of water stress (blue water consumption), pollution in terms of photochemical ozone formation, terrestrial acidification, freshwater eutrophication and marine eutrophication from EXIOBASE.

The major limitations of EEIO databases in assessing carbon footprints and drivers of biodiversity loss relate to the lack of granular data (only 200 product categories in EXIOBASE) and to the oldness of data (some impact categories are from 2011). However, this is not an inherent limitation of the methodology itself, but points out to the need to improve national and regional data collection. Furthermore, EEIO databases cannot distinguish between two products of the same sector. The results produced by EEIO databases are also sensitive to changes in pricing, meaning that more costly products tend to have higher carbon and biodiversity footprints even though they might not be more materially intensive. The regional accuracy of EXIOBASE also leaves a lot for improvement, especially for the economies of the global South. It has also been shown that for some categories results derived with LCA and EEIO databases might show differences, indicating greater uncertainties related to the assessment models of those categories (Steubing et al., 2022). Furthermore, EEIO databases have generally been used more to assess the environmental impacts of large entities such as nations, regions and international trade, and the uncertainties in the underlying data might become more prevalent when moving to assess individual organizations and supply chains (Stadler et al., 2018). It has also been argued, however, that EEIO analyses can provide interesting insights even when looking at individual product-specific supply chains (Moran et al., 2016).

The geographical locations of the drivers of biodiversity loss were assessed with the Pymrio tool, which can be used to analyse EEIO databases (Stadler, 2021, 2022). Pymrio makes it possible to locate the geographical origin of the drivers of biodiversity loss, based on the structure of the global economy and trade, and their interlinked environmental impacts. At this stage the amount of the driver of biodiversity loss per unit of consumption (in this case euros) was known in addition to the geographical origin of the drivers (on a country or region level).

Finally, the biodiversity impact of different drivers of biodiversity loss in a specific location (PDF/amount of driver) were extracted from the LC-IMPACT database (Verones, 2021; Verones et al., 2020) and paired with the information gained from EXIOBASE and Pymrio to produce the monetary biodiversity impact factors for different drivers of biodiversity loss per ecosystem type (PDF/€). Then I merged the different ecosystem types with ecosystem specific weights that are based on the assessed species richness of different ecosystem types (Román-Palacios et al., 2022), to derive biodiversity impact factors integrated across ecosystem types, i.e. biodiversity equivalent (BDe/€, further explained and justified in the results of Article 4).

Major limitations in the use of LC-IMPACT database relate for example to the differences in regional accuracy between LC-IMPACT and EXIOBASE. Since the version of EXIOBASE used was geographically less accurate with many LC-IMPACT countries belonging to the rest-of-the-world regions. Thus, an assumption had to be made that the drivers of biodiversity loss derived from EXIOBASE would distribute evenly among the countries of the rest-of-the-world regions. In addition, the use of LC-IMPACT in the developed methodology was limited to country-scale analysis. However, in the future it might be possible to apply the more regionally granular ecoregion-specific approach (Verones et al., 2020). Some drivers of biodiversity loss also cannot be well covered, such as direct exploitation of natural resources and invasive alien species, although it seems that the methodologies are being expanded and developed to cover missing drivers in the future (Borgelt et al., 2024). There are also limitations in terms of taxonomic coverage and in the reliability of the results especially within the marine ecosystems, which are not currently well covered (Verones et al., 2020).

Before the monetary carbon and biodiversity impact factors could be multiplied with the financial account values, the financial account prices had to be harmonized to match the price concept of EXIOBASE. This meant taking into account inflation due to the difference in the origin of the baseline data year of EXIOBASE and financial accounts. Furthermore, the harmonization included converting financial account prices (which are purchaser prices) to basic prices that exclude taxes less subsidies, trade and transport margins and value-added tax. In Article 4 I calculated basic price conversion factors for the Finnish economy. When all carbon and biodiversity impact factors had been derived, whether they were monetary or non-monetary, they were combined with the consumption data to derive the final carbon and biodiversity footprints.

Article 3 was a conceptual book chapter that did not utilize similar quantitative research methodologies. Instead, it reviewed existing literature around the concepts of financial and environmental accounting and their integration, and positioned this discussion around the concept of planetary well-being (Kortetmäki et al., 2021).

4 RESULTS

4.1 Article 1 – The Carbon Footprint of Volunteer Tourism

In Article 1 I explore the carbon footprint of volunteer tourism. Volunteer tourism is an emerging form of tourism where a person uses "discretionary time and income to travel out of the sphere of regular activity to assist others in need" (McGehee & Santos, 2005). While I analyse the carbon footprint of the volunteer tourists, the hosting organization, an Indian non-governmental organization was a key unit in the study. This gave me the first key insights into assessing the carbon footprints of organizations. The objective of the study was to assess the carbon footprint of the volunteer tourists and the hosting organizations, including domestic and international travels and consumption of products, services and energy.

The total average carbon footprint of a volunteer tourist was around 2 731 kg CO_2e, depending on where they took their flight from. The emissions for the volunteers' round-trip flights to and from India were 1 349 kg CO_2e on average. The other half of the footprint comprised of consumption of different products, services and electricity. The consumption of miscellaneous food and beverages had the highest total impact. The flight's share of the total annual carbon footprint could change depending on the length of stay, ranging from 96% for a 2-week stay to 49% for a 1-year stay, while the total absolute flight emissions would of course remain unchanged. The results of the study also show that the volunteers' carbon footprint in the destination country tended to be lower than the average carbon footprint of a citizen in their home country, even when the flight emissions are considered, but only after a lengthier stay of at least five weeks for example. However, I did not for example discuss the additionality of impacts and no consideration was given to future scenarios where the carbon footprint of the volunteers' home countries might drop, thus increasing the share of flight emissions.

The study showed that with the right type of data, it is possible to calculate carbon footprints even for a small organization with limited resources. The study also sheds light to the often-unspoken conflicts between personal aspirations and environmental impacts in volunteer tourism, where the climate impact of the volunteers has not been considered widely. While the volunteer work in the destination might be truly important and impactful for the local people, the environment and the volunteers themselves, communities in rural India and other parts of the global South are especially vulnerable to accelerated climate change (IPCC, 2023).

4.2 Article 2 – The carbon footprint of a knowledge organization and emission scenarios for a post-COVID-19 world

In Article 2 I analyse the carbon footprint of a multinational knowledge organization that had offices in Finland, Germany, Spain and Asia. The study mostly focused on the European offices. In the article I also sought to address carbon footprint mitigation strategies. In addition, since the COVID-19 crisis happened during the writing process of the article, I studied how the pandemic effected the carbon footprint and how it might change after the pandemic, especially in terms of business travel. Mitigation scenarios were assessed based on research literature and assessments on the level of business travel rebound in a post-COVID-19 world. Scenarios 1 and 2 estimated that there would be a drop of 19% and 36% in business travel (McCartney, 2020). Scenario 3 was based on actual data collected from the organization during the COVID-19 pandemic and showed a drop of 93% in flights. The organization was identified to be a knowledge organization: an organization that creates, applies, and invests on knowledge. This was particularly interesting because knowledge organizations do not necessarily have many direct sources of emissions, but their emissions mostly comprise of indirect upstream (scope 2 and 3) emissions.

The total carbon footprint of the organization was 644 tonnes of CO_2e (t CO_2e) and 5 t CO_2e per employee in 2018. Top contributors to the carbon footprint were flights (62%), heating (12%) and hotel and restaurant services (7%). Large majority, 87%, of the emissions belonged to scope 3, while the remaining 13% belonged to scope 2. No scope 1 emissions were identified. When combined together, all travel-related activities took a share of 79% of the total carbon footprint.

Flights accounted for 79% of the total travel-related carbon footprint. Most kilometres were flown on medium- and long-haul flights, but the emission intensity (g CO_2e / passenger kilometre (pkm)) was highest in long-haul business class flights (210 g CO_2e/pkm) and short-haul domestic economy class flights (147 g CO_2e/pkm). Short-haul flights were especially prevalent at the Finnish office, where annually 364 flights were taken to and from the capital of Finland, Helsinki.

Three largest offices in Finland, Germany and Spain were explored in terms of their carbon footprints. Flights were the largest source of emissions in all three offices, while differences could be seen for example in heating (Spanish office was run by geothermal heating) and commuting. Commuting took a share of 13% in the Finnish office, while in the other offices it only took a share of 2%.

A survey was conducted to better understand the motives and structure of business travel and commuting in the organization and its different offices (n=72, response rate of 62%). Many people argued that their recent trips could not have been avoided and also thought that choosing alternative transportation methods would not have been possible due to increase in travel time, costs and lack of options. Travel policy that does not take environmental impacts into account was mentioned as one of the key barriers to implementing more sustainable travel. A regression model showed a statistically significant difference of commuting distance and office location on individual commuting choices. Financial support for using public transport, bicycle purchases or bicycle maintenance were mentioned as possible ways for the organization to support more sustainable commuting habits.

Finally, three scenarios for the change of business travel and other consumption were assessed for a post-COVID-19 world. Scenario 1 showed that a drop of 19% in business travel and a 40% rate of home office would drop the carbon footprint of the organization by 22%. In scenario 2, where business travel would drop by 36%, the total carbon footprint of the organization would be lowered by 34%. Despite the significant drop in business travel, travel-related emissions would still represent a majority of the total carbon footprint of the organization. However, in the most dramatic scenario 3, where business travel would drop by 93%, travel-related emissions would represent only 34% of the total emissions making heating the largest contributor.

This research article further emphasized the importance of scope 3 emissions in carbon footprint assessments, which is a result aligned with other similar carbon footprint assessments of organizations (Larsen et al., 2013; Letete et al., 2011; Ozawa-Meida et al., 2013). While organizations might have less control over their scope 3 emissions, I argued that they could be significantly dropped, for example with changes in travel policies or other mitigation strategies that are summarized in Table 4. For example, based on previous research (Baumeister, 2019), I estimated that replacing all domestic flights in the Finnish office with train travel would have reduced total flight emissions by 6%. The survey results showed that the travel policy also plays a key role in reducing emissions in the organization, which is also supported by previous research that indicates the importance of managerial support (Blok et al., 2015; Lo et al., 2012, 2013; Ramus & Steger, 2000).

Carbon offsetting can be a partial and temporary solution to balance emissions, after or in parallel with avoiding and reducing impacts. Currently provided conventional carbon offsets have been criticized for failing to achieve quality components of quality carbon offsets, such as additionality (Becken & Mackey, 2017; Cames et al., 2016). In the article I discussed another form of offsetting, so-called internal offsetting, sometimes referred as insetting (Mohd Noor et al., 2017; Smedley, 2015; Tipper et al., 2009). The idea in the presented model is that the organization would impose an internal tax on emissions and collect it to an internal fund. The internal fund would then be used to support the mitigation of emissions in the organization, for example by compensating pricier train tickets, investing in local renewable energy production or in projects that provide sustainability solutions to the society. The internal offsetting system has been piloted in many knowledge organizations (ETH Zürich, 2023; UCLA, 2023; Yale University & Second Nature, 2023).

Table 4: Policy framework for mitigating travel-related emissions of a knowledge organization by avoiding, reducing and offsetting impacts (El Geneidy, Baumeister, et al., 2021).

Avoid	
Stop travelling	• Avoid all unnecessary travel • Implement more online meetings • Continue practices from COVID-19 lockdown
Avoid premium class flights (Bofinger & Strand, 2013)	• Emissions can be 2.3 times higher flying in business class • Emissions can be 6.9 times higher flying in first class
Reduce	
Choice of transportation mode	• Reduce trips by aircraft, especially domestic flights • Reduce trips by car • Travel more by train or long-distance bus
Improve travel policy	• Policy needs to take into account climate impacts • Provide more information and flexibility in terms of alternative travel modes • Include carbon offsetting
Support employees in commuting	• Create incentives and support employees in selecting less carbon-intensive commuting modes • Offer more opportunities to work from home
Offset	
Carbon offset (external)	• Carbon offset through verified external offset providers • Overcompensate to account for risks
Carbon offset (internal)	• Carbon offset by investing in internal offsetting projects

4.3 Article 3 – A planetary well-being accounting system for organizations

In this conceptual book chapter, I discussed how the integration of financial and environmental accounting in organizations could support the transition towards planetary well-being: a state in which both human and nonhuman well-being are considered.

Financial accounting is an efficient system in tracking financial flows of consumption and production. Thus, nearly anything an organization consumes and produces, and consequently its environmental impacts, should be visible in financial accounts. Environmental impacts could be accounted for in parallel with financial transactions, albeit more information about consumed products and services should be reported in transaction receipts to truly make this happen. With adequate information, the EEIO and LCA methodologies that were introduced in section 2.2.1 could indeed be utilized to assess the environmental impacts of financial transactions.

To make data readily available for key decision-makers and stakeholders, the financial and environmental information should be integrated in a financial-environmental impact statement. In traditional financial accounting an income statement characterizes the performance of an organization, for example by presenting figures of revenue and expenses (J. Chen, 2023). Future financial-environmental impact statements should also capture the environmental (and social) performance of an organization. Assets any organization uses are called capital goods and have been classified into three different categories: natural, human and produced capital (Dasgupta, 2021). Organizations and the society needs to shift to an accounting model where in addition to produced capital human and natural capital are also tracked (Dasgupta, 2021). The big picture of financial and environmental accounting and the role of the financial-environmental impact statement in the chain of organizations producing and consuming goods, services, assets and investments is illustrated in Figure 8.

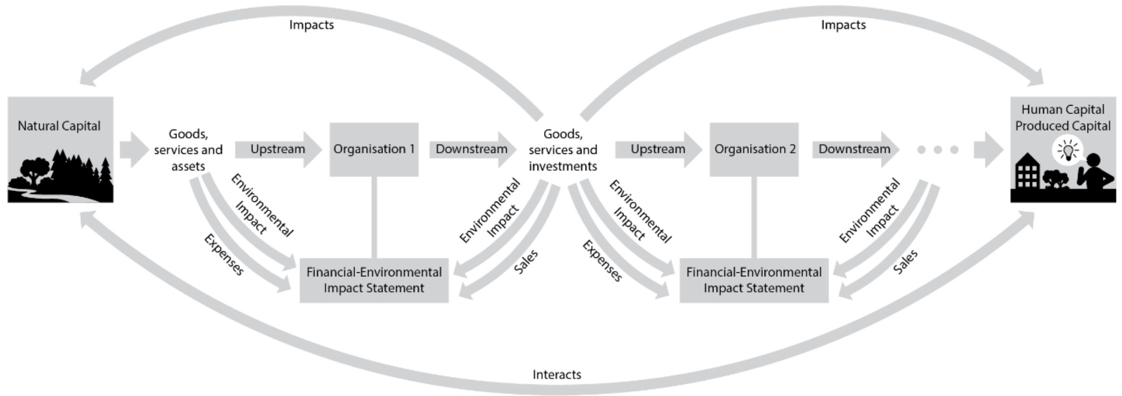

Figure 8: Presentation of the big picture of financial and environmental accounting of organizations in the society in relation to natural, human and produced capital (El Geneidy & Kotiaho, 2023).

Even though the integration of financial and environmental accounts is a crucial step towards a society where planetary well-being is taken better into account in decision-making, it should only be seen as the beginning of the journey. To truly have an impact, the integration needs to run deeper: the exposed environmental accounts will have to transform the financial value of organizations. While some development has been taking place in this regard, especially in technical accounting studies (El Geneidy et al., 2023b; Jørgensen et al., 2014; J. H. Schmidt & de Saxcé, 2016), transformation of accounting is also a public policy issue (Nicholls, 2020). Research has shown that voluntary reporting might not be as effective as mandatory reporting (E. P. Crawford & Williams, 2010; Gray, 2001; Koehler, 2007; Wu & Babcock, 1999). Indeed, international policy seems to be heading towards the integration of financial and environmental reporting for example in the form of the Corporate Sustainability Reporting Directive (CSRD), taxonomy for sustainable activities and carbon border adjustment mechanism in the European Union.

I concluded the chapter by making two policy suggestions. The integration of financial and environmental accounting should be made mandatory to all organizations with financial disclosure obligations. In addition, the information provided by the environmental accounts should be put into use in transforming the value of financial accounts. A value-transforming mechanism could be established for example with taxation, subsidies and mandatory biodiversity offsetting schemes (Moilanen & Kotiaho, 2018, 2021).

4.4 Article 4 – Value-transforming financial, carbon and biodiversity footprint accounting

Article 4 builds up on all the previous work to assess not only the carbon footprint, but also the biodiversity footprint of an organization. Additionally, the article analysed the possibility to transform the value of financial accounts with a pricing scheme based on carbon and biodiversity offsets. One of the most important contributions of the article is that it describes the biodiversity footprint methodology, which can be used to assess the biodiversity footprints of consumption globally. In the article, I present a five-step framework for implementing the value-transforming financial-environmental accounting model: (1) choose the report of financial accounts, (2) choose environmental accounting methods and indicators, (3) harmonize the accounts, (4) calculate results, and (5) assemble the value-transforming financial-environmental impact statement. I showcased the framework by implementing each step into the carbon and biodiversity footprint assessment of a Finnish organization, the University of Jyväskylä, during 2019-2021.

The first step of the framework points out that there are various financial accounts and reports that can be used to assess environmental impacts. If the focus is on environmental impacts of consumption, focus should be given to accounts of financial expenses. In addition, the level of detail should be granular enough to allow the adequate identification of different product and service categories.

In the second step, environmental accounting methods and indicators need to be chosen to assess the environmental impacts of the financial accounts derived in the first step. In this study the hybrid EEIO-LCA methodology was chosen, and the methods are further specified in sections 2.2.1 and 3. The imperative for tackling both climate change and biodiversity loss simultaneously is clear (Pörtner et al., 2021). Whereas the assessment of carbon footprints through carbon dioxide equivalents is relatively clear, there are numerous indicators for biodiversity footprints. In the article, I outlined why the global potentially disappeared fraction of species (PDF) (Verones et al., 2020) might be a good indicator in integrated carbon and biodiversity footprint assessments of organizations. I argue that the global PDF provides a common currency for measuring biodiversity loss across the planet. It indicates the potential fraction of the species of the world that are at risk of going extinct globally, if a driver of the biodiversity loss, such as land use, persists over time. Biodiversity and nature can be understood as one global life of the whole planet. Thus, it is possible to measure what kind of an impact a consumption activity has on the global biodiversity and compare consumption activities in different geographical locations. For this reason, I present in the article that the indicator could be called the biodiversity equivalent (BDe). I combined the EEIO database EXIOBASE (Stadler et al., 2018, 2021) with the life cycle impact assessment database LC-IMPACT (Verones, 2021; Verones et al., 2020) to derive spatially explicit biodiversity loss impact factors of consumption (BDe/€)[1].

In the third step, I provided information on how EEIO databases can be harmonized with financial accounts in terms of economic activity categorization and pricing. This necessary step has been rarely discussed and opened in the literature, which is why in the article I provided full equations on how to proceed with the harmonization process. The equations describe how financial account prices can be transformed to consider inflation of prices between the EEIO database base year and the financial accounts, and how to transform financial account prices to basic prices that exclude taxes and trade and transport margins.

The fourth step is about calculating and compiling the results to a meaningful format for decision-makers. In essence the calculation of results is very straightforward after the right impact factors have been derived and accounts have been harmonized: the account-specific impact factors (BDe/€ and CO_2e/€) are multiplied with the harmonized financial account prices. In terms of the biodiversity footprint, the results are first calculated for each driver of biodiversity loss and ecosystem type individually and finally merged with ecosystem specific weights indicating the division of the global species' between the different ecosystem types (Román-Palacios et al., 2022).

[1] The full dataset is provided after publication for open use in Zenodo: https://doi.org/10.5281/zenodo.8369650.

The results of the studied organization, University of Jyväskylä, showed that the carbon and biodiversity footprints decreased by 16% and 19% respectively from 2019 (16 150 t CO_2e, 41.7 nano BDe) to 2020 (13 568 t CO_2e, 33.8 nBDe), but slightly rebounded with an increase of 6% and 8% respectively from 2020 to 2021 (14 505 t CO_2e, 36.6 nBDe). The biodiversity footprint value, e.g. the 36.6 nano PDF's, indicates that on average the operations of the University of Jyväskylä cause the potential risk of extinction for 0.00000366% of the world's species if the consumption and the consequent drivers of biodiversity loss remain unchanged. The decrease in the footprints was likely driven by the COVID-19 pandemic, which can be inferred from the drop in the travel-related footprints, similar to Article 2, and increase in IT supplies. Results by consumption category are summarized in Figure 9a.

In terrestrial ecosystems land use, climate change and pollution contributed to average to 47%, 46% and 7% respectively to the total annual biodiversity footprint, while water stress, climate change and pollution contributed to 55%, 42% and 3% of the biodiversity footprint in freshwater ecosystems. Pollution was the only driver that could be incorporated with the marine biodiversity footprint.

I also assessed the similarities of the different consumption categories in terms of their carbon and biodiversity footprints. The scatterplot shows the relative carbon footprint of each consumption category on the relative biodiversity footprint of the corresponding consumption category in 2021 (Figure 9b). The results show that in many categories there are similarities, which could also be explained by the fact that nearly half of the biodiversity footprint was explained by climate change impacts in the terrestrial and freshwater ecosystems.

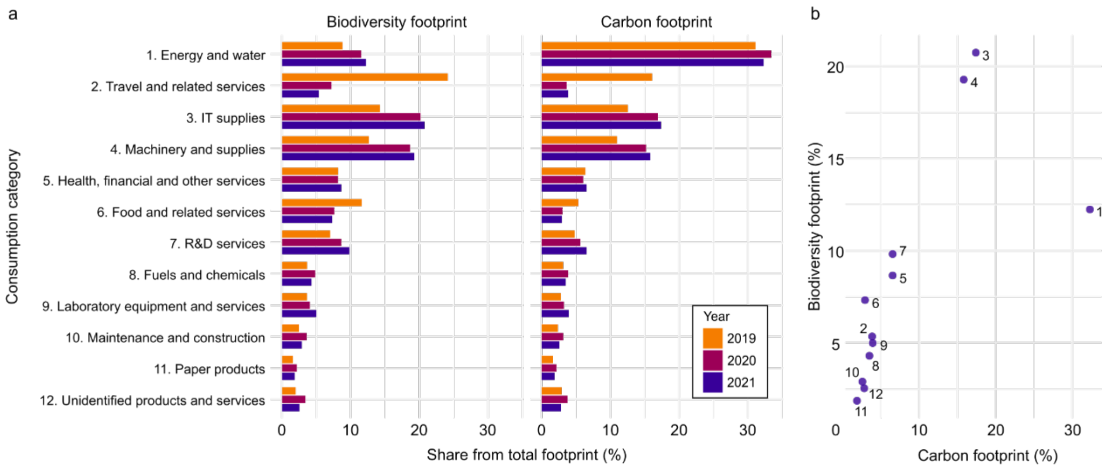

Figure 9: The carbon and biodiversity footprint of the University of Jyväskylä 2019-2021 (a) and the scatterplot of footprints (b) (El Geneidy et al., 2023b).

In addition, I assessed the geographical location of the carbon and biodiversity footprints of the University of Jyväskylä in 2021 (Figure 10). The Figure shows the geographical location of the University's carbon footprint (tCO2e) (panel a), biodiversity footprint (BDe) (panel b), land use (ha) and biodiversity footprint (BDe) due to land use (panels c and d respectively) and freshwater pollution (kg) and biodiversity footprint (BDe) due to freshwater pollution (panels e and f respectively). Small island states that are not visible in the map were excluded from the scales of the map. Although in the analysis the carbon footprint contains all greenhouse gases, in this figure, only CO2 is depicted Results showed that in terms of the carbon footprint, most emissions were generated in Finland, Russia and China, while the biodiversity footprint was focused for example to Estonia, Indonesia, India, Finland and small island states such as Guam and Seychelles. 66% of the carbon footprint and 98% of the biodiversity footprint was situated outside of Finland.

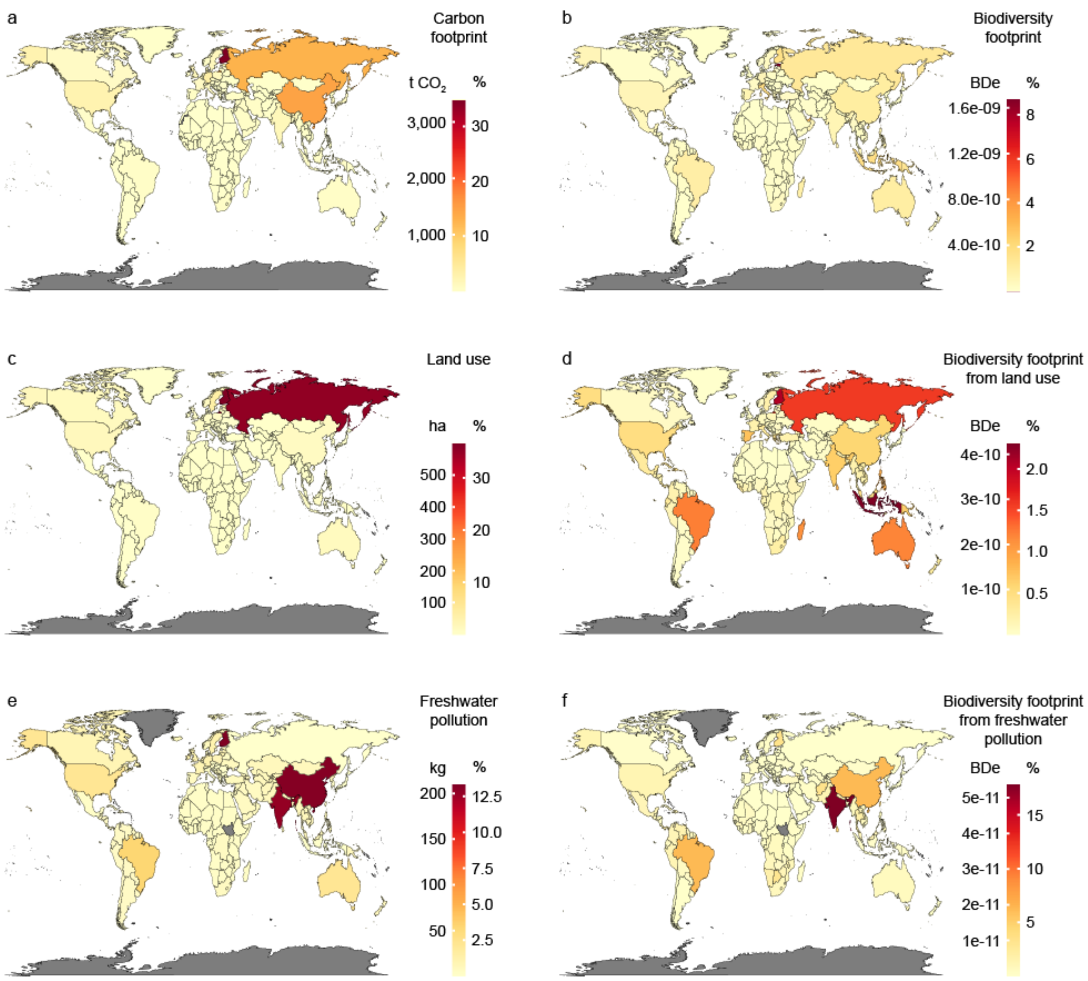

Figure 10: The geographical location of the University's carbon and biodiversity footprints in 2021.

In the fifth and final step of the framework, the value-transforming financial-environmental impact statement is assembled from the calculated results. Building up on the conceptual lessons derived from Article 3 and previous research (Houdet et al., 2020; Nicholls, 2020), I drafted a pilot financial-environmental impact statement. I showcased the transformation of financial value by assigning a cost to the carbon and biodiversity footprints, based on their presumed offsetting values derived from literature. The University of Jyväskylä carbon offsets would have cost 673 000 € in 2021, while the biodiversity offsets, implemented by conserving forests from economic activities, would have cost around 125 000 000 € (per annum for 30 years) if offsets were fully implemented in Finland and 204 000 € if fully implemented in Brazil.

This article developed a spatially explicit biodiversity footprint assessment dataset, which will be openly available for further use in the Biodiversity Footprint Database (El Geneidy et al., 2023a). In addition, I did not only focus on the environmental footprints of an organization but aimed to bring them into the centre of a wider discussion on how organizations are managed through financial accounts and reports, and how they could be transformed. Even though the financial valuation of the footprints was methodologically rough, it sets an example on how carbon and biodiversity offsetting could work as a proxy for pricing environmental impacts.

5 DISCUSSION

The overall aim of my doctoral dissertation has been to develop the methodologies of carbon and biodiversity footprint assessment in organizations. In addition, I aimed to develop pathways for consistent reporting, mitigation and offsetting of carbon and biodiversity footprints in organizations. While the organizations I have explored vary by nature, I aim to discuss and synthesise some key points and learnings that can be derived from the results of the four articles for science, organizations and policymakers. Furthermore, some level of organizational and societal changes are necessary to halt climate change and biodiversity loss. Thus, I discuss based on the presented theories of organizational and transformative change, whether or not the integration of financial and environmental accounting could play a role in catalysing transformative changes in organizations and societies.

5.1 Carbon and biodiversity footprint assessment

Overall in all studied organizations the energy and travel-related carbon footprints had a high relative importance to the total carbon footprint of the organization, which is in line with previous studies around similar organizations (Larsen et al., 2013; Ozawa-Meida et al., 2013; Thurston & Eckelman, 2011; Wynes & Donner, 2018). Similarly, in Article 4, the biodiversity footprint of travel-related activities in the University of Jyväskylä was high until the pandemic years. Although the COVID-19 pandemic caused a drop to travel-related carbon and biodiversity footprints, emissions and frequency of flights have already rebounded towards pre-pandemic levels, are expected to return to 2019 levels by 2025, and continue increasing thereafter (EUROCONTROL, 2023; European Environment Agency, 2023). Article 4 also showed that the relative importance of the carbon and biodiversity footprint of consumables such as IT supplies and other equipment has risen throughout the years, which could be due to the increased digitalization of communications during the pandemic, but further research would be needed in other similar organizations to verify this conclusion.

The carbon and biodiversity footprint assessments of the studied organizations showed the relative importance of indirect (scope 2 and 3) impacts caused by consumption activities, which seems to be in line with previous research findings especially around carbon footprints (Bull et al., 2022; Hertwich & Wood, 2018; Matthews et al., 2008; Peters, 2010; M. Schmidt et al., 2022). The organizations I have studied provide a fruitful platform for discussion around indirect footprints because they were organizations that have very little or no direct emissions. While the assessment of indirect, and especially scope 3, carbon and biodiversity footprints remain difficult, the results show that by using a hybrid-LCA methodology, it is possible to identify consumption categories that have the largest contribution to the overall carbon and biodiversity footprints. Although methods exist to assess carbon and biodiversity footprint of value chains, perhaps one of the largest barriers in the organizations was the availability of data. The organizations did not, in many cases, have adequate information about the different consumption activities, which leads to the need to collect information from many different stakeholders and make multiple assumptions to complete the assessment. Hettler and Graf-Vlachy (2023) identified that literature around scope 3 carbon footprint assessments is scattered and that there is a clear need for more empirical research to enhance the comprehensiveness of scope 3 carbon footprint assessments in the society. Following the discussion raised by Tregidga and Laine (2021), by shifting the focus of environmental accounting from long-term to short-term, also in organizations, better monitoring of data necessary to assess indirect carbon footprints could be reached. In practical terms this means that the collection and accounting of data necessary for the assessment of indirect carbon footprints should be handled with sufficient urgency and seriousness, as is done to achieve the aims of conventional financial accounting and reporting.

The indirect nature of the carbon and biodiversity footprints also indicate that direct environmental impacts are only seemingly absent and are in fact exported along the value chain to other organizations, and geographical locations (Article 4). Exporting direct environmental impacts of production to other places has generally been observed in national and regional level assessments of carbon and biodiversity footprints, and is especially prevalent in the global North due to higher levels of consumption per capita (Hickel et al., 2022; Lenzen et al., 2012; Marques et al., 2019; Wilting et al., 2020). As Fankhauser et al. (2022) put it, a credible net zero target needs to be comprehensive. Organizations aiming to reach net zero, both in terms of carbon and biodiversity footprints, should aim to account for all direct and indirect impacts because their consumption activities drive the direct impacts of other organizations. However, in an ideal world all organizations would account for their direct impacts (i.e. another organization's indirect impacts) and convey the information in the value chain so that no organization would actually have the need to assess indirect impacts.

The biodiversity footprint assessment I have developed provides organizations with a way to assess their consumption-based biodiversity footprints (Article 4). While practical biodiversity footprint tools are becoming more abundant (Damiani et al., 2023; Lammerant et al., 2022; Sanyé-Mengual et al., 2023), their comprehensive scrutiny and testing by science has not been as widespread, especially in organizations (Bull et al., 2022; Taylor et al., 2023). The analysis of the drivers of biodiversity loss showed that climate change and land use had the highest contribution to the biodiversity footprint in terrestrial and freshwater ecosystems, and similar results were observed by Bull et al. (2022). The biodiversity footprint assessment opens an interesting avenue for further integration of carbon and biodiversity footprint assessments in organizations. This is because carbon footprint assessment is one of the intermediary steps of biodiversity footprint assessment, and also seems to be a high contributing driver of biodiversity loss, at least in this particular case but also in other similar examples (Bull et al., 2022; Peura et al., 2023; Pokkinen et al., 2023). Furthermore, the indicator of biodiversity loss used in Article 4, global potentially disappeared fraction of species (Verones et al., 2020), could function as a common currency for measuring biodiversity loss across the planet. The biodiversity equivalent, as I call it, brings the often local biodiversity issue into a global level by showing the contribution of any human activity on global biodiversity loss. Thus, it is theoretically possible to compare biodiversity loss in all geographical locations around the world. This provides not only organizations and their value chains, but also policymakers and nations around the world with an interesting possibility to set a joint global target for stopping biodiversity loss, as has been suggested by Rounsevell et al. (2020).

Finally, financial accounts and the information they provide have proven to be an interesting avenue for carbon and biodiversity footprint assessment. The presented hybrid-LCA methodologies complement previous research around the topic (R. H. Crawford et al., 2018; Larsen et al., 2013). I also aimed to disseminate the use of EEIO analysis in a more detailed manner to allow accessibility to different researchers and practitioners interested in the method. While the information relevant for environmental accounting provided by financial accounts can be coarse and more volatile to external conditions, such as pricing changes, they provide a relatively comprehensive and consistent picture of an organization's main consumption activities due to the global nature of trade, which makes it difficult to track information about consumption. With the proposed integration of financial and environmental accounting, organizations could conduct real-time carbon and biodiversity footprint assessments based on purchasing activities. Indeed, perhaps too much of current environmental accounting practices focus on historical impacts. I argue that more focus could be given to real-time and forward-looking accounting to create efficient future impact mitigation pathways. Furthermore, when investments are planned and budgeted, an organization could also assess the environmental impacts of the investments in advance to utilize the information in decision-making.

5.2 Carbon and biodiversity footprint mitigation

Reducing the amount of flying and by cutting travel in general or choosing alternative transportation modes can significantly reduce the carbon footprint of organizations (Articles 1 and 2). Flight emissions are especially relevant in universities and other knowledge organizations (Larsen et al., 2013; Ozawa-Meida et al., 2013; Wynes & Donner, 2018). As the results of Article 2 show, special emphasis could be given to low hanging fruits such as business class flights and domestic flights that can create a relatively high carbon footprint, with perhaps only a small benefit. It is likely that similar mitigation potential also applies to organizations where biodiversity footprint caused by flying is high (Bull et al., 2022; El Geneidy et al., 2023b), but further research is needed for more generalized recommendations. On a wider scale, it has been shown that actions to halt biodiversity loss are generally beneficial for climate action (Shin et al., 2022). Since our results showed that climate change can be a major driver of the biodiversity footprint of consumption in organizations, actions to halt climate change could also in some cases help reduce biodiversity impacts. More research is needed on the interplay, synergies and trade-offs of carbon and biodiversity footprint mitigation actions in organizations.

Energy-related footprints also had a relatively high share in the studied organizations, especially in terms of carbon footprint. As shown by previous research, organizations could significantly cut their footprints by shifting from fossil fuel based energy sources to low-impact energy sources (IEA, 2023; IPCC, 2022; UNECE, 2022). Special attention should be paid to potential trade-offs between climate and biodiversity impacts of biofuels in energy production (Norton et al., 2019; Rehbein et al., 2020; Santangeli, Toivonen, et al., 2016; Vainio et al., 2024). This seems to be an especially relevant discussion for organizations in Finland, where bioenergy production has been increasing as for example peat is replaced with wood-based fuels (Statistics Finland, 2023; Vainio et al., 2024).

Food consumption had a relatively high contribution to the carbon footprint of an organization and a high biodiversity footprint especially in terms of marine ecosystems (Articles 1 and 4). The biodiversity footprint of food consumption has also been reported to be relatively high in other studies as well (Bjelle et al., 2021; Peura et al., 2023; Pokkinen et al., 2024; Wilting et al., 2020). It currently seems rather evident that shifting towards plant-based food can reduce both carbon and biodiversity footprints of food consumption (Clark et al., 2022; Crenna et al., 2019; IPCC, 2022; Poore & Nemecek, 2018). While organizations generally cannot choose what people eat during their lunch breaks, organizations most certainly can influence what kind of food they procure for their events and what kind of partnerships they form with cafeterias and other food service providers.

The consumption of other goods and services, such as IT supplies also had an important and increasing contribution to the carbon and biodiversity footprints (Article 4). While organizations have less power over their suppliers than for example their own employees, they can exert some power for example by applying supplier policies or by reducing consumption in total. Another thing that could guide the consumption of organizations would be to assess organization-specific minimum material requirements needed to uphold the core functions of the operations. Earlier research has focused on assessing the material requirements of decent living standards from an individual's perspective (Millward-Hopkins et al., 2020; Vélez-Henao & Pauliuk, 2023), but similar research is lacking in the context of organizations.

As the travel survey conducted in Article 2 shows, employees thought that the absence of environmental aspects from the travel policy is a major barrier for more sustainable travel practices. Organizations that wish to reduce emissions from travel and other aspects, should consider formalizing environmental aspects into their key policies, which could show employees that the mitigation actions have managerial support (Blok et al., 2015; Lo et al., 2012, 2013; Ramus & Steger, 2000).

An impending challenge for mitigating carbon and biodiversity footprints of consumption in organizations is that majority of the impacts seem to be generally produced indirectly and occurring in organizations' supply chains, making them the direct impacts of other organizations. Who then should be responsible for the mitigation of those impacts? The one who produces the impacts or the one who drives the production with their consumption? In a sense it might not matter whose responsibility the impact mitigation is, but the questions become especially relevant when impacts are realized as financial costs, for example through carbon and biodiversity offsetting or tax and subsidy schemes. Ultimately it might be so that the responsibility should be with the one who produces the environmental impact and the associated cost with that responsibility should be transferred along the value chain to the ones who consume the end products. Thus, the responsibility can be shared between the producers and consumers. Nevertheless, this would require more thinking and it might be problematic to assume that only one end of the value chain would be responsible for the environmental impact. Researchers have suggested multiple ways to distribute environmental responsibility along global value chains, ranging from responsibility based on added value or income (Marques et al., 2012; Piñero et al., 2019) to using input-output methodologies to allocate responsibility between producers and consumers (Gallego & Lenzen, 2005; Lenzen & Murray, 2010; Rodrigues et al., 2006).

5.3 Carbon and biodiversity offsetting

Carbon and biodiversity offsetting have been traditionally used as tools to offset residual carbon and biodiversity footprints, allowing organizations to achieve net zero or net positive impacts (Broekhoff et al., 2019; Fankhauser et al., 2022; Moilanen & Kotiaho, 2018, 2021; Peters & Geden, 2017; ten Kate et al., 2004). However, the caveats of offsets have to be tackled if they are to be considered (Becken & Mackey, 2017; Cames et al., 2016; Spash, 2015). I suggested that carbon and biodiversity offsets can also be used as a tool to transform financial value in organizations (Article 4). Carbon and biodiversity offsets have been contested for their improper implementation (Becken & Mackey, 2017; Broekhoff et al., 2019; Cames et al., 2016) and over concern that offsetting could shift focus from avoiding and reducing of impacts to merely offsetting all impacts (Anderson, 2012). However, the system I have presented could give organizations and the society a solution to assign financial value to environmental impacts, and consequently drive the mitigation of impacts and offsets in the same process.

In Articles 2 and 4 I briefly discussed the idea of internal offsetting, or insetting (Mohd Noor et al., 2017; Smedley, 2015; Tipper et al., 2009), as an alternative to conventional "external" offsetting. Internal offsetting could provide organizations new ways to internally price their carbon and biodiversity footprints (Yale University & Second Nature, 2023) and "offset" their impacts in other manners than external offsetting providers. The overall idea of internal offsetting is presented in Figure 11. The operations of organizations can have negative environmental impacts, i.e. footprints, but also positive impacts, i.e. handprints (Pajula et al., 2021), that both affect the state of natural capital (Dasgupta, 2021). The idea would be to value these impacts in the financial-environmental impact statement of the organization and transfer the amount internally to an internal offsetting fund. An organization could for example determine the value of their carbon footprint with the EU market price for emissions. If the price of emissions would be 100 € / t CO_2, and the organization emitted 100 t CO_2, it would invest 10 000 € into the internal offsetting fund. The internal offsetting fund would then be used to invest to the mitigation of footprints within the organization to enhance the handprint or as direct investments to natural capital. Perhaps the logic could be seen as a kind of avoided loss offset (Moilanen & Laitila, 2016), where investments are made to internal consumption changes to prevent future loss. The idea of internal offsetting (or insetting) would need to be developed and researched more carefully, as there are many open questions left, such as can the mechanism be considered as offsetting or is it just complementary to conventional offsetting and impact mitigation practices. Furthermore, issues of social justice, that come increasingly relevant with financial valuation of impacts, within and between organizations would also need to be considered carefully.

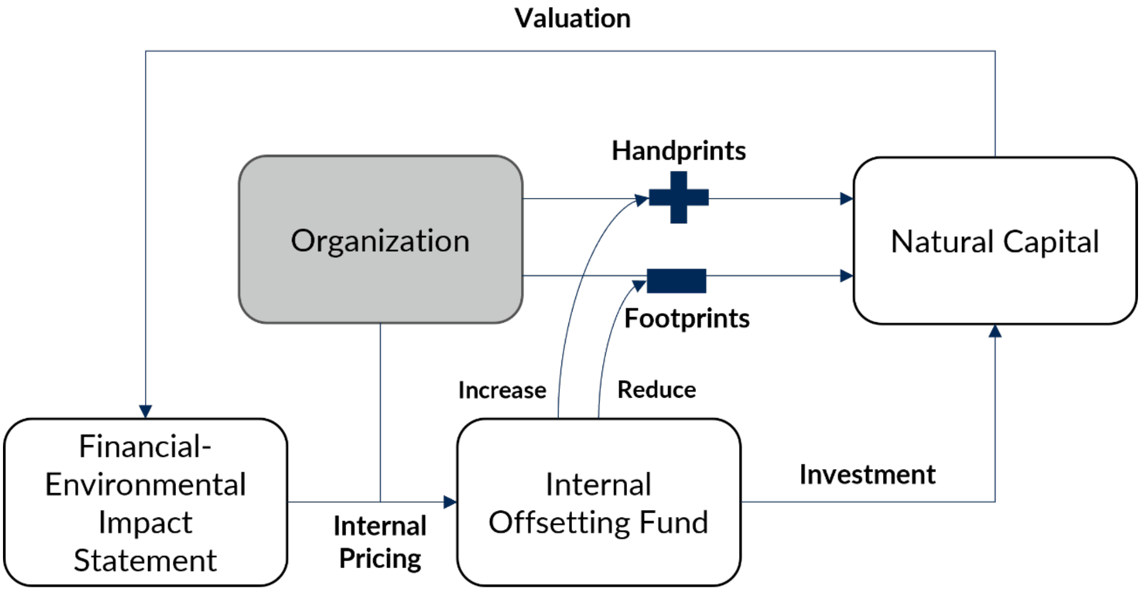

Figure 11: A conceptual figure about the internal offsetting scheme from the viewpoint of an organization. Adapted from El Geneidy et al. (2021).

Carbon offsets are generally not as location specific as biodiversity offsets (Moilanen & Kotiaho, 2018). Therefore, interesting issues arise when thinking about the biodiversity offsetting in international supply chains of organizations. The global PDF indicator makes it possible to compare biodiversity impacts in different locations, thus in theory making it possible to conduct biodiversity offsetting in any location to preserve the amount of global biodiversity that was lost due to activities around the world. However, to cover different aspects of biodiversity and its many functions, it might be beneficial to look at regional disappearance of species in addition to global disappearance (Scherer et al., 2023; Verones et al., 2020). Thus, it might be beneficial, but challenging, to consider the many locations of biodiversity loss in international supply chains.

Fankhauser et al. (2022) define the attributes of a credible net zero (climate) target, that could be at least partially applied to net zero biodiversity targets as well. I adapt their work to provide an overview of attributes that could guide credible integrated carbon and biodiversity offsetting (Figure 12). Front-loaded impact mitigation means that organizations need to cut carbon and biodiversity footprints as much as possible as soon as possible. Organizations also need to mitigate impacts as comprehensively as possible, for example by taking into account often challenging indirect scope 3 impacts. To reach net zero cautious use of offsets means considering integrated quality criteria for carbon and biodiversity offsets, some of which are presented in Figure 12. Finally, the offsets need to be effectively regulated to avoid failures in the offsetting markets (Arup & Zhang, 2015), such as incorrect implementation of offsets (Becken & Mackey, 2017; Cames et al., 2016; Spash, 2015).

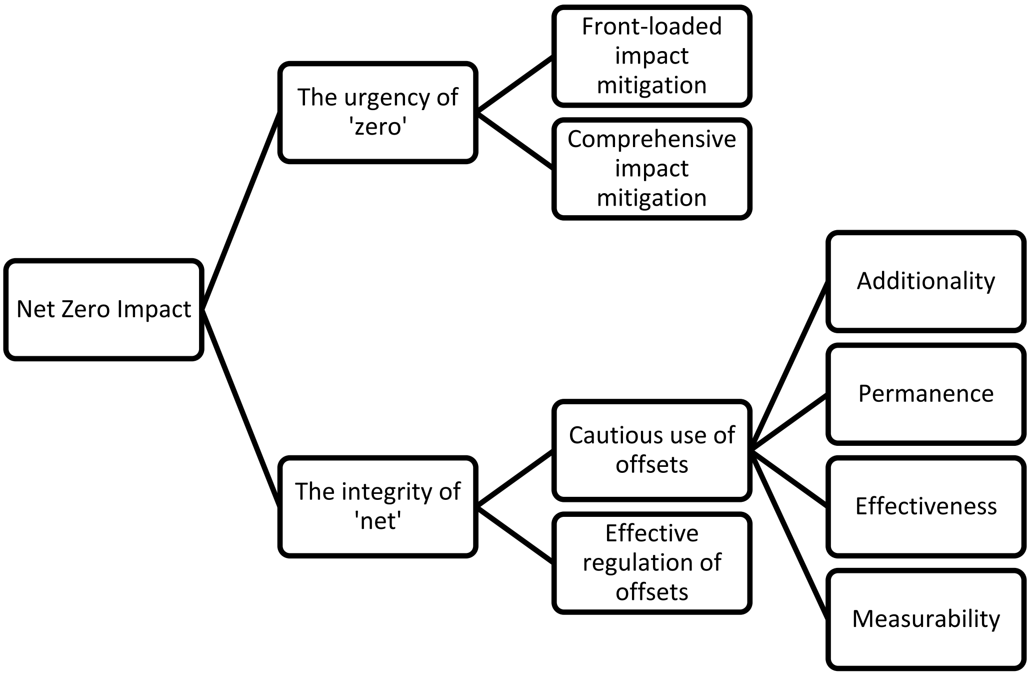

Figure 12: The Net Zero Impact framework for organizations in the context of climate and biodiversity impacts. Adapted from Fankhauser et al. (2022).

5.4 Integrating financial and environmental accounting

5.4.1 An initial step towards planetary well-being?

I also discussed the integration of financial and environmental accounting on conceptual and practical levels (Articles 3 and 4). Even though mergers of financial and environmental accounting have been tested in the past for example in the form of full cost accounting (Bebbington et al., 2001; Jasinski et al., 2015) and environmental profit and loss statements (Arena et al., 2015; Jørgensen et al., 2014; J. H. Schmidt & de Saxcé, 2016), scholarly efforts in this field have dwindled (Russell et al., 2017). In addition, these systems have not been operationalised to transform the value of financial accounts. In this sense, while the discussion on the integration of financial and environmental accounts is not new, I introduced carbon and biodiversity offsets, already existing mechanisms, as tools to operationalise the value-transforming integration in organizations. However, for a meaningful value-transformation of financial accounts, offsets would have to meet the criteria of offsets and the use of offsets should be complemented and guided with measurable impact mitigation goals. Furthermore, the financial valuation of environmental impacts would need careful consideration, although it seems that much of the critique is perhaps related to the valuation of nature per se (Matulis, 2014; Russell et al., 2017), not impacts on nature. Nevertheless, they might have the same implications in the end, but more discussion and research around the implications of valuing impacts on nature is needed.

The proposed value-transforming financial-environmental impact statement has two dimensions. First, I assessed the carbon and biodiversity footprints caused by the consumption of the organization and integrated them with the financial accounts and reports. Second, I also assessed what could be the financial implications of carbon and biodiversity footprints to the financial value of the organization. This is similar to the double-materiality assessment that organizations should adhere to in the coming corporate sustainability reporting directive (CSRD) (EU, 2022). The double-materiality assessment means that organizations will have to assess what kind of impacts they have on nature, but also what are their dependencies on nature, i.e. what kind of risks changes in nature can inflict on the organization. While I have mostly focused on impacts of the organization, some of the methodologies could be used as a first step to also assess the dependencies. To understand an organization's dependencies on nature, one has to understand what kind of resources it utilizes from nature. This then comes back to the midpoint indicators or drivers of biodiversity loss. If it is known how much and what kind of land use the organization causes, directly or indirectly, or how much water or forest products its operations causes, it indicates what kind of dependencies the organization has. In the future, the biodiversity footprint model I have presented could provide investors and other stakeholders with information on what kind of financial risks can be associated with the impacts and dependencies of an organization.

Another interesting avenue for further research in integrating financial and environmental accounting would be the use of double-entry bookkeeping. Double-entry bookkeeping conventionally means that the flow of money is tracked by taking into account where it was taken from and what it was used for, i.e. financial transactions are recorded in two opposite accounts (Hayes, 2021). In the context of environmental accounting this could mean that when a specific consumption activity is recorded, an organization would need to also record what is the footprint (where it was taken from) and handprint (what it was used for) of the activity. In addition, the system could be used to consider the accumulation of impacts, investments and assets to natural capital in the balance sheet of an organization. Double-entry bookkeeping has already been tested in the context of natural capital accounting (Houdet et al., 2020), but more research is needed to understand how the system could be used in a wider perspective and what implications it would have, if any.

The integration of financial and environmental accounting is not only a technical issue that is to be solved by science, organizations and accountants, but it is also a public policy issue (Nicholls, 2020). Nicholls (2020) argues that the narrative and traditionally acclaimed view of a wealth-maximising investor, for whom financial accounting is provided, should be transformed, and this process could be supported by adequate legislation that takes into account the diversity of investor and other stakeholder motivations (Hartzmark & Sussman, 2019; Jansson & Biel, 2011). The legislation could ensure that accounting standards provide investors with adequate information about environmental impacts, and even that financial returns could be subject to net zero or net negative/positive impacts (Nicholls, 2020). The integrated carbon and biodiversity footprint assessment model I have presented, could be a starting point for such a legislative effort.

In fact, the concept of planetary well-being could work well as an overarching goal for integrated financial and environmental accounting. Public policy could state that the purpose of accounting, in addition to providing information about financial status, is to provide information to investors and other stakeholders whether the organization's activities are supporting the transition towards planetary well-being or hindering it. Further consideration would of course be needed on what kind of indicators should be used to measure progress towards planetary well-being. Puurtinen et al. (2023) suggested that species extinction risk could be a good indicator of planetary well-being. Indeed, the methodology that I have provided shows potential global species extinction by consumption activities and thus could perhaps work well as a measure of global nonhuman well-being.

5.4.2 A catalyst for transformative organizational change?

Another important question that remains unanswered is whether or not the proposed model of the integration of financial and environmental accounting could catalyse transformative organizational change. This question has been explored in other settings and previous literature around sustainability accounting and reporting (Garcia-Torea et al., 2023). By bringing this discussion to the context of this dissertation, I analyse what is the potential of the presented methodology and its practical implications to drive transformative organizational change and how the methodologies should be developed and applied in the future.

The integration of financial and environmental accounting and its further implications might actually be positioned in various different ways in Laughlin's (1991), Tilt's (2006) and O'Brien & Sygna's (2013) models depending on how the methodologies are applied in the organization or the society. From an organization's perspective (Laughlin, 1991; Tilt, 2006), it would be difficult to see the adoption of the integrated financial and environmental accounting system initiating a process that merely counters the change (rebuttal). The carbon and biodiversity footprint assessment I have presented gives a rather comprehensive picture of the core environmental issues of an organization, including "bad" performance data. However, the adoption of the integrated accounting system could initiate a change where the organization's operations are reoriented, with some changes for example in decision-making and reporting practices (reorientation) (Laughlin, 1991; Tilt, 2006). Although the level of environmental accounting would increase in this scenario, it is possible that the organization only uses environmental accounting to showcase a high level of accounting and disclosures, but not necessarily initiate strategies and activities to act upon the results. The proposed accounting model could indeed be used by organizations as a technical response to initiate incremental changes, with some impacts on the systems and structures of the organization, but little impacts on the core beliefs, values and mission of the organization. From a societal perspective (O'Brien & Sygna, 2013) it could be argued that the methodologies I have proposed methodologies focus on technical tools and solutions in organizations, and do not for example explore power relations or social structures that could facilitate transformative change. However, even though the integrated financial and environmental accounting model might only initiate incremental changes in organizations and the society, these changes can enable the structural and political foundation of transformative change (Contrafatto & Burns, 2013; Garcia-Torea et al., 2023; Mitchell et al., 2012). Nevertheless, the tools I have developed can also act as barriers to transformative change, if they are used to make incremental tweaks to the system to back up the dominant system of increasing production and consumption levels.

To understand how integrated financial and environmental accounting might catalyse transformative changes, focus needs to be given to the conceptual and technical discussion around value-transforming financial-environmental accounting (Articles 3 and 4). The value-transforming integration of financial and environmental accounting has the potential to address the underlying structures and decision processes of organizations, or even values and beliefs, by changing the way how different activities are financially valued in the organization. The value-transforming integration can be mandatory (colonisation) or it can be initiated voluntarily (evolution) (Laughlin, 1991; Tilt, 2006). This is also where the concepts of transformative change overlap on an organizational and societal perspective because mandatory changes can generally be understood as changes in policies and legislation. A transformative change in how organizations operate could be initiated by policies that enforce the transformation of financial value based on environmental accounts. Such changes have already been seen for example in the form of the EU Emission Trading System that puts a price on greenhouse gas emissions for example in the energy and manufacturing sectors (European Commission, 2024). However, it is not clear whether the EU Emission Trading System has had the intended impact on adopting low-carbon technologies (Teixidó et al., 2019). Furthermore, the planned Carbon Border Adjustment Mechanism plans to put a price on imported products and their emissions in certain sectors (EU, 2023). Nevertheless, the planned regulations are currently not holistically covering both carbon and biodiversity footprints. They are also focused on certain sectors rather than organizations in general. In addition, the policies are predominantly focusing on how organizations can technically react by introducing low-carbon technologies, rather than considering whether the core business models can be sustained in their current format. If and when biodiversity footprints are incorporated into such pricing schemes in the future, the implications to organizations might be wider.

Even though mandatory policies might prove to be efficient in catalysing transformative accounting practices in organizations, voluntary initiatives could also play a role. The value-transforming financial-environmental accounting model could also be initiated by the organization itself, for example with the proposed internal offsetting mechanism (Figure 11). In Laughlin's (1991) model of organizational change, the internal offsetting mechanism could be seen as an approach that can drive transformative, evolutionary change, because it is initiated voluntarily. Two things could support the transformative nature of the internal offsetting mechanism. First, it transforms the financial value of the organization's activities based on environmental accounts. This could further influence the decision processes and structures of the organization. This is also where mandatory and voluntary approaches might mingle to create effective combinations: the organization might voluntarily implement an internal offsetting mechanism, while regulation would outline the rules and overall principles of the offsetting mechanism. Or even though the internal offsetting mechanism would be enforced by regulation, organizations could still decide how they want to design the system and how to use the generated proceedings internally. Second, the implementation of the internal offsetting mechanism requires a discussion about the core values and mission of the organization. The organization has to decide where the internally collected funds are directed: what is the "good" the organization can contribute towards and what is the "bad" it has to mitigate. However, it is important to note that depending on how the internal offsetting mechanism is implemented and initiated, it can be used for both incremental and transformative changes. I have positioned the discussed levels of accounting to the theoretical framework that I proposed in chapter 2.1.3, Figure 4, to illustrate how the different levels of environmental accounting and integration of financial and environmental accounting might drive transformative changes in organizations and the society (Figure 13). While all environmental accounting initiatives can initiate incremental changes that eventually lead to transformative changes, focus should be given to solutions that aim to transform the systems and structures, and beliefs and values in organizations, and consequently in the society.

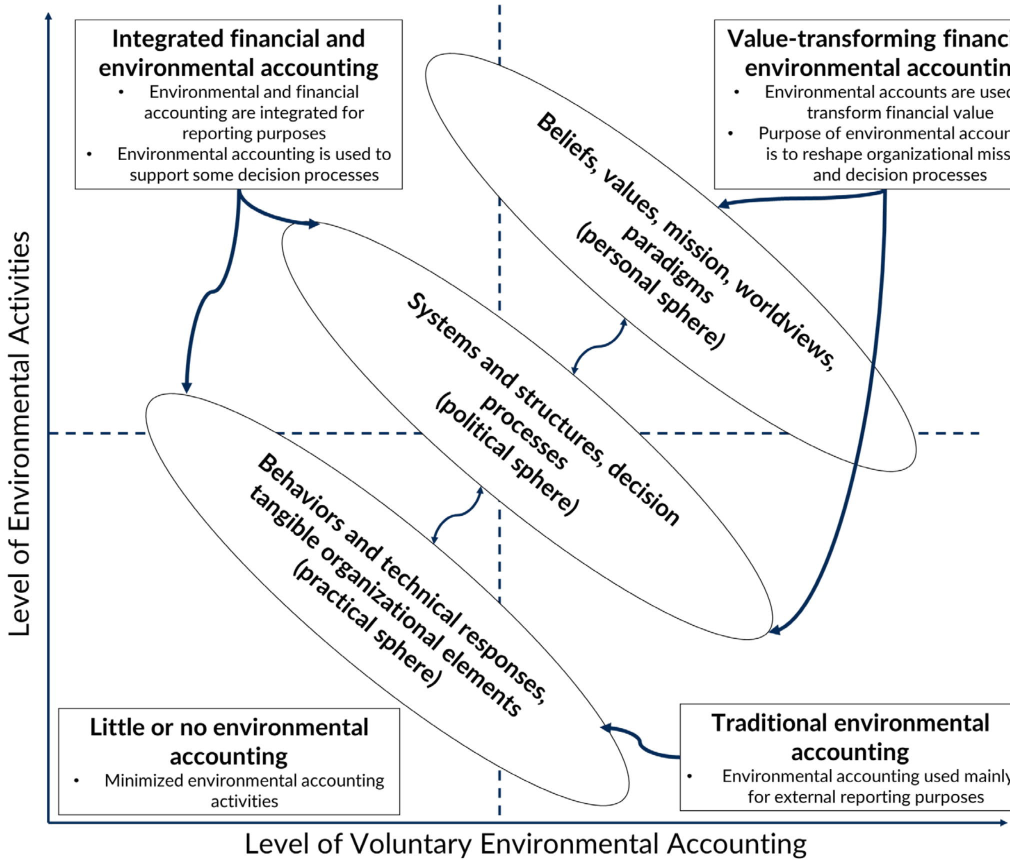

Figure 13: Positioning the discussion of different levels of environmental accounting and its integration with financial accounting into the framework connecting organizational and societal level transformative change (adapted from Laughlin (1991), O'Brien & Sygna (2013) and Tilt (2006)).

I have largely focused on methodological development and technical solutions on how to improve the state of environmental accounting in organizations. As such, the solutions I have proposed do not necessarily touch upon the greatest potential for transformative change: beliefs, values, worldviews and paradigms. The developed tools can even act as barriers to transformative change, if they are used to make incremental tweaks to back up the dominant system of increasing production and consumption. However, the value-transforming integration of financial-environmental accounting can have the potential to initiate transformative changes in organizations and the society, when designed to influence the structures and decision-making processes in organizations. Furthermore, even though the focus has been on financial value-transformation, an avenue for further discussion remains open in how the introduction of a new visible stakeholder, nonhuman nature, could drive value-transformation in a wider sense. While the existence of environmental accounts per se, does not mean that the organization recognizes nonhuman nature as a stakeholder, the valuation of environmental accounts would mean that it has to consider nonhuman nature to some degree. Planetary well-being could be used as an overarching concept to measure and understand how organizations incorporate nonhuman nature in their core decision making processes. Transformative changes in organizations could be initiated by taking planetary well-being as an integral part of their values and mission.

6 CONCLUSIONS

In this dissertation I explored how organizations can assess, mitigate and offset their consumption-based carbon and biodiversity footprints. Furthermore, I discussed what is the role of financial and environmental accounting in reaching planetary well-being. Finally, I aimed to analyse whether the integration of financial and environmental accounting can serve as a technical response to catalyse transformative change in organizations.

The research results reveal the significant role of upstream value chain carbon and biodiversity footprints in many organizations. The assessment of upstream carbon and biodiversity footprints is becoming more and more relevant for organizations also from the regulatory side. The EU CSRD, Taxonomy and Carbon Border Adjustment Mechanism regulations (EU, 2020, 2022, 2023), and Due Diligence proposal (European Commission, 2022) all have implications for how organizations should assess and report their carbon and biodiversity footprints. Furthermore, even though the Global Biodiversity Framework has yet to operationalize in regional and national policies, it also seems to indicate that the global community is moving towards regulated measuring of dependencies and impacts on nature at the level of organizations (CBD, 2022).

Carbon footprint assessments have become more and more commonplace, while biodiversity footprint assessments in organization are just gaining ground. Many things remain to be explored in organizations' biodiversity footprint assessments. For example, the implications and use of the so-called biodiversity equivalent need more scrutiny. Furthermore, more research is needed to understand how different indicators of biodiversity loss could converse with each other to bring clarity to the field of scattered biodiversity footprint indicators. However, even the carbon footprint assessments vary and there is a lack of regulation and common guidelines on how carbon footprint assessments should be conducted in organizations. One step forward could also be to make all carbon and biodiversity impact factors public so that all actors could use them to transparently assess their carbon and biodiversity footprints. In addition, governments should support organizations in their carbon and biodiversity footprints assessments by providing national footprint databases, as has been done in terms of carbon footprints in the UK (DEFRA, 2022). On the global stage, a lot of attention has been given to national emission inventories, but I argue that it would be time to commit organizations more stringently to discussions around climate and biodiversity policies.

Finally, I argue that environmental accounting practices, such as carbon and biodiversity footprint assessments, are not taken seriously enough, when compared to financial accounting practices. Many of the limitations in environmental accounting relate to the availability of data about different consumption activities. While the assessment of upstream value chain impacts is difficult from an organization's point of view, the value chain impacts are always someone else's direct impacts. Thus, if information about the environmental impacts could be conveyed through the value chain, organizations would not need to assess their value chain environmental impacts with the methodologies I have presented. In a perfect world the current consumption-based assessments of carbon and biodiversity could in fact be seen as a temporary phase in time. In any case, change in the system is likely to take time so the current methodologies can be used to put pressure on the value chain. In essence, environmental accounting practices and regulation should have the same level of rigour than in financial accounting.

Assessment of carbon and biodiversity footprints in organizations is only the first step towards net zero impacts and stopping biodiversity loss and climate change. Solutions already exist to mitigate carbon and biodiversity footprints ranging from the reduction in total consumption to phasing out fossil fuels and moving towards plant-based diets. Thus, I argue that one of the key potentials in developing better carbon and biodiversity footprint assessments lies in how they can be utilized to transform value. Financial accounting is operated under certain rules that are often taken for granted. Those rules can be changed and accustomed to meet the needs of the planet. In the future, the profit and loss of organizations could be driven by planetary well-being.

YHTEENVETO (SUMMARY IN FINNISH)

Ihmisen toiminta on lämmittänyt maapallon ilmastoa sekä aiheuttanut luontokatoa, eli luonnon monimuotoisuuden köyhtymistä. Luontokatoa aiheuttavat maa- ja merialueiden käyttö ja niiden muutokset, luonnonvarojen suora hyödyntäminen, ilmastonmuutos, saasteet sekä haitalliset vieraslajit. Vakaa ilmasto ja terveet ekosysteemit ovat välttämättömiä ihmisen hyvän elämän kannalta. Vaikka ihmiskunnan toiminta on hyödyttänyt joidenkin ihmisten ja eliöiden elämää lyhyellä tähtäimellä, se on vaarantanut jokaisen edellytyksiä hyvään elämään pitkällä tähtäimellä.

Toimia ja suunnitelmia ilmastonmuutoksen ja luontokadon ehkäisemiseksi on tehty sekä kansallisesti että kansainvälisesti. Nykyiset toimet ovat kuitenkin suurelta osin osoittautuneet riittämättömiksi kansainvälisesti sovittujen tavoitteiden saavuttamiseksi. Lisäksi tiedeyhteisö on painottanut, että luontokato ja ilmastonmuutos on ratkaistava samanaikaisesti. Planetaarista hyvinvointia, eli tilaa, jossa kaikkien eliöiden, mukaan lukien ihmisten, tarpeet toteuttaa lajityypillisiä ominaisuuksiaan säilyvät, voisikin pitää sopivana tavoitteena ilmastonmuutoksen ja luontokadon vastaisessa työssä.

Organisaatiot ovat keskeinen osa ihmisten elämää. Organisaatioita ovat esimerkiksi yritykset, julkiset instituutiot, kansalaisjärjestöt ja erilaiset yhdistykset. Koska organisaatioilla on iso rooli ihmisten jokapäiväisessä elämässä, iso osa ihmiskunnan ympäristövaikutuksista syntyy organisaatioiden kulutuksen ja tuotannon seurauksena. Organisaatioiden ympäristövaikutuksia pitää mitata, jotta organisaatiot, ja niiden sidosryhmät, voivat kehittää tehokkaita toimia ympäristövaikutusten pienentämiseksi.

Hiilijalanjälkeä on käytetty jo kohtuullisen pitkään organisaatioiden ilmastovaikutusten laskennassa. Hiilijalanjäljen laskenta erityisesti organisaatioiden arvoketjun, eli esimerkiksi hankintojen, osalta ei kuitenkaan ole vakiintunutta. Monet tutkimukset ovat osoittaneet arvoketjun hiilijalanjäljen suuren merkityksen, erityisesti kehittyneissä, niin sanotun globaalin pohjoisen, maissa. Luontojalanjälkeä ei ole hyödynnetty vielä laajasti organisaatioiden luontovaikutusten laskennassa. Luontojalanjälki mittaa organisaation kulutuksen tai tuotannon aiheuttamien luontokadon ajureiden, kuten maankäytön tai saasteiden, määrää sekä niiden aiheuttamaa haittaa luonnon monimuotoisuudelle tietyssä maantieteellisessä sijainnissa. Luontojalanjälki on siis luontohaittojen kokonaisvaltaiseen mittaamiseen kehitetty työkalu.

Tutkin väitöskirjassani ympäristötilinpidon (ja ympäristökirjanpidon) menetelmiä organisaatioiden kulutusperustaisen hiili- ja luontojalanjäljen laskemiseksi ja kehittämiseksi. Lisäksi tutkin keinoja hiili- ja luontojalanjäljen pienentämiseksi ja kompensoimiseksi. Menetelmänä käytin yhdistelmää elinkaariarvioinnista ja ympäristölaajennetusta panos-tuotos-menetelmästä. Selvitin myös ympäristö- ja talouskirjanpidon yhdistämistä teoreettisella tasolla kirjallisuuskatsauksen kautta.

Kahdessa ensimmäisessä artikkelissa tarkastelin kahden erilaisen organisaation hiilijalanjälkeä. Kummassakin organisaatiossa arvoketjun päästöt muodostivat valtaosan organisaation kokonaispäästöistä. Lentomatkustamisen hiilijalanjälki oli erityisen korkea. Toisessa artikkelissa osoitin, että koronapandemia romahdutti lentämisen hiilijalanjäljen tutkitussa organisaatiossa. Arviot päästöjen kehityskulusta kuitenkin näyttivät, että lentämisen rooli tulee olemaan todennäköisesti edelleen tärkeä, sillä päästöjen arvioitiin palautuvan lähelle pandemiaa edeltävää tasoa joidenkin vuosien kuluessa.

Neljännessä artikkelissa kehitin organisaatioiden luontojalanjäljen laskentamenetelmän laskemalla Jyväskylän yliopiston hiili- ja luontojalanjäljen. Kehitetyn menetelmän avulla on mahdollista laskea taloudellisen kulutuksen aiheuttama luontojalanjälki, mutta menetelmää voidaan soveltaa myös muunlaisen kulutuksen luontojalanjäljen laskentaan. Luontojalanjäljen mittarina käytin osuutta maailman lajeista, jotka todennäköisesti häviävät sukupuuttoon (englanniksi potentially disappeared fraction of species, PDF), jos kulutuksen ja luontohaitan ajurin aiheuttama paine jatkuu samanlaisena. Koska mittari kuvaa todennäköisiä globaaleja sukupuuttoja, sen avulla voidaan verrata luontojalanjälkeä eri maantieteellisissä sijainneissa. Lisäksi mittariin lisättiin painokertoimet ekosysteemien arvioidun lajimäärän perusteella, jotta eri ekosysteemityyppien luontojalanjälki pystyttiin yhdistämään. Esitän, että ekosysteemityyppien yli yhdistettyä luontojalanjäljen mittaria voisikin kutsua luontoekvivalentiksi (englanniksi biodiversity equivalent, BDe), sillä sen voidaan nähdä täyttävän samanlaisen tarpeen kuin hiilidioksidiekvivalentti, jota käytetään mittarina hiilijalanjäljen laskennassa.

Kuten esimerkit kansainvälisestä työstä osoittavat, hiili- ja luontojalanjäljen laskenta on yksinään riittämätön toimi muuttamaan vallitsevia organisaatioiden ja yhteiskunnan talouden rakenteita. Talouskirjanpito on laajasti hyödynnetty järjestelmä, joka kuvaa organisaation kulutuksen ja tuotannon taloudellisia virtoja. Talouskirjanpitoa ei tule kuitenkaan nähdä vain teknisenä ja objektiivisena järjestelmänä, vaan sen avulla määritellään useita keskeisiä muuttujia, kuten tilikauden voitto tai tappio, jotka vaikuttavat suoraan organisaation päätöksentekoon.

Kolmannessa ja neljännessä artikkelissa keskityin hiili- ja luontojalanjäljen laskennan lisäksi analysoimaan talouskirjanpidon roolia osana laskentaa. Tarkastelin artikkeleissa myös, miten hiili- ja luontojalanjäljen laskentaa voitaisiin yhdistää vahvemmin osaksi talouskirjanpitoa. Hiilikompensaatiota ja ekologista kompensaatiota voidaan hyödyntää arvon asettamisessa hiili- ja luontojalanjäljille. Tulokset osoittivat, että koko arvoketjun luontojalanjäljen kompensoiminen voisi muuttaa organisaation taloudellista tulosta merkittävästi.

Esittämäni menetelmät ja tulokset viitoittavat tietä organisaatioiden hiili- ja luontojalanjäljen laskennan kehittämiselle. Vaikka keskityin väitöskirjassani organisaatioiden hiili- ja luontojalanjäljen laskentaan, on selvää, että laskennan perimmäinen syy on jalanjälkien pienentäminen. Organisaatiot voivat käyttää väitöskirjani tuloksia oman laskentansa kehittämiseen. Julkishallinto voi käyttää tuloksia sääntelyn kehittämiseen esimerkiksi osana EU:n yritysvastuuraportoinnin direktiiviä, yritysvastuudirektiiviä, metsäkatoasetusta ja hiilirajamekanismia. Muut sidosryhmät kuten sijoittajat voivat soveltaa menetelmiä sijoituskohteiden hiili- ja luontoriskien arviointiin. Hiilikompensaation ja ekologisen kompensaation roolia hiilineutraalisuuden, luonnon kokonaisheikentymättömyyden tai nettonolla-tavoitteiden saavuttamiseksi pitäisi pohtia laajemmin. Kompensaatioita voidaan hyvin toteutettuna hyödyntää taloudellisina ohjausmekanismeina. Ympäristökirjanpidon ja talouskirjanpidon roolia osana organisaatioiden toimintaa tulisi myös miettiä laajemmin ja yhtenäisemmin. Kirjanpidon murros voi parhaimmillaan mahdollistaa organisaatioiden ja yhteiskunnan rakenteiden, päätöksenteon prosessien ja jopa taloudellista päätöksentekoa ohjaavien arvojen muutoksen.

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ORIGINAL PAPERS

I

THE CARBON FOOTPRINT OF VOLUNTEER TOURISM

by

Sami El Geneidy & Stefan Baumeister, 2019

European Journal of Tourism, Hospitality and Recreation vol 9(2), 15-25

https://doi.org/10.2478/ejthr-2019-0010

Research Article

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The Carbon Footprint of Volunteer Tourism

https://doi.org/10.2478/ejthr-2019-0010
received June 5, 2019; accepted November 26, 2019

Abstract: Tourism is growing at a fast rate and so is its carbon footprint. Alongside conventional tourism, a new form of tourism, so-called voluntourism, has emerged. The discussion on voluntourism in the existing literature has hereby mainly centred around its positive impacts on the health and education of communities and the local environment in developing countries. Nevertheless, little attention has been drawn to its climate impacts. This study set out to investigate the carbon footprint of voluntourism. The data were collected at a local non-governmental organisation (NGO) in India working with voluntourists. Both the carbon footprint of the stay in India and that from the round trip by air were taken into consideration. The results showed that although the carbon footprint of voluntourists during their stay is comparable with that of locals, the flight significantly contributes to the carbon footprint of voluntourism. Depending on the distance flown and the length of the stay, the average share of the carbon footprint stemming from the flight can be between 83% and 96%. The article concludes that faraway destinations and short stays should be avoided; otherwise voluntourism might cause more harm than good. On the basis of the findings, this article provides recommendations for policymakers and further research.

Keywords: Carbon footprint; Tourism; Volunteering; Voluntourism; Air transport; Sustainability

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1 Introduction

According to Lenzen et al. (2018), tourism is currently responsible for about 8% of all global greenhouse gas emissions. Furthermore, the tourism industry's contribution to emissions is expected to rise, because it is experiencing fast growth (Simpson et al., 2008; UNWTO, 2018). According to a report by UNWTO (2018), total international tourist arrivals grew by 7% during 2017, which was the highest growth in the past 7 years. Several studies have highlighted the high emission intensity of tourism (Dwyer, Forsyth, Spurr & Hoque, 2010; Gössling & Peeters, 2015; Rico et al., 2018; Sharp, Grundius & Heinonen, 2016; Simpson et al., 2008). The major impacts include aviation, which is the number one emissions contributor in most of the studies that include aviation in their boundaries, with a share ranging from 50% to 95% of the total carbon footprint (Dwyer et al., 2010; Gössling & Peeters, 2007; Peeters & Schouten, 2006; Sharp et al., 2016), other transportation, accommodation and production and import of goods (Dwyer et al., 2010; Hu et al., 2015; Jones & Munday, 2007; Liu et al., 2017; Puig et al., 2017; Rico et al., 2018; Sharp et al., 2016).

An emerging trend alongside conventional tourism is volunteer tourism, the so-called voluntourism (Wearing & McGehee, 2013). A volunteer tourist is a person who uses 'discretionary time and income to travel out of the sphere of regular activity to assist others in need' (McGehee & Santos, 2005). Despite research being conducted on assessing how international voluntourism impacts the target communities, the volunteers' attitudes and perceptions and the local environment (Bailey & Fernando, 2011; Brown, 2005; Lough et al., 2014; Lupoli et al., 2014; McGehee & Santos, 2005; Schneller & Coburn, 2018), little attention has been drawn to the question of how international volunteering affects the global climate and what are the trade-offs of voluntourism in the environmental context (Mustonen, 2007; Rattan, 2015). Similarly, little emphasis has been given to the carbon footprint of voluntourism and its contribution to global climate change. As conventional tourism continues to grow, it is likely that voluntourism will also grow in the future, as more and more young people are interested in making an impact whilst simultaneously enjoying the cultural experience of tourism (Wearing & McGehee, 2013). Therefore, it is important to estimate the climate impact of voluntourism in order to formulate mitigation policies and to be able to inform the voluntourism industry and international volunteers about their environmental impacts. When the quantity of the emissions is known, offsetting, compensation and awareness creation programmes can be designed more efficiently and accurately.

The aim of this research is to study the carbon footprint of international volunteer tourists, which has yet to receive much attention in the literature even though its environmental impacts might resemble that of conventional tourism. Although voluntourism is often considered for its positive impacts on the health and education of communities and the local environment in developing countries, it also creates environmental impacts that need to be addressed. Otherwise voluntourism might cause more harm than good. For this purpose a comprehensive carbon footprint analysis was conducted to understand and quantify the extent of emissions of international voluntourism. The study was conducted in an Indian non-governmental organisation (NGO) working with volunteer tourists. India is one of the most popular voluntourism destinations worldwide. Between 2006 and 2015, India has seen significant growth in the arrivals of foreign tourists, which has further fuelled India's economic growth (Vedapradha, Hariharan & Niha, 2017). Yet the environmental costs of such growth have received little attention. This study focuses on both direct (scope 1) and indirect (scopes 2 and 3) emissions, with an emphasis on Scope 3 emissions, those being the major contributors of emissions in many case studies yet not very widely studied (Larsen et al., 2013; Liu et al., 2017; Matthews, Hendrickson, & Weber, 2008; Ozawa-Meida et al., 2013; Rico et al., 2018; Sharp et al., 2016).

2 Carbon Footprint

In quantifying emissions, carbon footprint is one of the widely used tools. Even though there has not been a clear definition for carbon footprint in the literature (Matthews et al., 2008; Weidmann & Minx, 2008), Weidmann and Minx (2008) suggest that carbon footprint could be defined as 'a measure of the exclusive total amount of carbon dioxide (CO_2) emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product' (p. 4). However, it should be noted that this definition does not include gases other than CO_2. One of the keys for the success of carbon footprint as a method for quantifying emissions is its simplicity and straightforwardness, when compared to, for example, conventional life cycle assessment (LCA) (Weidema et al., 2008).

Carbon footprint is usually expressed in terms of CO_2 equivalents (CO_2-eq) (Weidmann & Minx, 2008). This means that in addition to CO_2, other greenhouse gases (GHGs), such as methane (CH_4) and nitrous oxide (N_2O), are converted into equivalent amounts of CO_2 based on their radiative properties (IPCC, 2014), also known as the global warming potential (GWP).

An important aspect of a carbon footprint is its system boundaries. By defining system boundaries, decisions are made as what aspects to include in the scope of the carbon footprint. Carbon footprint commonly uses the concept of life cycle thinking (Weidema et al., 2008), meaning that the emissions are investigated throughout the life cycle of a product or a service. The different boundaries are referred to as 'scopes' or 'tiers' of the carbon footprint (e.g. Greenhouse Gas Protocol, 2019; Matthews et al., 2008). Scope 1 emissions include direct emissions, such as those emissions coming directly from the production of goods at a manufacturing site. Scope 2 emissions consist of indirect emissions caused by external energy and electricity production. Scope 3 emissions are all other indirect emissions such as consumption of goods or the consequential emissions from waste management. Even though the definition of scope 3 emissions can be a daunting task, these emissions have been the major source of emissions in many studies, thereby indicating their importance in carbon footprint analysis (Larsen et al., 2013; Liu et al., 2017; Matthews et al., 2008; Ozawa-Meida et al., 2013; Rico et al., 2018; Sharp et al., 2016). However, the lack of data often makes it challenging to widen the system boundaries and include scope 3 emissions in the carbon footprint analysis.

Matthews et al. (2008) discussed the importance of carbon footprint estimation boundaries in the context of the United States. They estimated that scope 1 emissions only contribute to around 14% of total industry emissions, on an average, whereas scopes 1 and 2, when combined, contribute to around 26%. This would suggest that most of what is left would fall under scope 3 emissions, which raises concerns about misleading results if narrow boundaries are followed. Clarke, Heinonen and Ottelin (2017) raised a similar concern in the case of Iceland, where the national energy supply is almost 100% renewable. However, as they studied the carbon footprint of Icelandic households using a consumption-based method, they found that transportation and the import of products were the most important factors in determining high GHG emissions in Iceland. Furthermore, Ivanova et al. (2015)

showed, in their study of global household consumption, that the indirect carbon footprint of household consumption contributes to a major share of the total household carbon footprint in many countries. For example, in India where production is largely domestic, the indirect domestic carbon footprint was relatively large for households.

Whilst carbon footprint analysis is a useful tool to easily assess the climate change impacts of products and services, it has also been criticised for overly simplifying environmental impacts and consequences (Laurent, Olsen, & Hauschild, 2012; Weidema et al., 2008). Using carbon footprint as the only environmental indicator can lead to misleading results and misguide policymakers (Laurent et al., 2012; Weidema et al., 2008). For example, carbon footprint does not correlate with the possible emissions of toxic substances (Laurent et al., 2012), which is why it could be said that carbon footprint is not always a good representative of holistic environmental sustainability. However, Weidema et al. (2008) also argued that the simplicity of carbon footprint has made it possible for it to become a widely used concept and tool. Whether holistic evaluation of environmental impacts is important or not, carbon footprint can at least provide a direction, which can be enough for decision-making (Weidema et al., 2008).

3 Carbon Footprint of Tourism

Tourism is globally responsible for about 8% of all GHG emissions (Lenzen et al., 2018). The emission intensity of tourism has to be taken into account to tackle climate change effectively. With a growth of 7% in international tourism arrivals in 2017 (UNWTO, 2018), tourism might be an even larger contributor to climate change in the future.

Many studies have tried to assess the emissions caused by tourism, which is usually a complicated task because of the complexity of the tourism industry, which comprises both products and services, meaning indirect impacts have a high importance (De, Peeters, Petti, & Raggi, 2012; Dwyer et al., 2010; Hu et al., 2015; Liu et al., 2017; Munday, Turner, & Jones, 2013; Puig et al., 2017; Rico et al., 2018; Sharp et al., 2016).

Sharp et al. (2016) studied the carbon footprint of tourism on a larger scale, using a consumption-based LCA methodology to assess the carbon footprint of inbound tourism to Iceland. They found that from 50% to 82% of the carbon footprint consists of aviation-related impacts, the fluctuation being a result of different flight distances. A study by Rico et al. (2018) also discussed the importance of indirect transportation-related emissions (96% of the total emissions), particularly aviation, in the carbon footprint of tourism in Barcelona. They also identified accommodation and leisure activities as important contributors. Overall, scope 3 emissions contributed to 96% of the total emissions. However, it is important to notice that this study did not take into account the energy used for the production of goods. In the context of Australia, Dwyer et al. (2010) estimated that, between 3.90% and 5.30% of the total industry, GHG emissions is caused by tourism. They included domestic aviation in the direct emissions, and it contributed to around 57% (domestic air transport) of the total direct emissions, followed by accommodation services (9%) and shopping (7%). The largest contributors in indirect emissions were electricity by coal, which contributed to around 37% of the total indirect emissions, followed by agriculture, forestry and fishery (31%). These studies suggest the importance of the transportation-related impacts of international tourism and that system boundaries should be wide when assessing tourism-related carbon footprints.

4 Voluntourism

Many researchers have studied voluntourism from a variety of different perspectives ranging from social research investigating the motivations of volunteers (Brown, 2005; Mustonen, 2007) and how volunteering impacts the volunteers and the host communities in a positive way (Bailey & Fernando, 2011; Lough et al., 2014; McGehee & Santos, 2005; Schneller & Coburn, 2018) to research that takes a more critical stance towards voluntourism (Guttentag, 2009; Pluim & Jorgenson, 2012). These studies, and many others, suggest a strong growth in the voluntourism sector, a view which is further supported in the review conducted by Wearing and McGehee (2013).

According to a popular definition, volunteer tourists are people 'who for various reasons, volunteer in an organised way to undertake holidays that might involve the aiding or alleviating the material poverty of some groups in society, the restoration of certain environments, or research into aspects of society or environment' (Wearing, 2001). Another, broader definition is given by McGehee and Santos (2005), who described volunteer tourists as people who use 'discretionary time and income to travel out of the sphere of regular activity to assist others in need' (p. 760). Volunteer projects usually extend from a couple of weeks to over several months and up to 1 year (Tomazos & Butler, 2009). Popular projects in voluntourism organisations include environmental projects such as the planting of trees and plants, environmental education, the care and monitoring of wildlife, trail maintenance and organic gardening/agriculture. Community development project encompass education for children and adults, skills training for community members, infrastructure development, promoting income generation activities and empowering women's groups (Lupoli et al., 2014).

Some scholars have attempted to study the motivations of people who embark on volunteering journeys. Brown (2005) listed four main themes as the main motivators for volunteers: cultural immersion, desire to give back, friendship and relationships with other volunteers and family bonding. Her study also identified two different types of volunteers: those who are inclined towards the actual volunteering work (volunteer minded) and those who are focused on travelling and other tourism-related activities (vacation minded) (Brown, 2005). Mustonen (2007) studied the motivations of volunteers from another perspective, assessing the concept of altruism and egoism and which would be the motivator for a volunteer tourist. He argued that volunteers' motives lie in both altruism and egoism and that they are interconnected. This mix of motives is formed by a combination of 'pursuit of individuality' and sociality (Mustonen, 2007).

Some benefits of voluntourism for its participants and for society could be the enhancement of civic attitudes and activism (Bailey & Fernando, 2011; McGehee & Santos, 2005), growing concern for social and environmental issues amongst participants (Schneller & Coburn, 2018), and the improvement of international concern and intercultural relations (Lough et al., 2014). Furthermore, Schneller and Coburn (2018) reported that host communities (voluntourism target communities) in Costa Rica felt that the implemented projects were meaningful and had visible benefits, and some studies have observed positive cross-cultural exchanges and financial benefits in host community members (Rattan, 2015).

On the other hand, only a few researchers have studied the possible negative impacts of voluntourism. Some reported negative impacts include the idea of voluntourism being an alternative form of neo-colonisation (Pluim & Jorgenson, 2012). According to this idea, voluntourism promotes dominant values and reinforces the superiority–inferiority binary, where host communities see volunteers as something superior. In addition, it is argued that although some volunteering programmes can be quite costly, it mostly allows middle or upper class people to participate, thus reinforcing the value systems that these people have according to their social positioning (Pluim & Jorgenson, 2012). Guttentag (2009) listed 'a neglect of locals' desires, a hindering of work progress and completion of unsatisfactory work, a disruption of local economies, a reinforcement of conceptualizations of the "other" and rationalisations of poverty, and an instigation of cultural changes' (p. 537) as some of the negative impacts of voluntourism. Similarly, Rattan's (2015) review of negative impacts includes cultural clashes, effects on local economies (e.g. unemployment) and the problem of commodification.

Rattan (2015) suggested that certifications and ecolabels could be an answer to addressing some of the issues caused by voluntourism. However, as he argued, these certifications should be closely followed and including tangible aspects is important. These certifications could be of help when the appropriate information about the negative impacts is known, but it is evident that there is little if any research focusing on the global environmental impact of voluntourism. Studies on the environmental impacts of conventional tourism are prevalent but to get a comprehensive picture of the role of voluntourism in terms of its global impacts, more research needs to be done. This would also assist voluntourism operators in forming suitable certifications and offsetting programmes.

Giving a more comprehensive picture of the environmental impact of voluntourism is one of the main aims of this study, which will hopefully initiate a discussion on not only the psychology and social impact of volunteering but also on its global environmental impact. Such a discussion would make it easier for voluntourism researchers, policymakers and practitioners to understand the comprehensive impact of voluntourism from all viewpoints of sustainability.

5 Data and Method

The data for the research were collected between June and November 2018, at the study site located in a village in Dharamshala area, Himachal Pradesh, India. The studied NGO operates in many areas such as agriculture, sanitation, health, education and waste management. Besides promoting the Sustainable Development Goals, the organisation aims at providing young people with leadership opportunities in order to for them to become responsible world citizens. The organisation is run by 9 locals and receives about 140 volunteers per year.

Regarding scope 1 emissions, data about distance driven by NGO's car were gathered through interviews and observations. The car was mainly used for airport pick-ups and drop-offs as well as for other work-related journeys. Information on the electricity consumption (scope 2 emissions) was obtained directly from the voluntourists' accommodations electricity bills. Not all electricity bills were available and some assumptions had to be made. Information on the scope 3 emissions (indirect emissions from consumption of food and other products) was collected through intensive waste analysis and interviews. Waste produced by volunteers and disposed at the volunteer houses was analysed by examining the packaging of disposed products. Data were collected to determine the product group (e.g. snacks) and category (e.g. food product), net quantity, manufacturing location and sales price. After a specific waste bag was analysed, it was stored, and an empty bag was made ready for use again. The analysis period lasted for 54 days. The waste analysis did not reach all the products used by volunteers, because they would not spend all of their time at the volunteer house. Furthermore, the analysis did not take into account products that do not have any disposable packaging (e.g. fruits and services).

Nearly all of the domestic product packaging examined in this study contained the manufacturer's postal code, which allowed the distance of transportation to be estimated with the help of Google Maps. After the transport distance for goods were determined, the capacity of an average transport vehicle was estimated, which was 15.6 tons according to Premier Road Carriers (2019), ranging from 3.50 to 27 tons. The current valid Indian emission's standard of EURO4 was considered. The accuracy of the transportation calculations should be reviewed critically. For example, the capacity of a transport vehicle can vary significantly from the average, which could cause error to the estimations. It is also possible that the types of transport have regional differences in India. However, the analysis provides an estimation of the possible magnitude of emissions associated with transportation of goods in this specific case.

The carbon footprint for local emissions was calculated using openLCA software with ecoinvent 3.4 and EXIOBASE 2.2 databases. ecoinvent was used because it contains international information on several different products and product sectors, which made it possible to calculate a fairly representative life cycle carbon footprint for some of the products included in this study. The major difference to EXIOBASE (besides the database using different methodology) was the ability to use physical units instead of having to rely on monetary conversions. Some food-related carbon footprints were calculated based on Pathak et al. (2010), because the openLCA databases did not contain such specific information. Pathak et al. (2010) provided more detailed information on the carbon footprint of Indian meals, taking both vegetarian and non-vegetarian diets into account. The carbon footprint of liquefied petroleum gas (LPG) that is used as a cooking fuel at the NGO was assumed to emit 134 kg of CO_2-eq per GJ (Jungbluth, Kollar & Koß, 1997) whilst 1 ton of LPG equals 49.6 GJ (UC Berkeley, 2019).

Data for all direct flights from the five countries from which the organisation received the most volunteers (Australia, Canada, Japan, the United Kingdom and the United States) to Delhi Indira Gandhi International Airport (DEL) were considered in this study. Because no detailed information was available from the volunteer's exact ports of departure, the largest airports of the five origin countries were chosen for the study. For Australia, this was Kingsford Smith International Airport in Sydney (SYD); for Japan, it was Narita International Airport in Tokyo (NRT); and for the UK, it was London Heathrow Airport (LHR). For the United States and Canada, the two major east and west coast airports were selected. In the United States, these were John F. Kennedy International Airport in New York (JFK) and San Francisco International Airport (SFO). For Canada, these were Pearson International Airport in Toronto (YYZ) and Vancouver International Airport (YVR). As all volunteers continued their onward journey from Delhi to Dharamshala area by airplane, all direct flights from Delhi to Gaggal Airport in Dharamshala (DHM) were added to the study.

The CO_2-eq emissions per passenger for a round trip from the seven origin airports to Gaggal Airport in Dharamshala were calculated based on the following formula:

$$CO_2 - eq\ (kg)/p = \left(\frac{total\ fuel\ (kg)}{pax\ to\ freight\ factor} \times 3.169\right) + \left(28 \times \frac{total\ fuel\ (MJ)}{pax\ to\ freight\ factor} \times 0.0000005\right) + \left(265 \times \frac{total\ fuel\ (MJ)}{pax\ to\ freight\ factor} \times 0.000002\right) \div (total\ seats\ \times pax\ load\ factor)$$

All direct flights from the seven origins to Delhi, the flight numbers, distance and aircraft type were obtained from FlightStats (2019). The fuel data were extracted from the Euorpean Environmental Agency Air Pollutant Emissions Inventory Guidebook (EEA, 2016) based on the aircraft type and flight distance. CO_2 emissions were calculated by multiplying the fuel burned by 3.169, which represents the kilograms of CO_2 produced when burning 1 kg of aviation fuel (VTT, 2017). For calculating the CH_4 and N_2O emissions, respectively, 0.0005 and 0.002 g/MJ were assumed, whilst the heat value of the fuel in MJ was determined with 43 MJ/kg of fuel based on Technical Research Center of Finland (VTT, 2017). In order to allocate the fuel burned for transporting passengers, a region-specific passenger-to-freight factor based on International Civil Aviation Organization's (ICAO) Carbon Emissions Calculator Methodology, Version 10 (2017) was multiplied with the fuel. Following Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, we estimated the global warming potential for 100 years (GWP_{100}) by multiplying CH_4 by a factor of 28 and N_2O by a factor of 265 (IPCC, 2014). Finally, in order to calculate the CO_2-eq emissions per passenger, the total emissions per flight were divided by the total amount of seats provided on the flight, extracted from FlightGuru (2019) and multiplied by the load factor that was region-specific, estimated by ICAO (2017). On those routes where more than one direct flight option was available (LHR-DEL, NRT-DEL and DEL-DHM), the emissions for all flights were calculated separately and then the average CO_2-eq emissions for these routes were determined.

6 Results

The annual CO_2-eq emissions in kilograms per volunteer during their stay are presented in Table 1. The emission categories 'Food products (other)', 'Beverages (other)', 'Tobacco products' and 'Electronics' include emissions from product transportation, which partly explains their higher contribution to the overall carbon footprint. The transportation emissions for the other product groups were not known.

Table 1: CO_2-eq emissions in kg per volunteer's stay per annum

Emission Category	CO2-eq (kg)/year	Share from total (%)
Transportation	44.05	3.19
Electricity (hydro)	14.89	1.08
Cooking fuel (LPG)	14.48	1.05
Rice	17.36	1.26
Potatoes	0.74	0.05
Tomatoes	0.39	0.03
Pulses (lentils)	1.61	0.12
Poultry meat	0.74	0.05
Mutton	18.76	1.35
Eggs	1.56	0.11
Milk	5.95	0.43
Onion	2.06	0.15
Wheat	4.81	0.35
Sugar	1.72	0.12
Oil	0.69	0.05
Salt	0.13	0.01
Tissue paper (toilet)	1.55	0.11
Food products (others)	626.12	45.32
Beverages (others)	476.86	34.51
Tobacco products	91.45	6.62
Electronics	55.78	4.04
Total	1,381.61	100.00

Table 2 provides a more detailed look into the emissions of certain product categories, revealing the separate emissions of production and transportation.

Although the results in Table 1 and 2 only present CO_2-eq emissions figures for an average volunteer in the studied organisation, Table 3 presents the results of the CO_2-eq calculations for round-trip flights by the different nationalities arriving from seven origins to Gaggal Airport in Dharamshala.

According to Otoo et al. (2016), a voluntourist's duration of stay can vary from a few days up to more than a year, and to date, the literature has established no clear consensus for the typical length of stay. On the basis of the information provided by the studied organisation, volunteers typically stayed from 2 to 5 weeks with some staying for longer periods such as 10 weeks or even longer. In order to compare the carbon footprint of the entire stay with that of the emissions produced by the flight alone, we have calculated those for the length of 2 weeks, 5 weeks, 10 weeks and, in addition, 1 year. The share of the flight round trip of the entire emissions is presented in Table 4:

According to the Emissions Database for Global Atmospheric Research (European Commission, 2017), the CO_2-eq emissions per capita for the departure countries of volunteers were 26,360 kg for Australia, 20,560 kg for Canada, 10,660 kg for Japan, 8,720 kg for the United Kingdom and 19,560 kg for the United States. To better understand the overall impact of voluntourism in relation to a volunteer's emissions in their home country, the emissions a volunteer would have produced in their home country was compared with the time a voluntourist spent in India. The results of this comparison are presented in Table 5.

7 Discussion

Although, scope 1 emissions were amongst the highest because of the carbon-intensive flights, the results also showed that scope 3 emissions can be significant, especially when the transport-related emissions are taken into account as shown in Table 2. Scope 2 emissions were rather marginal in this study. The average flight emissions per voluntourist (1349.36 kg CO_2-eq) for a round trip to India is at a similar level to the average emissions for a voluntourist's stay for an entire year (1381.61 kg CO_2-eq). When comparing the average share of the flight emissions with the total emissions depending on the length of the

Table 2: CO_2-eq emissions in kg for producing and transporting goods

Emission Category	Production Emissions	Transportation Emissions	Total
Food products (others)	1.75	624.37	626.12
Beverages (others)	0.31	476.55	476.86
Tobacco products	9.80	81.65	91.45
Electronics	38.89	16.89	55.78
Total	50.75	1,199.47	1,250.22

Table 3: CO_2-eq emissions in kg for volunteer's round trips

Country	Route	Flights	CO2-eq (kg)/p
Australia	SYD-DEL-DHM	AI 301	1,523.94
Canada East	YYZ-DEL-DHM	AC 42	1,204.65
Canada West	YVR-DEL-DHM	AC 44	1,152.52
Japan	NRT-DEL-DHM	JL 749/NH 827	1,201.22
United Kingdom	LHR-DEL-DHM	AI 162/BA 257/	968.94
		VS 300/9W 121	
USA East	JFK-DEL-DHM	AI 102	1,544.21
USA West	SFO-DEL-DHM	AI 174	1,849.99
Average			1,349.35

Table 4: Flights share of voluntourist's carbon footprint depending on stay

Country	2 weeks	5 weeks	10 weeks	1 year
Australia	96.64%	92.00%	85.19%	52.45%
Canada East	95.79%	90.09%	81.97%	46.58%
Canada West	95.60%	89.69%	81.31%	45.48%
Japan	95.77%	90.07%	81.93%	46.51%
United Kingdom	94.81%	87.97%	78.53%	41.22%
USA East	96.68%	92.10%	85.35%	52.78%
USA West	97.22%	93.32%	87.47%	57.25%
Average	96.07%	90.75%	83.11%	48.89%

stay (Table 4), the share ranges from 48.89% for a 1-year stay up to 96.07% for a 2-week stay. When comparing the carbon footprint of voluntourist's share of the flight emissions with those of conventional tourists, the share of voluntourists is significantly higher. This finding is especially surprising, given the fact that voluntourists usually stay longer at the destination than conventional tourists (Otoo, 2014; Sin, 2009). Sharp, Grundius and Heinonen, (2016), for example, found that the share of flight-related emissions for a 6–10 night stay in Iceland ranges between 50% and 82%, depending on the distance flown. Dwyer et al. (2010) also found that only 57% of the total carbon footprint of conventional tourists stems from aviation. Gössling and Peeters (2007) and Peeters and Schouten (2006) came up with similar results, indicating that the flight-related shares of conventional tourist's carbon footprint is between 60% and 95% of the total carbon footprint.

The results indicated that whilst the flight's share is a major part of a voluntourist's carbon footprint, it significantly decreases with the increase in length of stay. The lower share of the carbon footprint of voluntourists during their stay is most likely explained by the fact that voluntourists show similar consumption habits than locals in terms of housing, eating and local transport. In contrast to that, conventional tourists stay in hotels, dine out and use more transportation for sightseeing and recreation. According to the European Commission (2017), the average CO_2-eq emission of an Indian citizen is 2,500 kg. This is in the line with our results, given the fact that the carbon footprint for the stay of voluntourists contains only the daily consumption of food, electricity, heating and local transportation but does not include consumption of clothing, housing, other transportations or tourism.

When comparing the total emissions of a voluntourist's stay and the flight emissions with the average CO_2-eq emissions of an average citizen staying in his or her origin

Table 5: CO_2-eq emissions in kg for staying at home versus going to India

Country	2 weeks	5 weeks	10 weeks	1 year
Australia				
Stay at home	1,013.85	2,534.62	5,069.23	26,360.00
Go to India	1,620.10	1,764.33	2,004.71	2,903.94
Canada East				
Stay at home	790.77	1,976.92	3,953.85	20,560.00
Go to India	1,300.81	1,445.04	1,685.42	2,584.65
Canada West				
Stay at home	790.77	1,976.92	3,953.85	20,560.00
Go to India	1,248.68	1,392.91	1,633.29	2,532.52
Japan				
Stay at home	410.00	1,025.00	2,050.00	10,660.00
Go to India	1,297.38	1,441.61	1,681.99	2,581.22
United Kingdom				
Stay at home	335.38	838.46	1,676.92	8,720.00
Go to India	1,065.10	1,209.33	1,449.71	2,348.94
USA East				
Stay at home	752.31	1,880.77	3,761.54	19,560.00
Go to India	1,640.37	1,784.60	2,024.99	2,924.22
USA West				
Stay at home	752.31	1,880.77	3,761.54	19,560.00
Go to India	1,946.15	2,090.38	2,330.77	3,230.00

country instead (see Table 5), the results again showed that longer stays in the volunteering country are recommended. Depending on the average CO_2-eq emissions of the country of origin and the flight distance to India, avoiding a volunteering period of 2 weeks would have resulted in lower CO_2-eq emissions. For Japanese voluntourists as well as volunteers from the United Kingdom and the West Coast of the United States, a 5-week stay in India would have been more carbon intensive than staying home. Only for stays of more than 10 weeks, the emissions for volunteering in India would be lower than staying at home.

The existing literature also recommends a longer stay in target countries, not because of the large flight-related carbon footprint, as this study found, but also because of the greater impact the volunteering has on site and for the voluntourists themselves. Alexander (2012), for example, identified more potential benefits from volunteers staying 5 to 12 weeks, whereas Laythorpe (2009) detected an increased cultural immersion in the local community for volunteers staying longer than 6 months. Otoo et al. (2016) also found that shorter stays require more resources from the volunteering organisation because of the increased need for supervision. Finally, Birdwell (2011) found that longer stays provide volunteers with a greater learning experience and better career opportunities after the stay.

Finally, the results also showed that the role of transportation emissions in the life cycle emissions of different products is significant. The product categories that include transportation emissions (Table 2) represent a share of 90.50% from the total emissions (excluding flights). The average share of transportation emissions from the total emissions (production + transportation) in the studied categories is approximately 80%. This would indicate that the carbon footprint of other product categories, where transportation emissions are unknown, could rise substantially. Dwyer et al. (2010) included emissions from transport of imports (expenditure-based approach); they only accounted for 2.60% of the total direct and indirect GHG emissions in the Australian context. Similarly, Jones and Munday (2007) found, in the context of tourism consumption in Wales, that distribution and retail contributed to 4% of total emissions. Even though our study is different in both scope and methods, the conflict between these studies suggests that more research needs to be conducted to understand the role of transportation in the complete life cycle emissions of voluntourism and tourism.

8 Conclusion

The discussion on voluntourism in the existing literature has centred around its positive impacts on the health and education of communities and the local environment in developing countries. Yet little attention has been given to its climate impacts. This study set out to investigate the climate impacts of voluntourists by studying their carbon footprint. Voluntourists' carbon footprints were found to be rather extensive because of the carbon-intensive flight to reach the destination. At the destination, however, the carbon footprint was significantly lower than that of conventional tourists and more comparable with those of the local population. Therefore, in order to better justify the carbon-intensive flight, voluntourists should stay longer at the destination. Depending on the departure country and flight distance, short stays of less than 5 weeks should be avoided because they produce more carbon emissions than staying back home. At the same time, longer stays also have an increased impact on local communities, as previous studies have shown. On the basis of our findings, it would be recommended that voluntourists avoid short stays or alternatively search for less faraway destinations and try to reach those destinations with other modes of transportation that are less carbon intensive than flying. Our research also showed the importance of applying wide system boundaries when studying the carbon footprint, especially in the field of tourism. In addition, the inclusion of emissions related to the transportation of goods should be considered because it can have a significant impact on the total product-related scope 3 emissions.

In terms of limitations, the results of this study are only based on India as one possible voluntourist destination. In addition, the volunteers studied had all arrived from faraway countries that required extensive air travel, which resulted in a high share of flight-related CO_2-eq emissions. Although this study also took into account emissions related to the transportation of goods, the emissions for all the product categories were not available. Further studies could examine the carbon footprint of volunteering destinations other than India, particularly those that require less carbon-intensive transportation to reach. The possibility for voluntourism in the volunteer's own home country could also be further explored. In addition to the above considerations, the role of transporting goods in carbon footprint analysis should be recognised more because transportation adds a significant share to the overall carbon footprint.

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II

THE CARBON FOOTPRINT OF A KNOWLEDGE ORGANIZATION AND EMISSION SCENARIOS FOR A POST-COVID-19 WORLD

by

Sami El Geneidy, Stefan Baumeister, Valentino Marini Govigli, Timokleia Orfanidou & Venla Wallius, 2021

Environmental Impact Assessment Review vol 91, 106645

https://doi.org/10.1016/j.eiar.2021.106645

Environmental Impact Assessment Review 91 (2021) 106645

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

The carbon footprint of a knowledge organization and emission scenarios for a post-COVID-19 world

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ARTICLE INFO

Keywords:
Carbon footprint
Knowledge organization
Indirect emissions
Mitigation
Carbon offsetting
Travel
COVID-19 pandemic

ABSTRACT

The looming climate crisis requires an immediate response, in which organizations, as major contributors, should play a central role. However, these organizations need appropriate tools to measure and mitigate their climate impacts. One commonly applied method is carbon footprint analysis. Carbon footprint analyses have been conducted for various types of organizations, but knowledge organizations, such as universities and research institutes, have received far less attention, because their carbon footprint is often less visible and can be easily underestimated. This study is based on the carbon footprint analysis of one multinational knowledge organization. This analysis then helped identify the major sources of climate impacts in other such knowledge organizations. These are mainly indirect emissions (Scope 3) and to a large extent (79%) travel-related emissions. Based on these findings, three scenarios for a post-COVID-19 world were developed and analyzed. The results from the first two scenarios showed that despite a reduction in business travel and employees working from home, Scope 3 and travel-related emissions would remain the largest contributor. Only in the unlikely case of the third, non-recovery scenario did the share of travel-related emissions drop, turning heating into the largest contributor. In addition to measuring the carbon footprint, the study discusses potential mitigation strategies knowledge organizations could apply to reduce their carbon footprint. The focus is on how to avoid and reduce emissions, but new forms of carbon offsetting are also addressed. Based on the findings, a mitigation policy framework and recommendations for further research are proposed.

1. Introduction

Climate change is the defining issue of our time. The steadily increasing greenhouse gas (GHG) emissions in the Earth's atmosphere will have unprecedented global and local impacts on the environment, societies, and economies in the near and long-term future (IPCC, 2014, p. 8). The Intergovernmental Panel on Climate Change (IPCC, 2018) states that fast, wide-ranging and unprecedented changes in society are essential if we are to limit global warming to 1.5 °C. In the last decade, GHG emissions increased by about 1.5% per year, with the 20 largest economies of the world accounting for 78% of global GHG emissions (UNEP, 2019a). Furthermore, UNEP (2019a) reported that even if all countries fulfilled the Paris Agreement commitments, the world is heading towards a 3.2 °C rise in global temperature, which will lead to irreversible socioecological consequences.

An immediate response and action are needed on all levels: individuals, cities, regions, countries and organizations. Wright and Nyberg (2017) see a central role for organizations, in particular. They argue that because organizations have a role in the production of GHGs, they also have great potential to mitigate them with innovative solutions. In order to better manage GHG emissions and identify which emissions reductions measures are the most effective, organizations

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https://doi.org/10.1016/j.eiar.2021.106645
Received 21 January 2021; Received in revised form 7 July 2021; Accepted 11 July 2021
Available online 29 July 2021
0195-9255/

need to obtain a better understanding of where those GHG emissions occur (Eurostat, 2020).

GHG emissions are far more visible in manufacturing and among service providers, but they can hardly be traced within organizations that operate in the so-called knowledge industry. These organizations, referred to here as knowledge organizations, include education, science, consulting, finance, insurance, and communications. A large body of research exists on the GHG emissions of manufacturing industries and service providers, yet the impacts of knowledge organizations have received far less attention. Previous research has mainly focused on the GHG emissions of universities (Larsen et al., 2013; Ozawa-Meida et al., 2013; Wynes and Donner, 2018), mostly neglecting other types of knowledge organizations. Our study, instead, is based on an internationally operating research institute based in Europe with offices in various European countries as well as in Asia.

One way to determine the GHG emissions of an organization is the calculation of its carbon footprint. An organizational carbon footprint can include, for example, the use of vehicles, the energy consumption of buildings, transportation and business travel of employees, the consumption of goods and services, and other direct and indirect activities (Awanthi and Navaratne, 2018). Previous studies and reports have found that the emissions of knowledge organization consist mostly of indirect, consumption-based emissions (Larsen et al., 2013; Ozawa-Meida et al., 2013; Wynes and Donner, 2018; UNEP, 2019b). A carbon footprint is an adequate tool for identifying consumption-based emissions at the organizational level and allows guidance for mitigating emissions. Pertsova (2007) highlighted the importance of quantitative assessment in environmental modelling, and noted the wide use of carbon footprint as an emerging concept for action against global warming.

This paper aims to estimate the carbon footprint of an organization in the knowledge service sector. After identifying the carbon footprint, it is possible to understand what the most important emissions sources are and how to mitigate them. Through our analysis, we found that most emissions arise from indirect activities (Scope 3; see Section 2.1 for a definition of different scopes). This leads to the questions of how to mitigate such emissions when the organization might not have direct influence over the activities. In addition, we took the novel COVID-19 crisis into account and developed three scenarios to assess (a) how the pandemic has influenced the carbon footprint of knowledge organizations and (b) where the focus of mitigation should be placed in a post-COVID-19 world. The three scenarios take into account the expected changes in business travel patterns as well as the increased use of home office in a post-COVID-19 world. For scenario 1 we assumed a reduction in business travel by 19%. For scenario 2, we assumed a 36% reduction, and for scenario 3, the so-called non-recovery scenario, we assumed business travel will remain as low as it has been during the pandemic, down by 93%. In terms of the increased use of home office, we assumed that in a post-COVID-19 world employees will work two out of five days remotely.

The findings of this study are novel because they quantify some of the hidden environmental impacts of knowledge organizations and provide suggestions for improvement that are relevant for all types of knowledge organizations. We present a framework that can guide knowledge organizations to mitigate their carbon footprint. Understanding the emissions structure and mitigation of knowledge organizations might also prove useful for other entities, such as those in the service sector, where most emissions are produced indirectly, driven by the consumption of products and services.

2. Theoretical background

2.1. Carbon footprint assessment and methods

Carbon footprint is a tool for quantifying emissions. According to Wiedmann and Minx (2007), it is "a measure of the exclusive total amount of carbon dioxide (CO_2) emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product". The carbon footprint can be calculated for a product, person, activity, event, or, as in this study, an organization. The carbon footprint is generally expressed in CO_2 equivalents (CO_2-eq), meaning that GHG emissions other than carbon dioxide (methane, nitrous oxide and fluorinated gases) are converted into CO_2-eq based on their potential to contribute to global warming (Weidema et al., 2008; Wiedmann and Minx, 2007). Emissions in organizational carbon footprint calculations can be divided into three categories, or "scopes" (Harangozo and Szigeti, 2017; WBCSD and WRI, 2011). Scope 1 emissions include direct emissions from the activities, products and processes under the control of the organization or owned by it. Scope 2 emissions include indirect energy (purchased heating and electricity) emissions. Scope 3 includes any further indirect emissions and is often the biggest contributor to an organization's carbon footprint (Harangozo and Szigeti, 2017; WBCSD and WRI, 2011).

Although the carbon footprint is a widely used tool that is relatively easy to comprehend, it has faced criticism for oversimplifying environmental impacts because it only takes into account GHG emissions, not toxic emissions to land and water, for example. For this reason, it might not fully represent an organization's sustainability (Laurent et al., 2012; Weidema et al., 2008). Calculating carbon footprints for products has multiple standards, so system boundaries and other methodological choices of carbon footprint calculations can vary, leading to differing results (Ng et al., 2013; Padgett et al., 2008; Pandey et al., 2011). This applies to less standardized organizational carbon footprint calculations as well. In general, the carbon footprint analysis of an organization should pursue accounting for all direct emissions (Scope 1), indirect energy emissions (Scope 2), and other indirect emissions (Scope 3) within the set boundaries and limitations of the assessment (Harangozo and Szigeti, 2017).

There are three key approaches to calculating an organizational carbon footprint: traditional process-based life cycle assessment (process-LCA), environmentally extended input–output analysis (EEIO), and hybrid-LCA (Nakamura and Nansai, 2016), also known as the hybrid economic input–output-based approach (EIO) (Onat et al., 2014). Process-LCA is a 'bottom-up approach' estimating the emissions that take place at each stage of a given system while the EEIO is a 'top-down' approach evaluating the linkages between economic consumption and environmental impacts (Kitzes, 2013). The biggest distinction between process-LCA and EEIO is that process-based approaches normally neglect financial flows, e.g. purchased services (Suh et al., 2004). EEIO also allows easier replication and comparability between organizations, yet it fails to allow comparison between different products and services of the same industry (Kitzes, 2013; Suh et al., 2004). The hybrid EEIO-LCA (or hybrid-LCA) is a combination of process-LCA and EEIO analysis that is typically used to optimize the strengths of each method (Crawford et al., 2017).

2.2. Knowledge organizations and their carbon footprints

The use of knowledge for the creation of goods and services plays a paramount role in modern knowledge economies. These economies revolve around the concept of knowledge, which characterizes the production, use and diffusion of all economic activities involved (Hadad, 2017). Within these economies, knowledge organizations can be defined as the agents "which provide the underlying infrastructure and processes that enable a knowledge market to function" (Simard et al., 2007). Knowledge organizations represent two main types of actors: (i) those who invest in knowledge (i.e. a university), and (ii) those who apply knowledge in the production, usage and distribution of goods and services (i.e. a knowledge-based company; Karlsson et al., 2009).

White et al. (2012) further classify knowledge organizations according to their structural characteristics. They identify open innovation, education, knowledge management, creativity, and a solid IT infrastructure as the main pillars that characterize any major agent playing a substantial role in the knowledge economy. However, knowledge organizations can also be apprised according to subsequent and interlinking stages. Simard et al. (2007) identify nine different stages of each knowledge service system: (i) generate content, (ii) transform content into products and services, (iii) manage the knowledge flow, (iv) use it internally, (v) transfer it, (vi) add value, (vii) use it professionally as well as (viii) personally, and (ix) evaluate it.

Estimating the carbon footprint of knowledge organizations requires identifying the primary activities of the organization' responsible for the production, usage and distribution of knowledge. Using Simard et al.'s (2007) classification, we can identify the following major activities that account for the majority of any knowledge organization emissions:

- Employees' office hours and employees' internal meetings (Generate knowledge content)
- Business travels to attend conferences and meetings, employees' office hours (Transform knowledge content in products and services)
- Organization of events and production of dissemination and communication materials (Knowledge transfer)

During the last decade, various companies and organizations have taken the initiative to calculate their own carbon footprints. Universities have been especially active in calculating their carbon footprints and publishing the results in scientific journals (e.g. Larsen et al., 2013; Letete et al., 2011; Ozawa-Meida et al., 2013). Indirect (Scope 3) emissions generally form a large share of the emissions especially for knowledge organizations (Larsen et al., 2013; Ozawa-Meida et al., 2013; Wynes and Donner, 2018; UNEP, 2019b).

Mobility, which is a part of the indirect emissions of a knowledge organization, is generally a key component in the carbon footprints of universities, knowledge organizations, and more generally, to science as a whole (e.g. Achten et al., 2013; Glover et al., 2018; Wynes and Donner, 2018). Air travel typically has the biggest impact and, thus, the biggest mitigation potential. Achten et al. (2013) found that for a PhD study, videoconferencing could have reduced the carbon footprint by 44%. Wynes and Donner (2018) estimated that business-related air travel at a Canadian university contributed to 63% to 73% of the university's carbon footprint. Despite air travel's relatively large environmental impact, it is not always taken into account in the sustainability strategies and recommendations of universities (Glover et al., 2018). Meanwhile, Ozawa-Meida et al. (2013) calculated that procurement, at 38%, was the biggest contributor to a UK university's carbon footprint, while travelling was slightly less important as a source of emissions, with 11% coming from staff and student travels, and a further 18% from commuting. Using EEIO analysis, Larsen et al. (2013) calculated that the carbon footprint of a Norwegian university was 92 kt of CO_2-eq in 2009, or 4.6 t per student. Energy, buildings, and equipment were the biggest contributors, at 19% each. Travel accounted for 16% of the total carbon footprint. Another example is the United Nations (UN), where the estimated average carbon footprint per employee is 7 t of CO_2-eq (UNEP, 2019b). Of the total carbon footprint, 42% came from air travel and 12% from other transportation. However, there are significant differences between different UN entities and organizations, and air travel is a significantly more important source of emissions in, for example, the United Nations Environment Programme (UNEP) than it is in United Nations International Children's Emergency Fund (UNICEF), ranging from 85% of total emissions in the former to 35% in the latter (UNEP, 2019b).

However, comparing different studies on a detailed level is difficult and rarely sensible, because the methods and focus points vary significantly. Not all carbon footprint calculations fully take Scope 3 emissions (indirect emissions in the value chain) into account, and all business-related travel might not be included due to lack of data (Wynes and Donner, 2018).

2.3. Expected impacts due to COVID-19 pandemic

Previously, mobility has been identified as a key contributor to the carbon footprint of knowledge organizations. For this reason, the novel COVID-19 crisis can be understood as a game changer because it has a significant impact on business travel, and it is expected that business travel will not fully recover in a post-COVID-19 world. According to estimates made by Sharfuddin (2020), in a post-COVID-19 world business travel will decrease considerably and be replaced by virtual meetings. Ioannides and Gyimothy (2020) even speak of a paradigm shift in business travel. Zahra (2021) assumes that as organizations and employees have become used to working from home during the pandemic, they will be less likely to return to regular business travel as in the past. The pandemic has shown that online communication is an effective working tool while also being far less expensive. A recent survey among 1414 business travelers conducted by YouGov (2021) for the European Climate Foundation found that 42% of the participants expect to travel less due to increased use of video conferences during the pandemic. In the same survey, 22% of the participants claimed that they will replace more than half of their business travel with videoconferencing. A recent article in The Wall Street Journal (2020), citing leading airline industry experts, estimated that 19% to 36% of all business travel will not return. Alon (2020) further postulates that new technological solutions, such as augmented and virtual realities, could enhance the quality of online meetings in the long term.

Nevertheless, the pandemic has also led to an increase in working from home and this is expected to continue in a post-COVID-19 world. Sharfuddin (2020) estimates that companies will encourage employees to work more from home in the future, with them being present for three out of five workdays per week. This will mean a reduction in the need for office space, heating, and electricity and a decrease in employees' commutes, which will further reduce the carbon footprint of knowledge organizations.

3. Data and methods

In this study, we calculated the carbon footprint of a knowledge organization. At the request of the organizational management and to maintain confidentiality, the case organization remains anonymous in this paper. The case organization is a multinational organization with five offices in Europe and additional project offices in Asia. At the time of data collection, the organization had 125 employees. The data for the carbon footprint assessment were collected between July and December 2019 in various regional offices of the organization. To get a full picture of annual emissions the data collected was mostly based on 2018 consumption figures and accounts. The studied institution represents a knowledge organization because of the scope of its activities: producing and communicating knowledge for policymakers.

To account for the environmental impacts of the knowledge organization's monetary and physical consumption, a hybrid EEIO-LCA (sometimes called hybrid LCA) model was used in this study (similar to Larsen et al., 2013 and Onat et al., 2014). Process-LCA is the most commonly used method (Junnila, 2006; Suh et al., 2004), but a hybrid EEIO-LCA is more appropriate for knowledge organizations because it extends the system boundaries to include monetary consumption. Furthermore, the level of detail required for a traditional LCA cannot usually be achieved when calculating the carbon footprint of a knowledge organization, where indirect emissions play a greater role. EEIO-LCA is thus less time- and labor-intensive and requires less effort than the conventional approach does (Suh et al., 2004; Junnila, 2006; Nakamura and Nansai, 2016). Heinonen and Junnila (2011) identified the main disadvantages of an EEIO-LCA as the high level of industry aggregation, potential temporary (differences in inflation and currency) and regional (different industrial structures) stats, and model asymmetries as well as the hypothesis of domestic import production (Suh et al., 2004; Suh and Huppes, 2005; Junnila, 2006).

In this study, the hybrid EEIO-LCA model was hybridized in terms of heating, flights and commuting emissions, which were calculated using emission factors based on process-based LCA information. In these categories, the results are limited because the process-based emission factors do not take into account all the indirect emissions related to a process (Kitzes, 2013; Suh et al., 2004). All other categories were calculated utilizing the EEIO database EXIOBASE (Stadler et al., 2018), with openLCA software (GreenDelta, 2021). openLCA makes it possible to carry out simple EEIO-based calculations, such as carbon footprint analyses, with EXIOBASE without the need for manual calculations and EEIO handling. For a summary of the model and categories included, see Fig. 1.

In the EEIO analysis, environmental impacts are calculated based on economic activities representing consumption (Kitzes, 2013). EEIO-based approaches are widely utilized and can be used in analyzing virtually any environmental impacts, not just carbon footprints. The goal of EEIO analysis is to identify and quantify embodied (upstream) environmental impacts caused by downstream consumption (for an introduction, see e.g. Kitzes, 2013; Leontief, 1970; Schaffartzik et al., 2014). Different environmental account databases and input–output tables can be used for EEIO analysis in analyzing the impacts of certain processes and products. Global databases, such as Eora, EXIOBASE, GTAP and WIOD, are generally used in order to acquire harmonized and detailed data (Kitzes, 2013; Stadler et al., 2018). In this study, the main input–output database was EXIOBASE. For organizational carbon footprint analysis, EXIOBASE performs well compared to other databases because of its high sectorial detail, including around 200 different product categories, and free usage (Stadler et al., 2018).

EXIOBASE is a multiregional, environmentally extended supply-use table and input–output table created for EEIO analyses (Stadler et al., 2018). Supply-use tables of EXIOBASE are monetary, meaning that the inputs need to be expressed as financial units, even though the newest hybrid version of the database also includes physical units (Merciai and Schmidt, 2018). EXIOBASE version 3 covers 44 countries, 200 products, 662 material and resource categories, and 417 emission categories (Stadler et al., 2018). EXIOBASE 3 includes base years of 1995 to 2011. In this study, we used the year 2011 in order to have the most up-to-date data. openLCA with EXIOBASE 3.4 and ecoinvent 3.4 databases were utilized for emissions calculations. Direct use of emissions factors either from national accounts or more specific sources were also used.

3.1. Energy

Data for energy (heating and electricity) usage came mostly from external stakeholders, because the organization does not own its office premises. Thus, the energy calculation methods for each office differed. For a summary of energy production types, consumption figures, emission factors and their sources, see Appendix 1. Heating and cooling emissions in the Spanish office were considered zero because heating and cooling were generated by geothermal energy. Heating emissions in the German office were calculated using the German district heating emission factor (0.28 t CO_2/MWh; BAFA, 2019). Heating emissions in

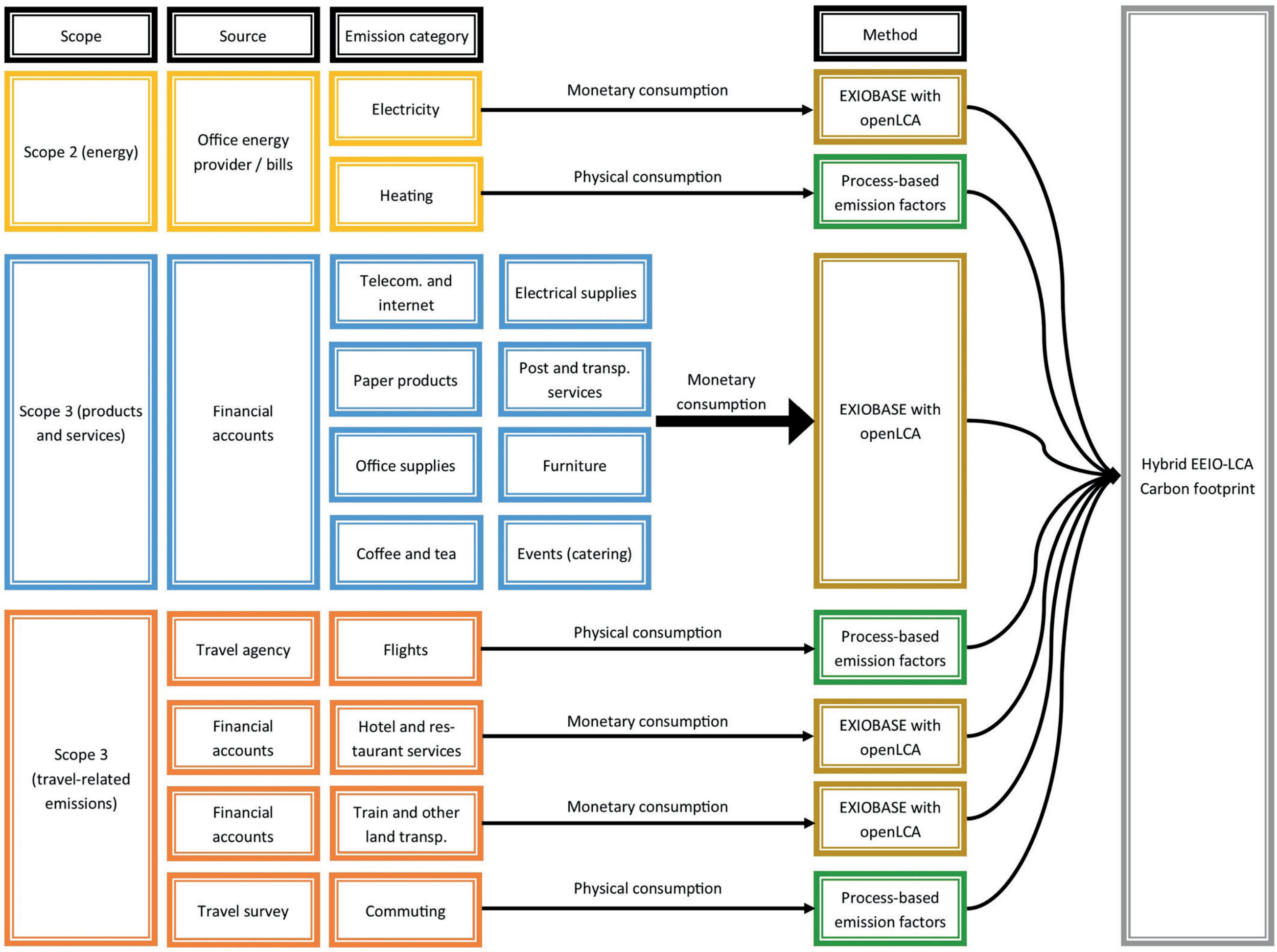

Fig. 1. Flowchart summarizing the data and methods of the study.

the French office were estimated by using the 2019 emission factor for burning oil (heating and lighting on domestic scale, 2.54 kg CO_2-eq/liter) for businesses based in the UK (DEFRA, 2020), because information about French emissions factors were not available. In the case of the Finnish office, energy consumption figures were given for the whole office building, which includes other organizations' offices as well. This means the organization's share of the energy use had to be estimated based on received information about the area occupied by the different offices in the building. Heating emissions were calculated with an emission factor (0.13 t of CO_2/MWh) provided by the local power plant. Heating emissions factors for the German and Finnish offices only considered carbon dioxide emissions, instead of carbon dioxide equivalent emissions, thus the numbers might not be strictly comparable. These emission factors were nevertheless used because more accurate data could not be found.

Electricity emissions in all offices were calculated with openLCA and EXIOBASE by utilizing electricity bills or by converting electricity consumption to monetary units. Conversion factors can be found from Appendix 1. The electricity source was considered to be an average national electricity mix, with the exception of the Finnish office where a renewable electricity mix was used. Furthermore, electricity consumption in the German office was not available, so an estimation based on the electricity use in other offices had to be made.

Energy-use information about other offices (Belgium and Asia) was not available or only a few staff members occupied the offices. In this case, they were considered of low importance in terms of total emissions and were left out from this analysis.

3.2. Products and services

Financial data from 2018 were utilized to obtain a general picture of how many products and services are consumed by each unit of the organization. Table 1 presents the names of financial accounts used, along with their respective categories from the EXIOBASE database, to calculate the organization's carbon footprint. Connecting a financial account with a respective EXIOBASE category was not straightforward in all cases (in Table 1, see e.g. financial account Office supplies and Short Term Equipm and Furniture). Some estimations of the possible content of the account had to be made based on observations and discussions with procurement officers.

Using EXIOBASE with openLCA requires identification of the country of final consumption, so a country was specified for each organizational project account based on the assumed location of the project office. The

Table 1
Name of accounts and representative categories in EXIOBASE.

Financial account name	EXIOBASE category (Stadler et al., 2018)
Coffee, tea	Beverages
ADP Supplies	Electrical machinery and apparatus
Events catering	50% Beverages, 50% Food products
Office supplies	1/3 Electrical machinery and apparatus, 1/3 Paper and paper products, 1/3 Rubber and plastic products
Short Term Equipment & Furniture	50% Furniture; other manufactured goods, 50% Office machinery and computers
Hotel/accommodation	Hotel and restaurant services
Restaurant Meals	
Courier Services	Other land transportation services
Group Transportations	
Journals	Paper and paper products
Paper (copy, printed)	
Printed Materials	
Mail	Post and telecommunication services
Phone, Fax, Datatran	
Internet	
Leasing	Renting services of machinery and equipment without operator and of personal and household goods
Tickets (land transportation estimate)	80% Railway transportation services, 20% Other land transportation services

CML 2001 baseline (Guinée et al., 2002) was used as the impact method, because it includes Global Warming Potential (GWP) for 100 years. Prices were fixed to match inflation from the EXIOBASE baseline year (2011) by using the euro area harmonized indices of consumer prices (Eurostat, 2020). Aggregated EU-level inflation data were used, because all of the offices were based in the EU. Other conversions to prices have not been made.

3.3. Travel-related and commuting emissions

Travel data were collected from the financial accounts (land transportation) and travel agency (flights). The organizational travel agency had readymade and detailed data about flight emissions. Their calculations were considered reliable for the purpose of this study because the calculations are based on DEFRA's GHG conversion factors on flight emissions (for the latest version, see DEFRA, 2020).

A travel and commuting survey was conducted within the organization, primarily to determine commuting emissions and some additional information related to employees' commuting and travel behavior and opinions. The data were collected between August and September 2019 by distributing an electronic survey to all employees in the organization. The survey was answered by 78 out of the 125 employees, a response rate of 62%. The responses were well balanced between the three major offices and in terms of employees' gender, age, education and duration of employment as shown in Appendix 2.

For commuting emissions, respondents reported their primary mode of transport to work, the travel distance (home–office–home) and the average number of trips per week. Employees commuting with a car were also asked additional questions regarding the vehicle type (size, production year and fuel type). OpenLCA with ecoinvent 3.4 database was utilized to calculate emissions and IPCC 2013 GWP was used as the impact assessment method. Walking and biking were considered as emission-free modes of transportation. Appendix 3 provides the survey questions used in this study.

To assess the extent to which individual sociological characteristics affect travel and transport choices and emissions, two linear regression models were run. The first model aimed to capture any significant statistical relationship occurring between individual commuting transport choices and a series of independent variables (e.g. gender, age, education, office location, number and times spent in commuting trips, and obstacles to choosing more sustainable commuting options). The second model captures the effect on the individual's willingness to reduce work-related flights of a series of sociological characteristics (as above) as well as employee perceptions of virtual communication tools, travel necessity, carbon footprint reporting, and more. Additional information on the regression models can be found in Appendix 4.

3.4. Post-COVID-19 scenarios

In order to account for the impacts of the COVID-19 pandemic on the carbon footprint of knowledge organizations, three post-COVID-19 scenarios were created. The scenarios are based on the data collected from the studied organization. The three scenarios take into account the expected changes in business travel patterns as well as the increased use of home offices in a post-COVID-19 world. The Wall Street Journal (2020) has estimated that 19% to 36% of business travel will not return, so we assume the following: a reduction in business travel by 19% for scenario 1, and a reduction of 36% for scenario 2. Scenario 3 is based on the drop in business travel during the pandemic, meaning a non-recovery scenario where business travel falls by 93%. This scenario is based on the 2020 flight travel data provided by the studied organization, which saw a decrease of 93% in flights during 2020. These reductions in business travel will have a direct impact on the following emissions categories: flights, hotel and restaurant services, train and other land transportation, events (catering) as well as telecommunications and the internet. For the last category, we assumed an increase of the same percent because it replaces business travel while we expect a decrease for all the other categories depending on the scenario. In terms of employees working from home, we assume that in a post-COVID-19 world employees will work only three out of five days (60%) in the office and the remaining two days (40%) from home, as estimated by Sharfuddin (2020). We therefore assumed a decrease of emissions of 40% for the following emissions categories: heating, commuting, electricity and paper products. For the remaining emissions categories we did not assume any changes in our three post-COVID-19 scenarios. Table 2 below provides a detailed overview of how our assumptions have affected the different categories based on the three scenarios.

4. Results

4.1. Emissions of a knowledge organization

The estimated total carbon footprint of the studied organization in 2018 was 644,137 kg CO_2-eq, which equals 5135 kg CO_2-eq per person. The categories that contributed the most to the carbon footprint were flights (62%), heating (12%) and hotel and restaurant services (7%) (Table 3). Most emissions belong to Scope 3 (87%), with only 13% of emissions belonging to Scope 2. No Scope 1 emissions have been detected in this study.

After we determined the total carbon dioxide equivalent emissions of the knowledge organization, we found that the largest part of emissions created by the studied organization were related to travel. While flights, at 62%, were found to be the largest emissions category, those combined with other travel-related activities, such as hotel and restaurant services, commuting as well as train and other land transportation add up to 79%, so almost four-fifths of the organization's total emissions. Because travel-related emissions make up the largest share of a knowledge organization's carbon footprint but also represent the greatest potential for emissions reductions through changes in travel behavior, the second part of our study focused on travel-related emissions and potential mitigation strategies.

4.2. Emissions by offices

Of total organizational emissions, 34% can be allocated to the Finnish office while the Spanish office and the German office account for 24% and 21% of total emissions, respectively. Smaller offices in Europe and Asia account for 21% of the total emissions altogether.

Emissions per activity were studied further in the three biggest offices: Finnish, Spanish and German offices. There are some notable differences in the shares of emissions per activity between offices (Fig. 2). Flights are the biggest source of emissions in all offices: 69% in Spain, 54% in Finland, and 48% in Germany. Heating in the Spanish office does not create emissions, because geothermal energy is considered to be emission free, while in the German office it accounts for 26% of total emissions and 15% in the Finnish office. Commuting is an important source of emissions for the Finnish office (13%), whereas in Spain and in Germany it accounts for approximately 2% of total emissions. The share of hotel and restaurant services varies between 5 and 9% and land transportation between 4 and 6%.

Table 2
Changes in emissions by category based on the three scenarios.

Emissions category	Changes in emissions by scenario		
	Scenario 1	Scenario 2	Scenario 3
Flights	−19%	−36%	−93%
Heating	−40%	−40%	−40%
Hotel and restaurant services	−19%	−36%	−93%
Commuting	−40%	−40%	−40%
Train and other land transport.	−19%	−36%	−93%
Telecommunication and internet	+19%	+36%	+93%
Events (catering)	−19%	−36%	−93%
Electrical supplies	0%	0%	0%
Electricity	−40%	−40%	−40%
Paper products	−40%	−40%	−40%
Post and transport. Services	0%	0%	0%
Office supplies	0%	0%	0%
Furniture	0%	0%	0%
Coffee and tea	0%	0%	0%

4.3. Travel-related emissions

In the travel-related carbon footprint, flights accounted for 79% of the total travel-related emissions. In terms of distance, most kilometers were flown on economy class medium- and long-haul flights followed by business class long-haul flights. However, most emissions per passenger kilometer (pkm) were produced by long-haul business class flights (210 g CO_2-eq) and economy short-haul domestic flights (147 g CO_2-eq). In comparison, economy class medium-haul flights produced on average only 87 g CO_2-eq per pkm, while for economy class long-haul flights it was only 72 g CO_2-eq.

Here the domestic short-haul flights between the organization's Finnish office and the capital stand out. Helsinki-Vantaa, as Finland's only international hub airport, is the gateway for international flights to and from Finland. In 2018, altogether 161 flights were taken that included a short-haul flight between the Finnish office and Helsinki in order to connect to a destination outside of Finland. In addition, 21 flights were taken as a domestic flight only to the capital Helsinki. All of these were return flights, so altogether 364 short-haul flights were taken between Helsinki and the Finnish office.

In addition to taking a closer look at the recorded travel-related emissions, a travel and commuting survey was conducted among employees to better understand their travel behavior and to discuss mitigation possibilities. The survey focused on long-distance work travel as well as commuting to work.

4.3.1. Long-distance work travel survey

The travel survey showed that for international travel most employees travelled by airplane (81%), followed by train (8%) and car (1%) while 10% did not travel internationally at all. For domestic travel, the train dominated with 67%, followed by car (8%), airplane (5%) and bus (1%). The remaining 19% of respondents did not travel domestically for work.

Respondents also answered a set of three questions related to their most recent long-distance work trip of more than 200 km taken by airplane or car. The first question was whether they think this trip could have been avoided. The majority (86%) thought that the trip could not have been avoided. The main reason provided by the participants was the benefits of face-to-face contact, which are experienced differently than those of virtual meetings. These benefits included better interaction in terms of networking, informal discussion, building trust and team building. Some trips were also for fieldwork or organizing an event that could not be avoided. Because so many meetings are already organized online, meeting at least from time to time offline was seen as acceptable. Some respondents, however, also mentioned that not all meetings would need to take place face to face.

In a second question, participants were asked whether they think it would have been possible to choose another mode of transportation. Here, 59% thought it was not possible, while 38% saw it as a possibility. Participants justified their answers mainly by mentioning a significant increase in travel time when changing transportation modes. Other reasons mentioned were higher costs as well as the lack of options.

In the third question, participants were asked whether they had carbon-offset the emissions generated by their trip. A vast majority of the respondents (81%) did not compensate for their trip. They justified their responses by saying that carbon offsetting was not part of the organization's policy and thus participants were not willing to pay for to offset business trip with their own budget. Furthermore, some participants stated they had not simply thought about it, that it was not

Table 3
Total emissions and share of emissions for each category for the 2018 baseline and the three COVID-19 scenarios.

Emissions category	Total emissions (kg CO2-eq)							
	2018 Baseline		Scenario 1 (19%)		Scenario 2 (36%)		Scenario 3 (93%)	
Flights	397,670	62%	322,113	64%	254,509	60%	28,125	18%
Heating	76,629	12%	45,877	9%	45,977	11%	45,977	29%
Hotel and restaurant services	42,686	7%	34,576	7%	27,319	6%	3019	2%
Commuting	34,305	5%	20,583	4%	20,583	5%	20,583	13%
Train and other land transport.	29,986	5%	24,289	5%	19,191	5%	2121	1%
Telecommunication and internet	13,646	2%	16,239	3%	18,559	4%	26,327	17%
Events (catering)	13,206	2%	10,697	2%	8452	2%	934	1%
Electrical supplies	9623	1%	9623	2%	9623	2%	9623	6%
Electricity	6418	1%	3851	1%	3851	1%	3851	2%
Paper products	5945	1%	3567	1%	3567	1%	3567	2%
Post and transport. Services	5303	1%	5303	1%	5303	1%	5303	4%
Office supplies	4937	1%	4937	1%	4937	1%	4937	1%
Furniture	3582	0%	3582	0%	3582	1%	3582	2%
Coffee and tea	201	0%	201	0%	201	0%	201	0%
Total emissions	**644,137**	**100%**	**505,537**	**100%**	**425,653**	**100%**	**158,150**	**100%**
Scope 1 emissions	0	0%	0	0%	0	0%	0	0%
Scope 2 emissions	83,047	13%	49,828	10%	49,828	12%	49,828	31%
Scope 3 emissions	561,090	87%	455,709	90%	375,825	88%	108,322	69%
Travel-related emissions	504,647	79%	401,560	80%	321,602	76%	53,848	34%
Emissions reductions compared to 2018 Baseline	–	–	138,600	−22%	218,484	−34%	485,987	−75%

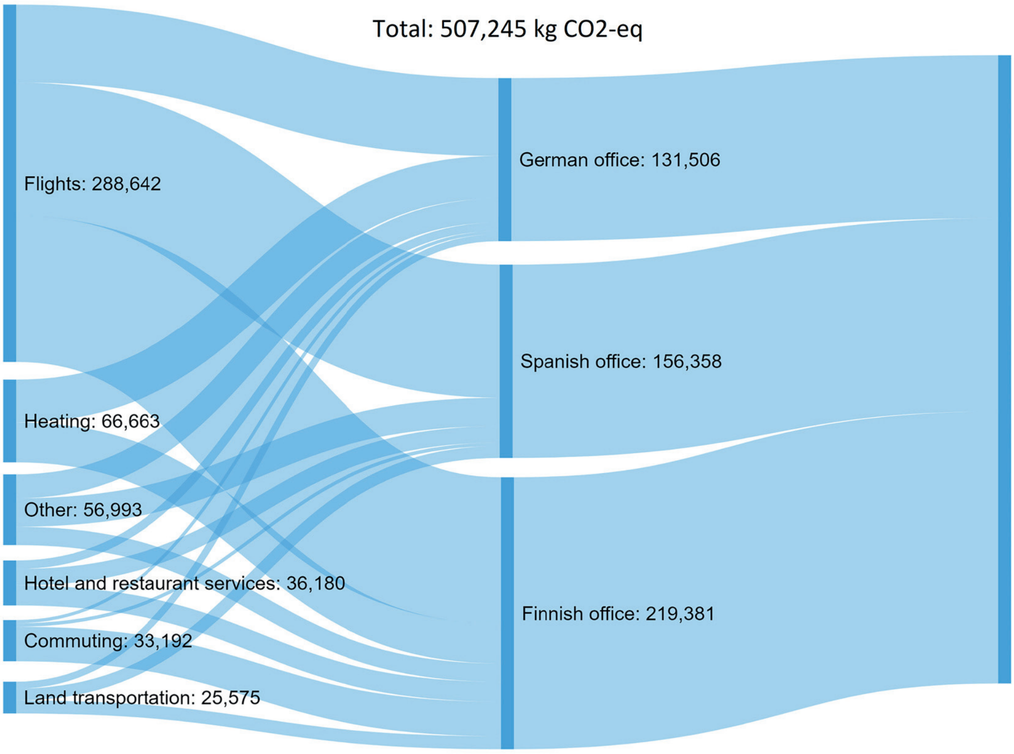

Fig. 2. Total emissions by office and emission category (excluding smaller offices in Europe and Asia).

available from the airline they flew with, or questioned the effectiveness of carbon offset schemes.

Finally, the participants discussed potential barriers they might face with the current travel policy of the organization and to name any potential solutions for reducing climate impacts related to work travel. The largest barrier was seen in how the policy focuses not on climate impacts but on reducing travel times and costs. No information about alternatives is provided. In terms of solutions on how to reduce impacts, carbon offsetting and the increased use of virtual meetings were mentioned the most. In addition, a change in organizational culture towards encouraging and rewarding train travel as well trying to use trains at least on parts of the trip was emphasized. Most employees would be willing to switch air travel to land travel when the journey lasts a maximum of six hours. Furthermore, 40% of the participants agreed that virtual communication tools cannot provide a good alternative to face-to-face meetings, while 39% disagreed with such a statement, and 21% neither agreed nor disagreed. This result could possibly differ from the current employee opinions regarding virtual meetings, which have been commonly used due to the COVID-19 pandemic. The regression model shows that those employees who have a positive view on virtual communication tools have rejected flights when they had the possibility. In addition, employees who value organizational flexibility regarding longer but more sustainable journeys tend to be more willing to reduce work-related flights (Appendix 4).

4.3.2. Commuting to work survey

The commuting survey found that most respondents commute by bicycle (35%), followed by car (23%) and public transport (17%). The average distance for a round trip to the office is 12.5 km. Most participants (42%) indicated they spend 15 to 30 min on their daily commute, 29% between 31 and 60 min, 9% over 60 min and the remaining participants less than 15 min or do not commute at all, working from home. Some differences between the individual offices could be found. Most staff members working in the German office commute by bike, while in the Spanish office most use public transport or walk and in the Finnish office most workers drive by car.

When workers were asked for reasons they chose certain transportation modes, travel time, convenience and flexibility followed by health reasons were mentioned the most. Environmental reasons and costs were mentioned to some extent. About half of the participants (51%) indicated that they would be willing to reconsider their commuting mode in case there would be no restrictions (e.g. time, flexibility, costs) with 65% selecting an environmentally friendlier mode (e.g. switching from car to bicycle) while the remaining 35% would opt for a less environmentally friendly mode (e.g. switching from public transport to car). The results of the regression model indicate a statistically significant effect of commuting distance and different office location on individual commuting transport choices. Employees closer to office locations and from the German and Spanish offices (compared to the French and Finnish offices) have the tendency to use more sustainable commuting modes (e.g. walking or biking vs. cars; Appendix 4).

In addition, respondents also named any possible ways the organization could support them in choosing more sustainable commuting modes. A frequent suggestion was financial support for using public transport, bicycle purchases or bicycle maintenance. Other ideas mentioned were the provision of office bikes and bike maintenance services. More support for home office and flexible working hours as well as organizing car pools was also mentioned.

4.4. Post-COVID-19 scenarios

The results of the three scenarios in Fig. 3 showed that a reduction in business travel by 19% and employees working from home for 40% of their working time could reduce the carbon footprint of the studied organization by 22%. Once the reduction of business travel increases to 36%, the carbon footprint could even be lowered by 34%. Nevertheless, despite a significant reduction in business travel and the 40% reduction in emissions from commuting due to the increased rate in employees working from home, the total share of travel-related emissions in both scenario 1 and scenario 2 remains as high as in the calculated carbon footprint for 2018, which was 79%. For scenario 1, the share even increased to 80% while in scenario 2 it only dropped to 76%. Even in a post-COVID-19 world where travel-related emissions are expected to decrease, for knowledge organizations travel-related emissions will remain the largest contributor to the carbon footprint and should therefore be actively addressed. Only in scenario 3, where no recovery of business travel was assumed (93% less than in 2018), did the share of travel-related emissions of the total carbon footprint drop, to 34%, turning heating into the largest contributor to the carbon footprint.

5. Discussion

5.1. The carbon footprint of a knowledge organization

The results of our study show that most of the carbon footprint in a knowledge organization stems from indirect, Scope 3 emissions. According to Harangozo and Szigeti (2017), Scope 3 emissions are usually the biggest contributor to an organization's carbon footprint and several studies on the carbon footprints of knowledge organizations, such as universities, are aligned with our results, indicating the importance of indirect emissions (ETH Zurich, 2018; Larsen et al., 2013; Letete et al., 2011; Ozawa-Meida et al., 2013; UNEP, 2019b). In terms of mitigation, organizations usually have the most control over their direct emissions (Scope 1), while it is much more difficult to control indirect emissions (Scope 2 and 3). This indicates that knowledge organizations would have very little control over their carbon footprint. However, based on our findings, we argue that with changes in travel behavior and policies, knowledge organizations could take control over their emissions. The largest share of the carbon footprint was generated by travel-related emissions (79%), with air travel accounting for 62% of the organization's total carbon footprint. Our findings are hereby in line with previous studies that found that emissions related to air travel represent a major share in the carbon footprint of knowledge organizations. The UN, for example, estimated that its emissions related to air travel were 42%. In some organizations within the UN system they were even higher: UN Volunteers was at 59% and the Convention on Biological Diversity had as much as 97% (UNEP, 2019b). According to a study by the SEI (2019), an organization similar in size and structure to the organization in this

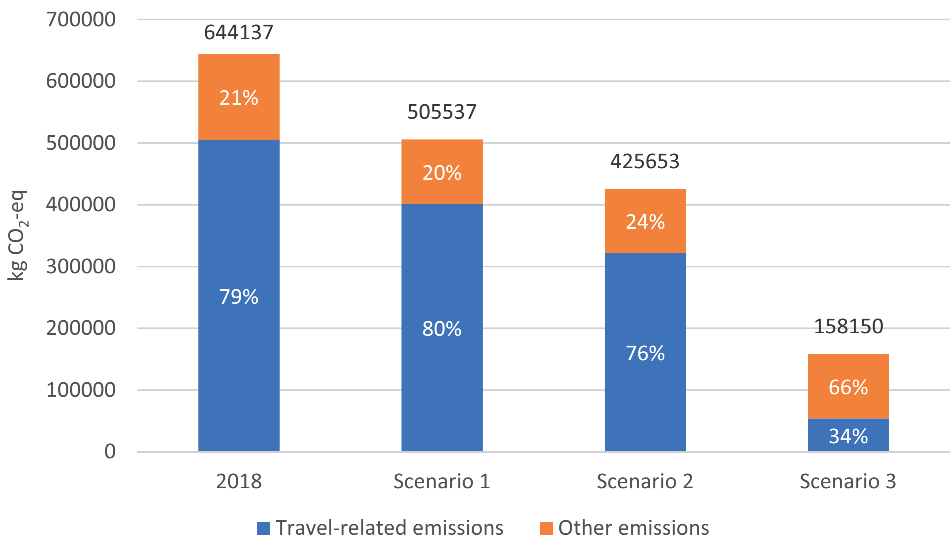

Fig. 3. Share of travel-related emissions by scenario.

study, it had emissions related to air travel per full-time employee of 4390 kg CO_2-eq, which is only slightly above those of our case organization, with 3787 kg CO_2-eq.

5.2. Expected impacts due to COVID-19 pandemic

Based on our scenarios, the total emissions of knowledge organizations are expected to drop due to the reduced amount of business travel. Nevertheless, based on the most likely scenarios (1 and 2) travel-related emissions will remain the largest contributor to the carbon footprint of knowledge organizations. Therefore, in order to reduce the carbon footprint of knowledge organizations, the focus of mitigation in a post-COVID-19 world should remain on travel-related emissions. Only in the unlikely event that travel-related emissions remain on the same level as they were during the pandemic (scenario 3) would other emissions categories gain more importance. In scenario 3, heating would become the single largest contributor, with 29% of the total emissions, raising the importance of Scope 2 emissions, which were negligible in the other scenarios. However, in scenario 3, the carbon footprint would already have decreased 75%, which once again stresses the significant contribution of travel-related emissions to the overall carbon footprint of knowledge organizations.

5.3. Mitigation strategies

In terms of mitigation, the most efficient way to reduce the carbon footprint of a knowledge organization would be to significantly cut or halt all travel, as has been the practice during the COVID-19 pandemic (presented in scenario 3). Prior to the pandemic, however, this did not always seem possible, as the results showed. At that time, the majority of employees (86%) thought their last trip could not have been avoided. Though fieldwork cannot easily be replaced with online tools, many face-to-face meetings and events such as conferences can, as the COVID-19 crisis has shown. Another measure to reduce emissions is the choice of transportation mode, such as avoiding or reducing air travel. A majority of employees did not think their last trip could have been avoided, but at least 38% of employees saw this as a possible solution. One simple measure is to avoid domestic flights, especially where alternatives such as good train connections exist. A large share of domestic trips within the case organization are already made by train (67%), yet many domestic feeder flights were used in Finland. There is a well-established railway connection between the Finnish office and downtown Helsinki as well as to Helsinki-Vantaa Airport, which provides door-to-door connections equal to that of aircraft (Baumeister, 2019). Based on Baumeister (2019), who studied the emissions reduction potential of replacing domestic flights in Finland with land-based transportation modes such as trains, the emissions for a one-way flight from the organization's Finnish office to Helsinki are 70.05 kg CO_2-eq. By train, they are only 8.77 kg CO_2-eq. If all flights had been replaced by train travel, 22,307 kg CO_2-eq could have been saved, which is 6% of the organization's total flight emissions. Here emissions could be easily reduced by replacing flight trips with train travel.

Another simple measure to reduce flight-related emissions is to cut down the amount of premium class flights, as their emissions are significantly higher than flying in economy class. According to Bofinger and Strand (2013), the emissions created by a flight in business class are on average 2.3 times higher than those in economy class and even 6.9 times higher in first class. Reducing work-related travel would not only cut down the emissions created from air travel and emissions of land-based travel modes but would also reduce the emissions created from hotel and restaurant services. These emissions can be significant, as they accounted for 7% of the total emissions of the studied organization. It has also been shown that frequent business travel can affect work–life balance (Liese et al., 1997; Striker et al., 2001; Lirio, 2014; Saarenpää, 2015). For example, in the World Bank the filing rate of medical claims among male travelers was 80% higher than it was among their non-travelling counterparts, and 18% higher among female travelers (Liese et al., 1997). Saarenpää (2015) found international business travel can affect work–family balance, with this imbalance producing negative mental and practical outcomes for travelers and their families.

Furthermore, the results also showed the important role the travel policy of an organization plays in efforts to reduce emissions. A travel policy that takes into account climate aspects could strongly encourage employees to choose alternative modes of transportation and think thoroughly about the importance of the trip. Previous studies have shown that manager support can be an important factor for employee's pro-environmental behavior (Blok et al., 2015; Lo et al., 2013; Ramus and Steger, 2000; Siu et al., 2013). A decision-tree and a pre-travel survey could, for example, help to choose and identify important trips, as practiced by the Tyndall Centre for Climate Change Research (2015). Similarly, the Stockholm Environment Institute (SEI, 2019) asks each of their offices to independently monitor flight emissions and develop environmental action plans; while ETH Zurich (2019) has implemented a voluntary carbon tax on its departments, and a similar approach has been implemented by the University of California, Los Angeles (UCLA, 2019) where a carbon mitigation fee is charged for each flight. Monitoring and justification of emissions, and encouraging employees to choose alternative modes of transportation are important parts of a travel policy aiming to take into account climate-related aspects (some example policies: LUCSUS, 2018; Tyndall Centre for Climate Change Research, 2015).

Finally, a surprisingly large share of the carbon footprint, 5%, of the studied case organization stemmed from commuting to work. Although it is the employee's individual choice how to commute to work, an organization can use incentives and support to motivate employees in choosing more sustainable modes of commuting. In our study, employees showed a strong willingness to reconsider their mode of commuting and a large share was interested in switching to environmentally friendlier modes.

After avoiding and reducing emissions, carbon offsetting or compensation can be a partial and temporary solution to achieve carbon neutrality. However, many challenges remain with conventional carbon offsets in the implementation and success of projects. These range from additionality and emission reduction estimates (Cames et al., 2016) to the fundamental issue of claiming that one tonne of additional emissions is "neutralized" by one tonne's worth of emission reduction units (Becken and Mackey, 2017). However, some of these issues and risks could be mitigated by overcompensation of emissions, in which case one tonne of emissions would be offset, for example, by two tonnes' worth of emission reduction units.

In addition to conventional carbon offsetting, often undertaken through external carbon offsetting providers, some knowledge organizations have been implementing alternative offsetting methods, known as internal offsetting. For example, ETH Zurich's (2019) carbon tax revenues are not used for conventional carbon offsets. Instead, the revenues are invested internally in "teaching, research and fostering young talent, with a focus on CO_2-reducing themes". Similarly, the Air Travel Mitigation Fund of UCLA (2019) is used to support "local on-campus projects resulting in lasting, measurable carbon reduction in order to mitigate air travel emissions". The University of Oregon and Yale University have also studied and piloted the implementation of carbon tax/charges, focused on flights and energy use (Kuang and Sternberger, 2017; Yale University, 2016). Moreover, these internal mechanisms could influence organizational and individual decision-making, as flights and fossil energy would have a higher price (Yale University, 2016). Internal offsetting could be a useful alternative for knowledge organizations, where they could be further extended. Organizations could use internal funds to mitigate organizational emissions, investing the internal funds into alternative business travel modes, local renewable energy and sustainable procurement solutions. However, the structure and collection method of the fund and the effect on financial performance would require careful consideration, depending on the

Table 4
Policy framework for mitigating the travel-related emissions of a knowledge organization.

Avoid	
Stop travelling	• Avoid all unnecessary travel • Implement more online meetings • Continue practices from COVID-19 lockdown
Avoid premium class flights	• Emissions can be 2.3 times higher flying in business class • Emissions can be 6.9 times higher flying in first class
Reduce	
Choice of transportation mode	• Reduce trips by aircraft, especially domestic flights • Reduce trips by car • Travel more by train or long-distance bus
Improve travel policy	• Policy needs to take into account climate impacts • Provide more information and flexibility in terms of alternative travel modes • Include carbon offsetting
Support employees in commuting	• Create incentives and support employees in selecting less carbon-intensive commuting modes • Offer more opportunities to work from home
Offset	
Carbon offset (external)	• Carbon offset through verified external offset providers • Overcompensate to account for risks
Carbon offset (internal)	• Carbon offset by investing in internal offsetting projects

structure of the organization.

5.4. Mitigation policy framework

Based on our findings and the above discussed mitigation strategies, we propose the following policy framework to mitigate the travel-related emissions of a knowledge organization (see Table 4). The priority should be avoiding emissions by stopping travelling and avoiding flights in premium class. We see these as the most effective ways of mitigation. Second priority should be given to reducing emissions through the choice of transportation modes, an improved travel policy and encouraging employees to use greener commuting. Finally, as a last resort and for remaining emissions, offsetting carbon emissions both externally and internally should be considered.

6. Conclusion

By assessing the carbon footprint of a knowledge organization, we found that indirect emissions (Scope 3) and travel-related emissions dominate. We used our findings to propose a mitigation policy framework for knowledge organizations to reduce their travel-related carbon footprint. This framework builds on three major activities: avoiding and reducing emissions while offsetting the remaining ones. It is commonly argued that organizations have little control over indirect emissions, but our framework demonstrates that knowledge organizations, whose carbon footprint is mainly based on indirect emissions, can use simple policy changes to effectively take control of their emissions. Though our study focused on knowledge organizations, the framework presented here can also be applied to any other type of organization that wants to mitigate travel-related emissions.

Even though our study shed some new light on the carbon footprints of knowledge organizations and discussed potential mitigation strategies, it also has some limitations. First, our results are based on only one case organization, which limits the generalizability of our findings. The studied organization had no Scope 1 emissions. The strong focus on travel-related emissions might also be misguided, because the share of those emissions can vary significantly between organizations, as previous studies have shown. Furthermore, the lack of availability of some data sources (e.g. energy-related emission factors or CO_2-eq) concerning the studied organization and some of the assumptions that had to be made during the calculation process, such as when EXIOBASE categories had to be matched with the financial accounts of the organization, might have led to errors in the estimation of the carbon footprint. In addition, the information provided by EXIOBASE was based on 2011 emissions, making the data somewhat outdated. The carbon footprint might also not present the full picture of environmental sustainability. Biodiversity impacts and toxic emissions, for example, have not been addressed. Finally, the travel survey, despite its good response rate, had a limited amount of participants, which restricts further statistical analyses.

Future studies could draw more attention to indirect emissions other than travel-related ones, because in some knowledge organizations their share might be significantly higher but also more difficult to mitigate. Research studies could also further explore the potential of internal carbon offsetting in organizations, which have yet to receive much attention in the literature. Finally, this study was mainly conducted prior to the COVID-19 crisis, so future work could also investigate the impacts the crisis has had on the carbon footprint of organizations, especially for work-related travel and commuting in a post-COVID-19 world.

Author statement

Sami El Geneidy as the first author was responsible for the conceptualization, data curation, formal analysis, methodology and he was involved in writing of the original draft. Stefan Baumeister, Ph.D. as the second author was involved in the conceptualization, formal analysis, methodology and in writing the original draft. Stefan was also responsible for the supervision and validation of the process. Valentino Marini Govigli, Ph.D., Timokleia Orfanidou and Venla Wallius were involved in the writing of the original draft and helped with the conceptualization of the study. All authors contributed equally to the reviewing and editing of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. A summary of key information related to office energy consumption and emissions

Office location	Emission category	Energy production type	Consumption (kWh)	Conversion factor to monetary units	Emission factor	Unit	Emission factor source
Finland	Electricity	Nordic renewable electricity mix (hydro and wind, Nordic Energy Research, 2017)	175,436	46.77 €/MWh (Nordpool, 2018)	Hydro: 0.37 Wind: 0.20	kg CO_2-eq/€	EXIOBASE (Stadler et al., 2018)
	Heating	Biomass, peat and biogas	247,674	No conversion done	0.13	t CO_2/MWh	Local power plant
France	Electricity	French electricity mix	9978		0.19		

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(*continued*)

Office location	Emission category	Energy production type	Consumption (kWh)	Conversion factor to monetary units	Emission factor	Unit	Emission factor source
				0.07025 €/kWh (average of 2018 prices, Eurostat, 2021)		kg CO_2-eq/€	EXIOBASE (Stadler et al., 2018)
	Heating	Oil	3923 (liters)	No conversion done	2.54	kg CO_2-eq/l	DEFRA, 2020
Germany	Electricity	German electricity mix	83,000	0.2707 €/kWh (SWB, 2019)	0.10	kg CO_2-eq/€	EXIOBASE (Stadler et al., 2018)
	Heating	German district heating mix	123,090	No conversion done	0.28	t CO_2/MWh	BAFA, 2019
Spain	Electricity	Spanish electricity mix	67,360	0.123 €/kWh (from electricity bill)	0.23	kg CO_2-eq/€	EXIOBASE (Stadler et al., 2018)
	Heating	Geothermal	104,133	No conversion done	0	None	None

Appendix B. Commuting and travel survey background statistics ($n = 78$)

Variables	Statistics
Responses across offices	Office location 1: 27 (35%) Office location 2: 22 (28%) Office location 3: 21 (27%) Office location 4: 4 (5%) Office location 5: 3 (4%) Office location 6: 1 (1%)
Gender	Female: 39 (50%) Male: 39 (50%)
Age	18–24: 3 (4%) 25–34: 26 (33%) 35–44: 28 (36%) 45–54: 11 (14%) 55–64: 8 (10%) Prefer not to say: 2 (3%)
Highest education completed	Bachelor's degree: 11 (13%) Master's degree: 48 (62%) Doctoral degree: 18 (23%) Other: 1 (1%) Prefer not to say: 1 (1%)
Duration of employment	0–1 year: 22 (28%) 2–4 years: 24 (31%) 5–10 years: 19 (24%) 10+ years: 13 (17%)

Appendix C. Survey questions

Background questions:

1. Gender
   a. Female
   b. Male
   c. Other
   d. Prefer not to say
2. Age
   a. Under 18
   b. 18–24
   c. 25–34
   d. 45–54
   e. 55–64
   f. Age 65 and older
   g. Prefer not to say
3. Highest education completed
   a. Bachelor's degree
   b. Master's degree
   c. Doctoral degree
   d. Prefer not to say
   e. Other
4. Employing office
   [interviewee could select one of the different offices where the organization is located].
5. Duration of employment until now

a. 0–1 year
b. 2–4 years
c. 5–10 years
d. 10+ years
e. Prefer not to say

6. Status of employment/Working time
[e.g. 70% or 100%, without the percentage “%” character].

Questions related to commuting emissions:

7. What is the primary mode of transport you take to work (on a typical day)?
   a. Single occupant car (driving alone)
   b. Car share (e.g. with family)
   c. Carpooling (service)
   d. Bicycle
   e. Electric bicycle
   f. Train
   g. Tram/subway
   h. Bus
   i. Local public transport (if e.g. bus + subway or walk + tram)
   j. Moped/Scooter
   k. Walk/Run
   l. Motorcycle
   m. Taxi
   n. I mostly work from home/0 days a week at the office
   o. Other
8. Please estimate the daily distance used to travel with the primary mode of transport (home–office–home) (kilometers/day). If you previously answered “I mostly do home office”, put 0 here.
9. Please estimate the average number of trips (1 trip = home–office–home) per week. If you previously answered “I mostly work from home”, put 0 here.
10. Please provide some of the main reasons for choosing your primary mode of transport
11. In case you did not choose a car as your primary mode of transport, you can skip to question 14. If you chose a car as your primary mode of transport, please specify the type of fuel used.
   a. Petrol
   b. Diesel
   c. Electric
   d. Hybrid
   e. Not applicable
   f. Other
12. In case you did not choose a car as your primary mode of transport, you can skip to question 14. If you chose a car as your primary form of transport, please estimate the production year of the car.
   a. 1992 or older
   b. 1996–1999
   c. 2000–2004
   d. 2005–2008
   e. 2009–2013
   f. 2014 or newer
   g. Not applicable
13. In case you did not choose a car as your primary mode of transport, you can skip to question 14. If you chose a car as your primary form of transport, please estimate the size of engine/car. Detailed evaluation is not necessary here.
   a. Small
   b. Medium
   c. Large
   d. Not applicable
14. On average, how much time do you spend daily commuting to work (home–office–home)?
   a. less than 15 min
   b. 15–30 min
   c. 31–60 min
   d. more than 60 min
   e. Home office
15. How much money do you spend on your weekly commute?
   a. Basically none
   b. less than €10
   c. €11–25
   d. €26–50
   e. €51–100

f. more than €100
g. Home office

16. Which one of these vehicles would you most likely use to commute to work if you didn't have money, time or other limitations?
    a. Car
    b. Car pooling
    c. Bus
    d. Train
    e. Tram/Subway
    f. Bicycle
    g. Electric bicycle
    h. Walk/Run
    i. Moped/Scooter/Motorcycle
    j. Other
17. What are the main obstacles you face (if any) in choosing your most appealing commuting option?
    a. Time
    b. Money
    c. Convenience
    d. Physical health
    e. Distance from home to office
    f. Lack of options/knowledge
    g. No obstacles
    h. Other
18. Can you think of any ways how [name of organization] could support you in choosing a more sustainable commuting option?
19. What is your most common mode of transportation for international work travel?
    a. Plane
    b. Train
    c. Bus
    d. Car
    e. Ferry
    f. No travel experience so far
    g. Other
20. What is your most common mode of transportation for national work travel?
    a. Plane
    b. Train
    c. Bus
    d. Car
    e. Ferry
    f. No travel experience so far
    g. Other
21. If you don't have work travel experience (national or international) by plane or car, you can skip to question 27. Think about the most recent long-distance (>200 km) work trips you took by plane or car. Do you think it could have been possible to avoid travelling?
    a. Yes
    b. No
    c. Not applicable
22. Please justify your answer. Why was it/was it not possible?
23. If you don't have work travel experience (national or international) by plane or car, you can skip to question 27. Think about the most recent long-distance (>200 km) work trips you took by plane or car. Do you think it would have been possible to use another mode of transportation?
    a. Yes
    b. No
    c. Not applicable
24. Please justify your answer. Why was it/was it not possible?
25. If you don't have work travel experience (national or international) by plane or car, you can skip to question 27. Think about the most recent long-distance (>200 km) work trip you took by plane or car. Did you compensate for the emissions of the trip (e.g. by paying a carbon offsetting fee)?
    a. Yes
    b. No
    c. Not applicable
26. Why did you/did you not compensate for the emissions of the trip?
27. What are the barriers you face with [name of organization] and travel agency's policies and practices, which make it difficult for you to make environmentally sustainable choices?
28. Please state your opinion on the following statements. Remember that the following statements are only related to work travelling.
    [Strongly Disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree, NA]
    a. Virtual communication methods do NOT generally provide a good alternative to physical "face-to-face" meetings
    b. I carefully consider the purpose of each trip before making the travel decision
    c. I have chosen not to fly even though flying would have been quicker or cheaper
    d. I have chosen not to fly even though flying would have benefited my work

e. It would be difficult for me to carry out my work/research if I did not fly
f. From a general perspective (not the organization perspective), flying less would negatively affect my career prospects
g. In most cases, I am expected to be physically present by the organization or other collaborators

29. Please state your opinion on the following statements
    [Strongly Disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree, NA]
    a. As an employee of [name of the organization], I would be ready to reduce flying even if it meant fewer meetings, conferences, international collaborations etc.
    b. I would be interested in voluntarily reporting and getting feedback about my work-related carbon footprint
    c. Support from the organization in terms of being flexible about the increased journey time would encourage me to use land travelling options
30. As an employee of [Organization name], I would be ready to switch air travel to land travel even if it meant…
    a. 0–2 h more travel time (compared to flight)
    b. 3–6 h more travel time (compared to flight)
    c. 7–10 h more travel time (compared to flight)
    d. 11–15 h more travel time (compared to flight)
    e. 1–2 days of travelling
31. What are the main BARRIERS of land travel in your opinion (compared to air travel)?
    a. Time
    b. Price
    c. Flexibility
    d. Services during travel
    e. Comfort while travelling
    f. Complexity of booking tickets
    g. Transfers during the trip
    h. Reliability of schedules
    i. Ease of working while travelling
    j. Baggage allowance
    k. No barriers
    l. Other
32. What are the main BENEFITS of land travel in your opinion (compared to air travel)?
    a. Time
    b. Price
    c. Flexibility
    d. Services during travel
    e. Comfort while travelling
    f. Reliability of schedules
    g. Ease of working while travelling
    h. Easier transitions in the departure and arrival destinations (center to center vs. airport to airport)
    i. Chance to enjoy landscapes and views
    j. Baggage allowance
    k. Environmental sustainability
    l. No benefits
    m. Other
33. Here you can provide any additional comments and feedback you might have about the survey.

Appendix D. Commuting and travel survey regression models

To assess the extent to which individual sociological characteristics affect travel and transport choices and emissions, two regression models were run:

1. The first model aimed to capture any significant statistical relationship occurring between employees' commuting transport choices and a series of independent variables. Due to the nature of the dependent variable (ordered categories), this relationship was explored using an ordered logit regression and quantified using relative odds ratios.
2. The second model captures the effect on the employees' willingness to reduce work-related flights of a series of sociological characteristics (as above) and additional employee perceptions.

The list of the dependent and independent variables of both models are reported in the table below. Backward stepwise regression analyses were used to find the most parsimonious model with each outcome. Model results were tested for normality (OLS) and collinearity. All analyses were performed using the programming software R (R Core Team, 2020).

Model	Dependent variable	Independent variables
1. Drivers of employees' community transport choices (Ordered logit model)	Commuting mode carbon footprint (question 7), recategorized as follows: Home office = 0; Walk/Run =1, bicycle = 2; electric bicycle = 3;	Gender (q.1); age (q.2); education (q.3); Office location (q.4); employment duration (q.5); commuting distance (q.8); number of

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(*continued*)

Model	Dependent variable	Independent variables
	Train, Tram/subway, Bus, and Local public transport = 4; moped, Motorcycle = 5; car share, Carpooling = 6; Single occupant car =7[a]	commuting trips (q.9); commuting time (q.14); total number of obstacles while commuting (q.17).
2. Drivers of employees' willingness to reduce work-related flights	Willingness to reduce work-related flights, quantified as follows: Strongly Disagree = −2, Disagree = −1, Neither agree nor disagree =0, Agree =1, Strongly agree = 2 (q.29: *As an employee of [name of the organization], I would be ready to reduce flying even if it meant fewer meetings, conferences, international collaborations* etc.)	Gender (q.1); age (q.2); education (q.3); Office location (q.4); employment duration (q.5); virtual communication tools acceptance (q.28); consideration of trip purpose (q.28); chosen not to fly even if quicker/cheaper (q.28); chosen not to fly even if would have benefitted work (q.28); difficult to carry out work/research without flying (q.28); impact on career prospects (q.28); expected to be physically present (q.28); report work related carbon footprint (q.29); flexible support from the organization (q.29); barriers of land travel (q.31); benefits of land travel (q.32).

[a] For respondents choosing hybrid options (e.g. walking and bus), only the means of transport with the highest pollution potential was chosen.

The full results of both regression models are hereby reported:

Results of the ordered logit regression model on drivers of employees' community transport choices.

Explanatory variable	Model coefficient	t value	Odds ratio	95% CI	p(>|t|)
Spanish office	−1.956	−3.361	0.14	0.04; 0.43	<0.001 ***
German office	−1.866	−3.231	0.16	0.05; 0.47	<0.001 ***
Commuting distance	0.073	3.711	1.08	1.04; 1.12	<0.001 ***
Number of commuting trips	0.196	1.484	1.22	0.94; 1.59	0.137
Obstacles while commuting	0.384	1.603	1.47	0.92; 2.38	0.109
Cut = 1[a]	−2.740	−3.116	–	–	<0.001 ***
Cut = 2[a]	−1.095	−1.345	–	–	0.178
Cut = 3[a]	0.801	0.998	–	–	0.318
Cut = 4[a]	1.085	1.349	–	–	0.177
Cut = 5[a]	2.150	2.636	–	–	<0.001 ***
Cut = 6[a]	2.580	3.117	–	–	<0.001 ***
Cut = 7[a]	4.271	4.598	–	–	<0.001 ***

Starting AIC: 280.6; final AIC: 268.8. Significance levels: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.
Cragg and Uhler's pseudo R^2: 0.444; *d.f.:* 5 and 70.

[a] Cut points representing the different levels of the ordered logit model.

The results of the ordered logit regression model indicate that, holding all other variables constant, employees living 1 extra km/day further away from the office location have 8% higher odds of choosing a more polluting commuting mode ($p < 0.001$). Additionally, this model shows an effect of different office locations on individual commuting transport choices, with the odds of an employee choosing a more polluting commuting mode being 86% and 84% lower when employees belong to the Spanish ($p < 0.001$) and German offices ($p < 0.001$) with respect to the baseline (Finnish office).

Results of the multiple regression model 2 on Drivers of employees' willingness to reduce work-related flights.

Independent variable	Estimate	SE	*t* value	p(>|t|)
Intercept	0.151	0.557	0.271	0.788
Education [Master's degree]	0.728	0.398	1.828	0.075
Education [Doctoral degree]	0.303	0.422	0.719	0.476
Employment duration	0.186	0.118	1.577	0.122
Virtual comm. Tools acceptance	−0.258	0.101	−2.554	0.014*
Consideration of trip purpose	−0.204	0.136	−1.499	0.141
Chosen not to fly even if would have benefitted work	0.375	0.123	3.064	0.004**
Flexible support from the organization	0.269	0.091	2.974	0.005**

Starting AIC: 132.1; final AIC: 119.0. Significance levels: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.
R^2: 0.566; d.f.: 7 and 41.

The regression model performed shows that employees who have a negative view of virtual communication tools ($p = 0.014$) tend to be more reluctant to reduce work-related flights. Conversely, employees who have rejected flying when they had the possibility ($p = 0.004$) and value organizational flexibility regarding longer but sustainable journeys ($p = 0.005$) are more willing to reduce work-related flights.

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III

A PLANETARY WELL-BEING ACCOUNTING SYSTEM FOR ORGANIZATIONS

by

Sami El Geneidy & Janne S. Kotiaho, 2023.

In Elo, M., Hytönen, J., Karkulehto, S., Kortetmäki, T., Kotiaho, J.S., Puurtinen, M., & Salo, M. (Eds.). Interdisciplinary Perspectives on Planetary Well-Being (1st ed.)

Routledge

https://doi.org/10.4324/9781003334002

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A PLANETARY WELL-BEING ACCOUNTING SYSTEM FOR ORGANIZATIONS

Sami El Geneidy and Janne S. Kotiaho

Introduction

Unsustainable land use and overexploitation of natural resources to produce the consumables necessary to satisfy the needs and desires of humankind has compromised ecosystem integrity to a degree that in many places ecosystems are losing their ability to support the diversity of life (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2018; Willemen *et al.*, 2020). Incremental changes in our production and consumption practices are unlikely to alleviate this state of affairs (Díaz *et al.*, 2019; IPBES, 2019), and we need to figure out ways to make considerable, even transformative changes that truly support the transition towards planetary well-being (Kortetmäki *et al.*, 2021).

We humans organize our everyday lives through organizations, be they private businesses or public services such as hospitals or education institutions. To understand organizations' role in enhancing or diminishing planetary well-being, we need to be able to identify and quantify the environmental impacts (*e.g.*, greenhouse gas emissions or biodiversity loss) their operations are causing. Although vital, such understanding alone is unlikely to facilitate the necessary transformative changes in production and consumption practices. Therefore, we argue here that a value-transforming integration of financial and environmental accounting and reporting is critical for ensuring that the environmental impacts really influence the management decisions of organizations.

As Schaltegger and Burritt (2000, p. 21) put it:

> Conventional financial accounting provides the most important information management system for any company because it links all company activities with performance and expresses these in the form of a single unit

DOI: 10.4324/9781003334002-21

of account—money—which can be used as a basis for comparing available alternatives.

Financial accounting is generally recognized to be an objective information management system, but we often fail to notice how much power it actually holds in creating the premises and boundaries of an organization. It is the financial accounts that, for example, define what are included or excluded in assets and liabilities and how profit and loss are calculated, which consequently defines the size, health, structure, and performance of the organization (Hines, 1988). We do not dispute the usefulness of the conventional financial accounting. However, we do note that the convention of only including information related to flows of money neglects the more complex web of impacts organizations have on society and the environment, both of which are not customarily expressed as money within the boundaries of the organization. Indeed, conventional financial accounting has largely failed to steer organizations towards environmentally and societally sustainable decision-making (Laine *et al.*, 2020; Maas, Schaltegger and Crutzen, 2016; Nicholls, 2020; Veldman and Jansson, 2020).

Environmental accounting has been developed to make visible the impacts an organization has on the environment (Bracci and Maran, 2013; Schaltegger and Burritt, 2000; Unerman, Bebbington and O'dwyer, 2018). In their review on the history of academic work on environmental accounting, Russell, Milne, and Dey (2017) explain that before the 1990s the focus was on extending accounting systems so that traditional accounts could include environmental impacts beyond market transactions. Dominant themes were identifying, measuring, counting, and ultimately monetizing environmental costs and benefits, and then drawing them into the conventional financial accounts of organizations. Russell, Milne, and Dey (*ibid.*) make the observation that during the past two decades this stream of scholarly investigation has dwindled, and that monetizing the environment in financial accounts has not caught on. The case today is still that financial decision-making does not value negative or positive environmental impacts (Nedopil, 2022). Nevertheless, monetizing nature, despite widespread criticism of the notion (*e.g.*, Redford and Adams, 2009; Spash, 2015), appears to be a growing practice (Russell, Milne and Dey, 2017), with at least about 100 different solutions applied across the world (Hein, Miller and De Groot, 2013; Kotiaho *et al.*, 2016; Nedopil, 2022).

Environmental and social issues are profoundly complex; so too is the matter of accounting for them (Gray, 2001). Therefore, it is unsurprising that we have faced serious challenges when attempting to integrate environmental and social, never mind sustainability, impacts into conventional financial accounting. Predominantly the challenges seem to relate to issues of whether such impacts can be quantified (Gray, 2010; Norman and MacDonald, 2004; Pava, 2007). For example, Norman and MacDonald (2004) considered it to be a specious promise that we could ever measure, calculate, audit and report an organizations environmental and social performance with the same rigour and detail as we can disclose its financial performance.

Although scholarly efforts to integrate environmental accounts with financial ones may have dwindled (Russell, Milne and Dey, 2017), non-financial disclosures and environmental accounts have become increasingly common. However, there is ample evidence that such non-financial environmental accounting remains isolated within organizations, and that even when it is included in reporting, it commonly remains unexploited in management decisions (Bracci and Maran, 2013; Maas, Schaltegger and Crutzen, 2016; Saravanamuthu, 2004; Veldman and Jansson, 2020). This observation indicates that simply mainstreaming environmental accounting across organizations is not enough. We think that a deep value-transforming integration of financial and environmental accounting is required to ensure that the disclosed environmental impacts capture the attention of the senior executives of the organizations. In other words, the depth of the integration needs to be such that the environmental accounts actually transform the value of the financial accounts.

Recently, Nicholls (2020) proposed that integrating financial, environmental, and social accounting should be a public policy solution. Before public policy can be implemented, however, some capacity building regarding how such integration might be done in practice is still needed. Although several methodologies towards integration of financial and environmental accounting have been developed (Maas, Schaltegger and Crutzen, 2016; Vallišová, Černá and Hinke, 2018; Veldman and Jansson, 2020; empirical case studies: Alvarez, Blanquer and Rubio, 2014; Larsen *et al.*, 2013; Thurston and Eckelman, 2011), generalized applications for the integration remain scarce. This is especially the case for applications that highlight environmental impacts by transforming the value of the financial accounts at the organization level.

Here we will first focus on how environmental impacts can be identified and quantified by utilizing financial accounts and environmentally extended input-output databases. Our perspective is slightly different from previous attempts to integrate environmental and financial accounts (Russell, Milne and Dey, 2017) in that initially we do not directly monetize nature. Rather, we quantify the environmental impacts (*e.g.*, biodiversity loss) caused by the money spent in an organization and thus disclose its environmental performance through the financial accounts.

What should be noted, however, is that even when the environmental impacts are disclosed through the financial accounts (and thus, in principle, the environmental impacts are indirectly monetized), the disclosure itself does not transform the value of the financial accounts. To facilitate value transformation, which we consider to be critical for ensuring that the environmental impacts really influence the management decisions, we need to create money-based incentives for the senior executives. We believe that executives will pay attention when causing environmental damage costs money (or enhancing the state of the environment pays off) and will consequently begin to avoid and reduce the negative environmental impacts of their organizations and thus support the transition towards planetary well-being. Therefore, in the proposed planetary well-being accounting system we will include an example in which biodiversity offsetting is used to concretely transform the value of the financial accounts. Noting that the financial performance of organizations is communicated through impact statements and balance sheets, we suggest that reporting as well should be developed towards integrated financial-environmental impact statements.

Integrating financial and environmental accounting

Conventional financial accounting is an efficient system with respect to what it was made for: Tracking the financial flows of consumption (expenses and investments) and production (sales and revenue) within an organization. In other words, anything an organization consumes and produces should be visible in its financial accounts and all of its operations are at least indirectly touched upon by financial accounting. Therefore, financial accounts provide a promising platform for a deep value-transforming integration of financial and environmental accounts.

Integrating financial and environmental accounting basically requires that when an organization accounts for the impacts of its financial transactions, it should simultaneously account for the environmental impacts associated with those transactions. While the financial accounts might hold information about the price and type of a good or service, additional tools and information are needed to quantify the environmental impacts because they are currently not visible in conventional financial transactions. What is in particular needed is detailed information about the identity of products and services, which is not always readily available in current financial accounts. Thus, development work regarding what kind of information is reported in financial accounts, and particularly in receipts of transactions, needs to be undertaken so that information allowing the environmental impacts to be quantified becomes available. Information about the physical quantities and specific types of goods and services is vital for quantitative environmental accounting. What would help the process would be to require producers in all the steps of the supply chain to report on the environmental impacts of the goods and services they provide, so that the same information can be used further along the supply chain when the products are consumed by other organizations or end users.

Negative environmental impacts can be quantified in various ways but two methodologies stand out in the context of assessing environmental impacts of organizations: Environmentally extended input-output analysis (EEIOA) and life cycle assessment (LCA). Similar to any methodology, the accounts need first to be identified, meaning it needs to be determined what kinds of products or services the financial transactions in the accounts refer to. As already stated, the current financial accounting and reporting system does not necessarily need detailed information about the products and services, and therefore, in some cases, this identification is difficult or even impossible to complete (Bracci and Maran, 2013). After the account identification, a suitable methodology for the assessment of each account's environmental impact can be chosen, based on whether the transactions of the specific account can best be quantified in terms of financial or physical units.

Generally, environmental impacts of financial accounts can be assessed by using EEIO databases, such as EXIOBASE, Eora, GTAP, and WIOD (for an introduction to the techniques, see Kitzes, 2013; Leontief 1970). For example, the biodiversity impact of procured information technology supplies can be assessed through an EEIO database by converting the unit of money spent in an organization (situated in a given country) into square meters of land used (in different ecosystems in different regions of the world) to produce the supplies. Land use can then be further converted into biodiversity impacts by utilizing another, for example LC-Impact, database (Verones *et al.*, 2020; El Geneidy *et al.*, 2021a,b; El Geneidy, Baumeister and Kotiaho, n.d.).

While EEIO operates predominantly on financial transactions, LCA databases, such as ecoinvent, LCA Commons and ELCD, can be used to assess the environmental impacts of different goods based on their physical consumption. An example of physical consumption better amenable to LCA than to EEIO methodology is the amount of megawatt hours of electricity consumed by an organization. More generally, physical consumption information about travel- and energy-related accounts is often readily available (El Geneidy *et al.*, 2021b; Larsen *et al.*, 2013), and consequently LCA-based approaches are more likely to deliver accurate results on environmental impacts than utilization of EEIO-based approaches on financial transactions alone.

A hybrid EEIO-LCA approach combines the strengths of both methodologies (Crawford *et al.*, 2018; Suh *et al.*, 2004; for applications see *e.g.*, El Geneidy *et al.*, 2021b; Larsen *et al.*, 2013; Marques *et al.*, 2017), and it may be that in the future we will see a stronger merger of the two approaches. It is worth noting that the process can be easily automated after the initial link between financial and environmental accounts has been constructed.

Even though the methodologies for assessing environmental impacts through both financial and physical consumption are already relatively well understood, from a practitioner's point of view the methods for utilizing financial accounts to calculate the environmental impacts of an organization are not yet readily available. In addition, information, especially about environmental impacts of physical consumption of goods, is in many cases still lacking, and this information is generally a prerequisite for LCA-based approaches. Also, while EEIO methodologies allow analysis of environmental impacts of different consumption sectors, they often cannot yet differentiate between two or more different products of the same sector (Stadler *et al.*, 2018).

Outlining financial-environmental impact statements

Once the the link between financial and environmental accounts has been established, we can start developing a financial-environmental impact statement. These can then be utilized to communicate the financial as well as environmental performance of the organization to the management of the organization, to other decision-makers such as investors, and to stakeholders such as non-governmental organizations.

In financial accounting, relevant information is generally compiled in an income (or impact) statement and a balance sheet. An income statement describes the performance of an organization over a certain period with key figures such as revenue and expenses (Chen, 2022). A balance sheet on the other hand shows the assets and liabilities of an organization at a specific point of time, that is, what the organization owns and owes (Fernando, 2022). Here we use the income statement as a model because, after scrutinizing both, we concluded that it is the impact statement that contains most of the information needed for accounting the negative environmental impacts of an organization. Nevertheless, in the future it might also be useful to develop a balance sheet to allow accounting of the cumulative negative and positive environmental impacts the operations of an organization cause. Current financial impact statements only capture the flows of produced capital, but as Dasgupta (2021) has argued, we need to shift towards a system where the impact statement of an organization also captures the flows of natural capital (as well as human capital, which is not in the scope of the current chapter). In Table 15.1 we present an outline of the potential content of the financial-environmental impact statement following the guidelines of the International Financial Reporting Standards (IFRS) on the contents of a conventional financial income statement.

In Figure 15.1 we illustrate the overall idea of how natural capital is utilized and passed from one organization to another to create human and produced capital.

TABLE 15.1 Potential content for the financial-environmental impact statement of an organization

	Financial impact	*Environmental impact*
Sales/downstream impact	Sales from operations	Negative and/or positive environmental impacts of the goods and services produced
Expenses/upstream impact	Expenses from operations	Negative environmental impacts of the goods and services consumed
Offsets	Financial value of offsets used to balance the negative environmental impacts	The quantity of offsets procured to balance the negative environmental impacts
Net impact	The net income (sales – expenses – offsets)	The net environmental impact (negative impacts – offsets)

We have included expenses from offsets to transform the value of the financial accounts. It is almost certain that even after careful avoidance of emissions and ecosystem degradation, not all negative environmental impacts can be evaded and hence organizations aiming for carbon neutrality and/or no net loss of biodiversity will have to resort to purchasing offsets.

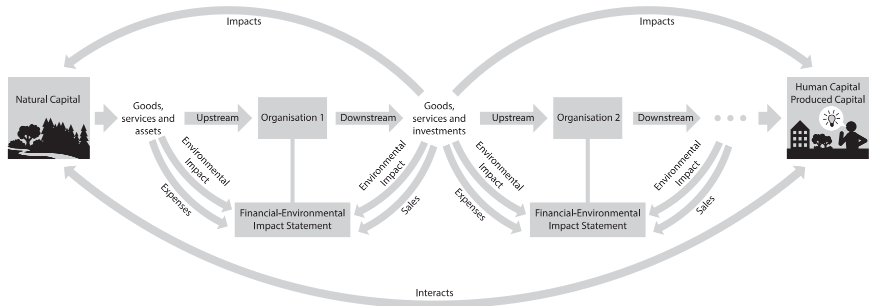

FIGURE 15.1 Visualization of financial and environmental flows relevant for the financial-environmental impact statement of an organization.

Assets any organization uses are called capital goods and have been classified into three different categories: Natural, human, and produced capital (*e.g.*, Dasgupta, 2021). Natural capital is directly consumed as upstream goods and services in Organization 1, which are in turn transformed and sold as downstream goods and services to Organization 2 or used to create produced capital. From the perspective of Organization 2, goods and services from Organization 1 are upstream goods and services that are again transformed and used further along the supply chain as different products and services. Consuming natural capital to create produced capital generally has a negative impact on the environment either by causing emissions or reducing biodiversity. Organizations can also procure assets from natural capital or provide investments to other organizations or to produced capital. Finally, the goods and services satisfy the needs of organizations or individuals and contribute to human and produced capital, which in turn can interact with natural capital.

Concluding remarks: The imperative of transforming financial value

If environmental information is not afforded the same value as financial information in decision-making, it can easily be ignored. In such situations the integration of financial and environmental accounting and reporting will not be sufficient to transform the operations of organizations and organizations will not become sensitive to the influence they have on planetary well-being. Indeed, our main thesis throughout this chapter has been that to truly make a difference in decision-making, environmental impacts uncovered by the integration of financial and environmental accounting and reporting need to transform the financial value.

Some initiatives are already piloting the financial valuation of environmental impacts, for example the so-called environmental profit and loss accounts (Høst-Madsen *et al.*, 2014; Schmidt and de Saxcé, 2016) and the social cost of carbon approach (Nordhaus, 2017). However, the valuation has not been deeply integrated into the financial accounts such that it would directly influence, that is transform, the financial value. The environmental information has generally been presented only as additional information alongside conventional financial information (Nicholls, 2020). In the worst cases such reporting has been used to exploit the concept of sustainability to back up the dominant financial discourses of development and growth (Zappettini and Unerman, 2016).

It may be that integrating environmental and financial accounting, and especially transforming financial value based on environmental impacts, is an issue that is best tackled by public policy (Nicholls, 2020). Important steps towards this goal have already been taken, for instance in the European Union (EU) with the adoption of the Corporate Sustainability Reporting Directive (CSRD) which builds upon an earlier Non-Financial Reporting Directive (Council of the EU, 2022a). In addition, the EU aims to scale up sustainable investments by classifying the sustainability criteria of economic activities for investors (European Commission, 2022a). While the EU taxonomy will include mandatory reporting requirements (connecting to the CSRD), it is up to the businesses to decide whether they want to apply for eligibility within the investment regime, and up to investors to decide whether they want to direct investments based on sustainability criteria. That said the possible adoption of a carbon border adjustment mechanism that puts a tax on certain goods imported to the EU based on their assessed climate impact (Council of the EU, 2022b) will also influence the financial accounting values of supply chains in organizations. Furthermore, some progressive corporations and financial institutions are actually calling for governments of the world to legislate mandatory disclosure of nature-related impacts and dependencies for businesses (Business for Nature, Capitals Coalition and CDP, 2022). Unfortunately, it seems that the current political initiatives aim to entrench the existing trend of environmental accounting as a separate aspect of corporate reporting, and we do not yet see any meaningful steps towards value-transforming integrated financial and environmental accounting.

As the value-transforming integration of financial and environmental accounting outlined here can be replicated in any organization with standardized financial accounts, we conclude that such integration offers a platform that could be used to initiate a truly transformative change in the management of organizations, one that supports the transition towards planetary well-being. We note, however, that the mere existence of the platform does not guarantee that the integrated reporting or the value transformation will be adopted by organizations. Indeed, there is evidence that voluntary reporting is not as effective as mandatory reporting (Crawford and Williams, 2010; see also Gray, 2001; Hess, 2007; Koehler, 2007; Wu and Babcock, 1999), and that value-transforming economic instruments to protect biodiversity, including biodiversity offset programs, do not and cannot operate without robust regulation and state involvement (Boisvert, 2015; Koh, Hahn and Boonstra, 2019; Koh, Hahn and Ituarte-Lima, 2017; Kujala *et al.*, 2022; Vatn, 2015). Therefore, we adopt the view that strong public oversight might be needed and offer two suggestions. First, make the integration of financial and environmental accounting mandatory for all organizations with financial disclosure obligations. Second, make the environmental impacts salient to the senior executives of the organizations by transforming the value of financial accounts on the basis of environmental impacts. This can be done for example by introducing mandatory biodiversity offsetting schemes (see *e.g.*, Moilanen and Kotiaho, 2018, 2021), new environmental protection taxes and subsidies, or some other instruments that have the potential to transform the value of the financial accounts. Perhaps it is worth noting that we are currently witnessing a shift away from policies that use offsets to balance environmental impacts, and moving towards political interventions that aim for net positive environmental impacts (Leclère *et al.*, 2020; Moilanen and Kotiaho, 2021; the Convention on Biological Diversity (CBD), 2022).

In this chapter, we focused exclusively on the integration of financial and environmental accounting. With a methodology analogous to the one outlined here for the accounting of environmental impacts of organizations, it might be possible to begin to quantitatively account at least some of the social impacts of the financial accounts of organizations. Quantitative accounting of both environmental and social impacts of financial accounts would be in line with the current political development in the EU towards a Corporate Sustainability Due Diligence Directive (European Commission, 2022b). Whether mechanisms such as offsets or taxes and subsidies can be innovated to transform the value of the financial accounts based on social impact accounts remains to be seen. Although we think the deep value-transforming integration of environmental accounts with financial accounts as outlined here is a critical step forward, the integration of social impacts and human capital is also needed. Once this step is taken, we may be close to a truly transformative planetary well-being accounting system.

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IV

VALUE-TRANSFORMING FINANCIAL, CARBON AND BIODIVERSITY FOOTPRINT ACCOUNTING

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Preprint at arXiv:2309.14186 [econ.GN]

https://doi.org/10.48550/arXiv.2309.14186

Value-transforming financial, carbon and biodiversity footprint accounting

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Abstract

Transformative changes in our production and consumption habits are needed to enable the sustainability transition towards carbon neutrality, no net loss of biodiversity, and planetary well-being. Organizations are the way we humans have organized our everyday life, and much of our negative environmental impacts, also called carbon and biodiversity footprints, are caused by organizations. Here we show how the financial accounts of any organization can be exploited to develop an integrated carbon and biodiversity footprint account. As a metric we utilize spatially explicit potential global loss of species which, we argue, can be understood as the biodiversity equivalent, the utility of which for biodiversity is similar to what carbon dioxide equivalent is for climate. We provide a global Biodiversity Footprint Database that organizations, experts and researchers can use to assess consumption-based biodiversity footprints. We also argue that the current integration of financial and environmental accounting is superficial, and provide a framework for a more robust financial value-transforming accounting model. To test the methodologies, we utilized a Finnish university as a living lab. Assigning an offsetting cost to the footprints significantly altered the financial value of the organization. We believe such value-transforming accounting is needed in order to draw the attention of senior executives and investors to the negative environmental impacts of their organizations.

Main Text

Introduction

Biodiversity loss is directly driven by human land and sea use and their changes, direct exploitation of nature, climate change, pollution, and introduction of invasive alien species(1). These direct drivers result from various underlying indirect root causes such as human population dynamics, consumption patterns, trade, and governance, which are in turn underpinned by societal values and behaviours(1–3). Managing the direct drivers of biodiversity loss alone will not produce sustained outcomes sufficient to bend the curve of biodiversity loss(4, 5). Instead, we must direct our efforts to the root causes such as consumption and trade.

Everyday life and the economics of societies are organized through organizations, be they private businesses, public services, or non-governmental organizations. The negative environmental impacts of nearly any organization extend through international trade and supply chains to all over the planet(6–8). While carbon footprint assessments are abundant(9–11) and a few biodiversity footprint assessments have been attempted(12–15), we take the approach a significant step further by showing how the financial accounts of any organization, coupled with global trade databases and a spatially explicit global biodiversity footprint indicator, can be used to estimate the potential global loss of species. We argue that this indicator can be understood as the biodiversity equivalent, the utility of which for biodiversity is similar to what CO_2 equivalent is for climate. The approach we have developed here allows financial and environmental accounting to be integrated to the extent that with some adjustments to public policy(16) (e.g. taxation or mandatory offsetting of the footprints) the financial value of the accounts can be transformed based on the environmental impacts.

Financial accounting

Decision-making in organizations is ultimately guided by information obtained from financial accounts(17–21). The International Accounting Standards Board defines the objective of financial reporting to be to provide financial information to management, investors, regulators and the general public(22). Financial accounting links the company activities with performance and distils all this information into a single unit of account: money(20). Financial accounts define what are included and excluded in assets and liabilities and how profit and loss are calculated, which consequently defines the size, structure and performance of the organization(18). Unfortunately, conventional financial accounting neglects the complex web of societal and environmental impacts organizations have beyond their socially constructed, and thus only presumed, boundaries(18, 20).

In the economics literature, these neglected impacts are called externalities(23). Externalities are something that happen to a seemingly uninvolved third party, such as the environment, when actions are taken to meet the needs of the so-called true stakeholders, such as the shareholders. Conventional financial accounting overlooks environmental externalities(21, 24, 25) and is therefore ill-equipped to be conductive to the sustainability transition. To facilitate a transformative change to more sustainable production and consumption patterns in organizations, we need to reconfigure the financial accounting to internalize the environmental impacts.

Environmental accounting

Environmental accounting should be a fundamental part of organizational decision-making. Unfortunately, environmental accounting seems to remain isolated within organizations and even when it is integrated with other reporting practices like financial reports it can still remain unexploited in management decisions(17, 19, 21, 24). It has even been argued that the integrated reports of companies merely exploit the concept of sustainability in order to buttress the dominant financial discourses of development and growth(26).

Basic principles for environmental accounting have been set by several standards such as the Sustainability Reporting Standards of the Global Reporting Initiative(27) and the International Financial Reporting Standards' Sustainability Disclosure Standard(28). Some standards are set to provide guidance for specific dimensions of environmental accounting, for example the Greenhouse Gas Protocol(29) or the Natural Capital Protocol(30). In addition, the International Integrated Reporting Framework(31) has developed a framework that brings financial, social and environmental information under a single report.

The qualitative characteristics set by the different sustainability reporting frameworks somewhat align with the basic principles of conventional financial accounting standards(22, 32). However, it seems that scrutiny of the latter is still much more profound than of the former(24, 33). For management decisions to be truly conductive to sustainability transition, the scrutiny of the two should be equal(19).

Integrating financial and environmental accounting and the results from the living lab

To integrate financial and environmental accounts we developed a five-step framework for value-transforming integrated financial-environmental accounting that can be replicated in any organization with financial accounts. We will focus on how environmental impacts, more specifically carbon and biodiversity footprints, can be estimated, communicated and prioritized by utilizing financial accounts. While the first steps towards integrating environmental information into financial accounts have already been taken(21, 24, 34–37), generalizable applications remain to be articulated.

We demonstrate the utility of the framework by assessing the carbon and biodiversity footprint of our living lab, the University of Jyväskylä in Finland, and construct a value-transforming integrated financial-environmental impact statement. In each step of the framework, we present general principles and then apply them to the living lab.

STEP 1: Choose the report of financial accounts

In environmental impact assessment through financial accounts, the boundaries of the assessment are set by the financial accounts. Thus, the first step is to choose an appropriate report of the financial accounts. Since we are interested in the environmental impacts of consumption, we focus on financial expenses exclusively and disregard revenues and other financial flows. The revenue of the organization might be of interest, however, if the analysis is expanded to consider handprints, that is, potential positive environmental impacts(38) that the organization produces. Some expenses are deemed not relevant regarding environmental impacts, for example staff salaries.

Reports with varying level of detail can be produced from the financial accounts. While a more detailed financial report might reduce error and provide more granulated data, using a more cursory financial report can limit the necessary work, especially during the harmonization of accounts (step 3), and makes future automated annual calculation more feasible. The most important consideration is that the chosen report provides account classification that retains enough detail to remain fit for the purpose. A typical financial impact statement where expenses are provided in very broad categories, for example in materials and services, is not sufficiently detailed for the evaluation of environmental impacts.

Here we utilize financial reports of the University of Jyväskylä containing 123 different expense categories for the years 2019–2021. The reports were procured from the university administration.

STEP 2: Choose environmental accounting methods and indicators

The hybrid EEIO-LCA methodology combines environmentally extended input-output (EEIO) analysis with life cycle assessment (LCA) and can be utilized to account the environmental impacts of organizations(36, 39–41). For this paper, it is enough to state that EEIO analysis connects the inputs an organization needs (measured as financial consumption revealed by the financial reports) with the environmental impacts of those inputs upstream in the supply chain. For certain financial accounts, such as energy and travel-related accounts, the LCA can reveal the environmental impacts more accurately by utilizing process-based impact factors obtained from service providers or from scientific literature. Hybrid EEIO-LCA combines the strengths of EEIO analysis and LCA approaches, and we anticipate that in the future we will see a stronger merger of the two.

Of the direct drivers of biodiversity loss[3], the EEIO and LCA databases generally cover land and water use (i.e. water stress), pollution, and greenhouse gas emissions. There are several sub-categories within each of the included drivers in the databases. For example, land use is divided into several land use types. The quantity of each of the drivers alone is not sufficient for the evaluation of the biodiversity footprint. However, by further integrating the EEIO or LCA analysis with other existing databases and frameworks, such as LC-IMPACT(42) or ReCiPe(43), the quantity of the driver can be converted to biodiversity loss.

Carbon footprints are generally expressed in carbon dioxide equivalents (CO_2e). Emissions other than carbon dioxide such as methane, nitrous oxide and fluorinated gases are converted into CO_2e based on their global warming potential(44). Biodiversity footprints can be measured with several indicators(14, 45–47). We opted for the global potentially disappeared fraction of species(42) for one specific reason: as an indicator, it has desirable characteristics much like CO_2e in that it provides a common currency for measuring biodiversity loss across the planet. For this reason we refer to the indicator as biodiversity equivalent (BDe). In essence, BDe tells what fraction of the species of the world are at risk of going extinct globally if for example 1 km^2 of land is continuously exploited by a specific driver of biodiversity loss, such as land use for intensive forestry(42), in any given country. The same amount of area occupied by the same driver causes less global biodiversity loss in relatively species poor areas than what it causes in relatively species rich areas. On the other hand, if both areas experienced a loss of the same amount of BDe, this would indicate both areas experienced the same global biodiversity loss. Different species would be lost in different parts of the world, but the fraction of globally potentially lost species would be the same.
Climate change and biodiversity loss are interconnected and thus should be solved together(1, 48, 49). In this regard the methodology we describe here is convenient: As climate change is one of

the drivers of biodiversity loss, assessing the carbon footprint becomes an obligatory intermediate step when assessing the biodiversity footprint.

To assess the carbon and biodiversity footprint of the consumption of the University of Jyväskylä we utilized a hybrid EEIO-LCA methodology. We derived emission impact factors (CO_2e/€) directly from the EEIO database EXIOBASE(50), amended by some of the service providers, and the LCA methodology (SI Appendix Dataset S5, S6). To obtain spatially explicit biodiversity loss impact factors (BDe/€) we combined the EXIOBASE with the LC-IMPACT (SI Appendix Table S5, S6). We provide the full dataset in https://doi.org/10.5281/zenodo.8369650.

STEP 3: Harmonize the accounts

The categorization of the financial accounts of the organization is usually not directly compatible with the EEIO economic activity categorization, and the account categorizations must be harmonized. Determining a suitable match from the EEIO categorization for all financial accounts of the organization can be onerous but it helps when the chosen EEIO database has high sectorial detail. The harmonization can be done based on the chart of accounts containing information about all accounts in the general ledger of the organization.

There are generally two further key transformation operations needed: inflation adjustment and conversion of the purchaser prices in the financial accounts of the organization to the basic prices in the EEIO databases.

In the living lab we opted for the EEIO database EXIOBASE because it has relatively high sectorial detail, allowing the University of Jyväskylä's accounts to be harmonized with it. Inflation adjustment and price conversions were calculated according to the equations presented in the Methods section (see also SI Appendix Table S7 and Dataset S3).

STEP 4: Calculate results

For the carbon footprint assessment, the monetary consumption (€) in each of the account categories of the organization is first multiplied with the category-specific emission impact factor (CO_2e/€) derived from the EXIOBASE. Carbon footprints that have been assessed by the service providers or with the LCA methodology can be directly imported to the specific account category. The total carbon footprint is then calculated by summing across all the account categories.

The biodiversity footprint is first calculated for each driver of biodiversity loss individually by multiplying the money (€) in each of the account categories of the organization with the category-specific biodiversity footprint impact factor (BDe/€) derived from the merger of EXIOBASE and LC-IMPACT, and then by summing the biodiversity footprint across the categories within each of the three impacted ecosystem types: terrestrial, freshwater and marine ecosystem. Finally, to arrive at a single BDe value for the organization, the biodiversity footprints in different ecosystem types are merged by taking a species-weighted average of biodiversity footprints over ecosystem types (see

Methods section). The complete process flowchart depicted in Fig. 1 illustrates the sequence of the calculations.

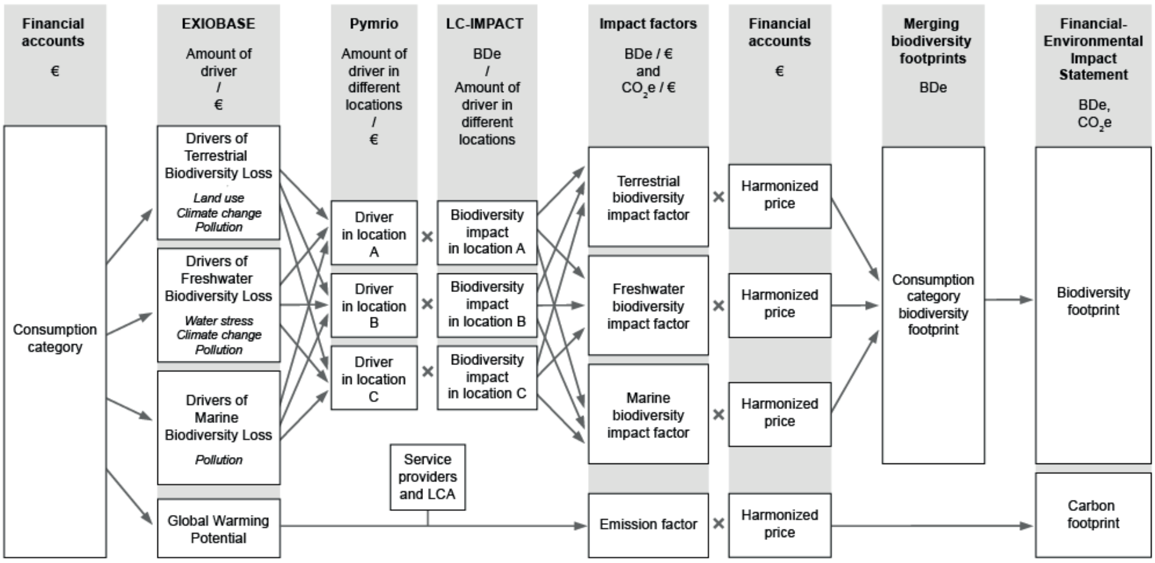

Fig. 1 | Process flowchart for calculation of the biodiversity and carbon footprints from financial accounts. Explanation of each of the steps are provided in the main text and further details for the calculations in the Methods.

To illustrate the results, we aggregated the consumption information of the University of Jyväskylä to 12 broad consumption categories and calculated the relative importance of each to carbon and biodiversity footprints (the carbon footprint and biodiversity footprints for each of the 123 accounts are tabulated in SI Appendix Dataset S4). The total annual carbon footprint decreased by 16% from 16 150 t CO_2e in 2019 to 13 570 CO_2e in 2020 (SI Appendix Table S1). Similarly, the total biodiversity footprint decreased by 19% from 4.17E-08 BDe in 2019 to 3.38 BDe in 2020 (SI Appendix Table S2). However, as biodiversity footprint is not cumulative over the years, we averaged the three years and on average 0.0000037% of the species of the world are potentially globally lost due to the operations of University of Jyväskylä, if no action is taken to reduce the pressures i.e. the consumption continues as is over time(42). The global biodiversity footprint impact factors we have calculated are provided for further research and applications in SI Appendix Datasets S1 and S2. Disaggregated results by ecosystem type can be found from SI Appendix Fig. 1 and SI Appendix Table S3.

The decrease of the total annual carbon and biodiversity footprints were both largely driven by a decrease in business travel and related services (Fig. 2a). From Fig. 2a we can also see that energy and water consumption had the highest overall carbon footprints while IT supplies, licenses and services, and machinery, equipment and supplies had the highest overall biodiversity footprints. As the chosen time interval coincides with the outbreak of the COVID-19 pandemic, some of the greatest annual variations are likely caused by signatures of the pandemic. Most obvious is the plummeting of the carbon and biodiversity footprints attributable to business travel and related services since 2019. Other clear changes are the increased footprints due to IT supplies and machinery and the decreased footprints due to food and related services. Both of these were likely caused by the increase in remote working practices due to the pandemic.

The annual share of terrestrial biodiversity footprint from land use, climate change and pollution was on average 47%, 46% and 7% respectively while the annual share of freshwater biodiversity footprint from water stress, climate change and pollution was 55%, 42% and 3%. In marine ecosystems pollution is the only driver that can currently be incorporated to the assessment (SI Appendix Table S4).

Assessing the carbon and biodiversity footprints simultaneously allowed us to see that the consumption categories had similar relative impacts on both. This similarity can be seen from Fig. 2b where we have plotted the relative carbon footprint of each consumption category against those of the relative biodiversity footprint. As was alluded to above nearly half of the biodiversity footprint was due to climate change in terrestrial and freshwater ecosystems, and therefore this similarity is easy to understand. These results illustrate that there are clear synergies to be obtained in combating climate change and biodiversity loss simultaneously. However, the disaggregated results by ecosystem type (SI Appendix Fig. S1 and Table S3) illustrate that there were also some residual impacts beyond climate change on biodiversity footprints that may need separate focus.

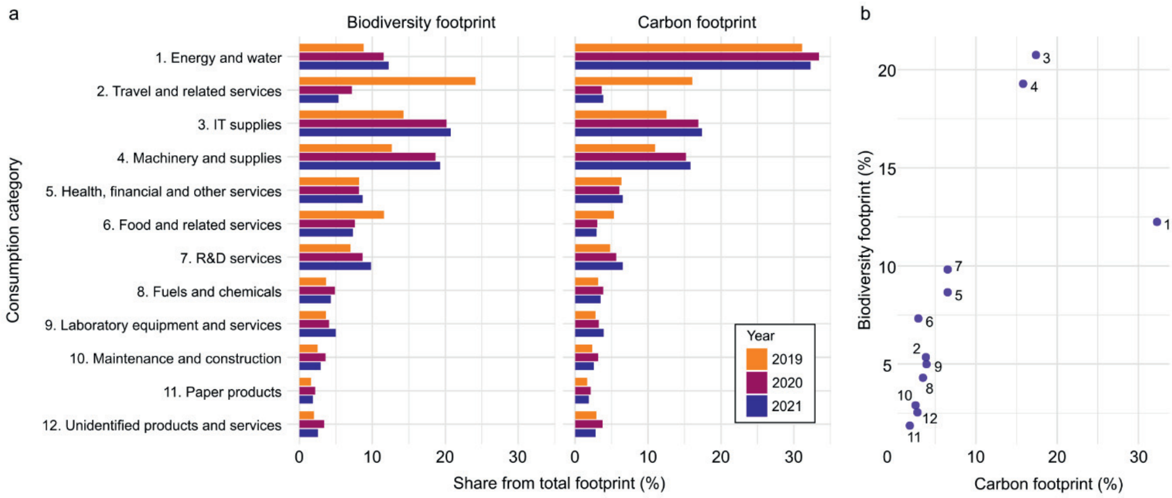

Fig. 2 | The composition of the carbon and biodiversity footprint of the University of Jyväskylä. The relative contribution (%) of different consumption categories of the University of Jyväskylän during 2019-2021 for the carbon and biodiversity footprints (**a**) and a scatterplot of the relative carbon footprint of each consumption category on the relative biodiversity footprint of the corresponding consumption category in 2021 (**b**). Small numbers in the scatter plot of panel b refer to the consumption categories in panel a.

The approach we have developed is spatially explicit (at a country level), and thus we were able to determine the geographical location of the carbon and biodiversity footprints of the University of Jyväskylä. In terms of the carbon footprint, largest share of the emissions was generated in Finland, Russia and China (Fig. 3a). Largest threats to biodiversity (Fig. 4b), can be observed in Estonia, United Arab Emirates, Palestinian Territory, Italy, Indonesia, Finland, and in several small island states (e.g. Guam and Seychelles) that cannot be distinguished from the map. It is notable that 66 % of the carbon footprint and 98 % of biodiversity footprint is situated outside of Finland. Furthermore, the data illustrates that the spatial analysis of the direct drivers of biodiversity loss produces a different outcome to the consequential global biodiversity footprint they cause (Fig. 4c-f).

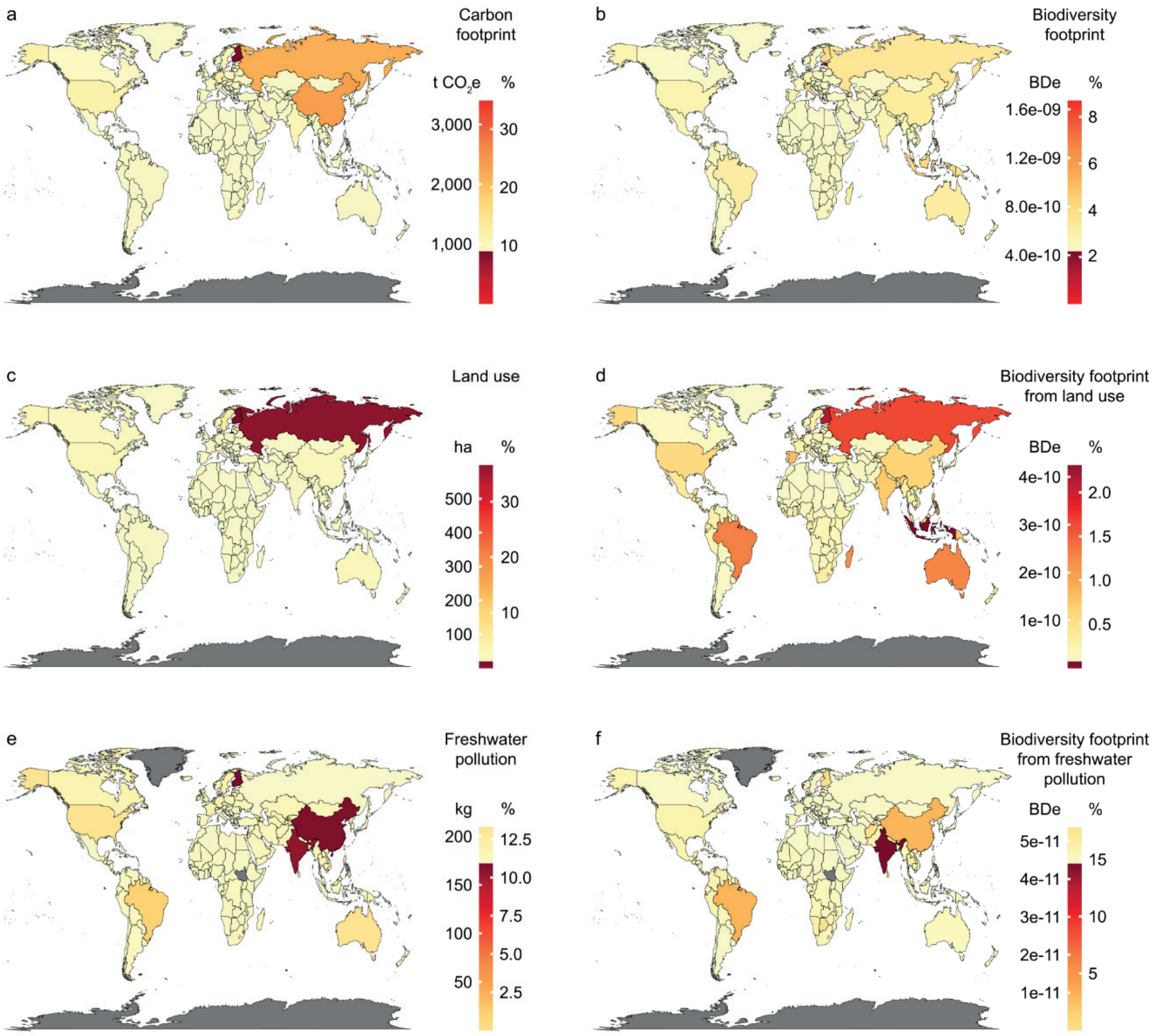

Fig. 3 | Geographical analysis of the carbon and biodiversity footprints of the University. The geographical location of the University's carbon footprint (tCO_2e) (panel a), biodiversity footprint (BDe) (panel b), land use (ha) and biodiversity footprint (BDe) due to land use (panels c and d respectively) and freshwater pollution (kg) and biodiversity footprint (BDe) due to freshwater pollution (panels e and f respectively). Small island states that are not visible in the map were excluded from the scales of the map. Although in the analysis the carbon footprint contains all greenhouse gases, in this figure, only CO_2 is depicted. Detailed data for each country, including the small island states', is provided in SI Appendix Dataset S7. Analysis was done in R.

STEP 5: Assemble the value-transforming financial-environmental impact statement

In financial accounting, the relevant information is generally compiled in an income statement and a balance sheet. For carbon and biodiversity footprint analysis it is the income statement which contains most of the information needed, that is, the incomes and expenses of the organization. The balance sheet, which contains information about the organization's assets, could be used in natural capital(34) and handprint(38) analyses, but these fall outside the scope of our current paper.

To transform the financial value, the carbon and biodiversity footprints need to have a cost that is visible in the income statement. One way to do this is to purchase offsets matching the footprints. To evaluate the offsetting cost of the carbon footprint, we used the World Bank's carbon pricing statistics for the European Union, which varied between 24.51 $/tCO2e in 2019 and 49.78 $/tCO2e in 2021(51). As no such statistics are available for biodiversity footprints, we developed one to demonstrate the idea.

As stated above, a desirable characteristic of the BDe is that it provides a common currency for measuring biodiversity loss across the planet. While we first used BDe to measure biodiversity loss due to factors like continued land use, here we reverse the logic and use the same land use biodiversity impact factors to estimate avoided loss(52), that is, the biodiversity gain achieved if the continuous exploitation is ceased for the purpose of offsetting biodiversity loss. For the sake of the example, here we only consider the biodiversity footprint in the year 2021. Potential leakage of the benefits is taken into account with a multiplier, as explained in the Methods section. Using the LC-IMPACT database, we calculated the area of land used for intensive forestry that should be permanently removed from use in Finland or in Brazil to offset the global biodiversity footprint of the University of Jyväskylä. To offset the 3.66E-08 BDe caused by the consumption of the university, altogether 574 000 or 6 800 ha should permanently be removed from intensive use in Finland or in Brazil, respectively. By multiplying the area with the average price of forest land in Finland (6524 €/ha(53)) or Brazil (901 €/ha converted from 979 $/ha(54)) (see Methods for details), we arrived at the total cost of 3 747 743 k€ in Finland or 6 117 k€ in Brazil to be transferred to the income statement. If the cost is distributed across 30 years, similar to the depreciation of large investments, the annual cost would be around 125 000 k€ if the offset was completed in Finland and 204 k€ if it was completed in Brazil.

Finally, building on earlier research(16, 34), we compiled a financial-environmental impact statement. By amending the statement with the carbon and biodiversity footprint offset values, we arrived at the value-transforming integration of financial and environmental accounts (**Error! Reference source not found.**). In financial accounts, net income is generally the deduction of expenses from revenue. By adopting the same logic, the net carbon and biodiversity footprint is the deduction of the footprints from their respective offsets. The integrated financial-environmental impact statement can be used to quickly deduce the economic and environmental position of the organization.

Table 1 | The financial-environmental impact statement of the University of Jyväskylä in 2021. As units we use thousands of euros (k€), tonnes of carbon dioxide equivalents (tCO_2e) and pico (10^{-12}) biodiversity equivalents (pBDe).

	Financial footprint (k€)	Carbon footprint (tCO_2e)	Biodiversity footprint (pBDe)
Revenue			
Government funding	148 826	-	-
Other revenue from operations	67 881	-	-
Expenses / Footprints			
Staff expenses	152 868	224	797
Depreciation	2 281	799	2 409
Grants	2 768	436	1 365
Raw materials, equipment, and goods	11 802	3984	12 008
Services	13 613	3146	12 059
Rents	25 575	4795	4 865
Travel	1 094	366	1 259
Other	9 700	747	1 887
Total Expenses / Footprints	**219 701**	**14 498**	**36 649**
Losses and Gains			
Fundraising	4 768	-	-
Investment gains and losses	31 666	-	-
Appropriation	-4 328	-	-
Internal impact pricing			
Carbon offsets	673	-14 498	-
Biodiversity offsets if in Finland	125 000	-	-36 649
Biodiversity offsets if in Brazil	204	-	-36 649
Net Income / Footprints			
Footprints without offsets	**29 112**	**14 498**	**36 649**
Footprints with offsets if in Finland	**-95 888**	**0**	**0**
Footprints with offsets if in Brazil	**28 908**	**0**	**0**

Discussion

The value-transforming integration of financial and environmental accounting presented here is motivated by the observation that environmental accounting has remained isolated and unexploited in management decisions(17, 19, 21, 24). While earlier research on linked financial and environmental accounting(16, 34–36, 55) has been pioneering, discussion about the implications of the integration for accounting itself(35–37, 41) or its wider societal importance(16, 17, 21) has remained scant. We think that extensive adoption of value-transforming integration is

essential in order to influence decision-making in organizations and to facilitate the much-needed transformative change in our production and consumption practices in support of planetary well-being(2, 56).
Adoption of the new accounting system is, however, not only a technical accounting issue; it is also a public policy issue(16). The mere existence of the framework does not guarantee that the value-transforming integration of financial and environmental accounting is adopted. Some forerunner corporations have called for mandatory assessment and disclosure of their impacts on nature(57) and mandatory reporting might indeed be a more effective strategy compared to voluntary reporting(58–61).

The introduction of mandatory offsetting is one policy intervention that would transform financial values of the accounts of the organizations. Taxes or subsidies based on the environmental footprints might be another(62), and internal pricing (or so-called internal offsetting(41)) of environmental impacts could be yet another. In internal pricing a cost is set for environmental impacts based on an agreed internal valuation scheme. The money is then placed in an internal fund to support activities that mitigate the footprint or enhance the handprint of the organization. Previously, it has been stressed that value-transforming economic instruments to protect biodiversity, including biodiversity offset programs, do not and most likely cannot operate without robust regulation and government involvement(63–67). Therefore, the value-transforming integration of financial and environmental accounting should be made mandatory for all organizations with financial disclosure obligations.

A massive 98% of the biodiversity footprint caused by the University of Jyväskylä's consumption is exported outside Finland through complex supply chains. As assessment of the biodiversity footprint of consumption is not yet mainstream, also the question of how to offset these exported biodiversity impacts has remained unexplored. We open the debate by arguing that as BDe provides a common currency for measuring biodiversity loss across the planet, it may also provide a location-independent common currency for offsetting the loss. While biodiversity is different from place to place, BDe focuses on the contribution of any activity anywhere on the planet to global species loss. As such, it measures biodiversity loss potential similarly to how the location independent CO_2e measures the global warming potential. To highlight this point, we provided a rough example of how the biodiversity footprint of the University of Jyväskylä, the majority of which is causing biodiversity loss outside Finland, could nevertheless be offset by protecting forests in Finland or in Brazil. Ideally, of course, the offsetting should be made in the countries and ecosystems where the biodiversity loss actualizes. From the global biodiversity perspective Finland is relatively species poor and much larger areas need to be protected as offsets than would be needed if the offsets were completed in relatively more species-rich areas such as in Brazil. Optimally locating the global offsets would therefore have an impact on the cost of offsetting, as our rough comparison between offsetting the biodiversity loss in Finland or Brazil clearly illustrated. Further supportive argument for the global offsetting comes from our finding that nearly half of the biodiversity footprint is actually driven by climate change, which may be challenging to offset locally.

As climate change is a major driver of biodiversity loss, it is easy to understand that the consumption categories had similar relative impacts on both. This observation is nevertheless important and confirms that environmentally informed prioritization of actions can yield synergies and thus cost savings when mitigating the negative climate and biodiversity impacts. A further interesting observation is that carbon footprint assessment is indeed an obligatory intermediate stage in biodiversity footprint assessment. Although currently the independent analysis of carbon footprints is common, we may see a merger of carbon and biodiversity footprint assessments in the future.

Setting boundaries between different organizations and how their financial-environmental impact statements might interact with each other will need some further development and conventions.

This is because the environmental impacts caused by consumption are simultaneously the environmental impacts of production along the supply chain. This is something that needs to be considered if environmental taxation, subsidies, or offsetting schemes are designed based on the value-transforming integration of financial and environmental accounting presented here. Indeed, if all organizations globally would offset their own direct footprints and transfer the cost of offsetting to the supply chain, the environmental accounting of supply chain impacts would become redundant. However, such a transformation needs time and the methodologies presented here are an important albeit perhaps only a temporary phase in our quest to stop biodiversity loss and climate change.

Materials and Methods

About the Living Lab, University of Jyväskylä

The University of Jyväskylä is a research and teaching institution that brings together education and psychology, natural sciences, humanities and social sciences, sport and health sciences, and business and economics. Finnish-language teacher education began here in 1863, and today the university is still Finland's largest teacher education provider. The university has 14 300 degree students, 2 800 staff members and 220 million euros in turnover(68).

Detailed step-by-step methods for the framework

Step 1. Choose the report of financial accounts

We selected a financial report containing 123 different expense accounts and conducted the analysis separately for three consecutive years 2019–2021. The reports of the financial accounts were procured from the university administration.

A common trait of financial accounting in organizations is depreciation value. Depreciation of goods is customarily applied on an annual basis, which means a fraction of the cost of the depreciated goods is visible in the financial accounts each year until their purchase value is zero. Depreciation accounts can be calculated annually like any other cost account, but it is worth noting that depreciation will distribute the environmental impact of the goods over several years like it does for the cost of the goods. If depreciated goods are purchased continuously across the years with approximately the same annual budget, depreciation has no great impact on the footprints of any given year.

Step 2. Choose environmental accounting methods and indicators

EEIO databases can be used to assess the environmental impacts of financial consumption. Fundamentally, input-output methodology assesses the inputs an economic sector needs to produce its goods and services and the outputs an economic sector provides to other sectors or to final consumption(69, 70). Environmentally extended input-output (EEIO) databases, such as EXIOBASE, Eora, GTAP and WIOD, connect environmental impacts, such as greenhouse gas emissions, land use and water pollution, with economic activities and transactions, thus aiming to reveal both direct and indirect environmental flows associated with downstream consumption of products and services by organizations, the public sector, households and final consumers(69, 70). One of the strengths of EEIO databases, especially in terms of biodiversity footprints, is that they allow modelling the location of supply chain environmental impacts. The impact factors of different product categories need to be extracted from the EEIO database for each country being analysed (place of consumption). For example, EXIOBASE provides readily calculated monetary impact factors for carbon footprints and for many of the direct drivers of biodiversity footprints(71). Pymrio is an open-source tool that can be used for calculating the environmental impact factors (impact/€) of some EEIO databases if the impact factors are not readily available(72). Furthermore, Pymrio can be used to analyse the location of the environmental impacts in the EEIO databases by modelling the structure of supply chains.

In the case study we used the EEIO database EXIOBASE(50) to calculate environmental impacts of financial consumption. EXIOBASE is suitable for assessing the financial accounts of organizations (as presented before(36)) because it has relatively high sectorial detail, namely, 200 different product categories (an advantage when harmonizing EEIO categories with financial accounts), and because it is open access. The latest version 3.8.2(71) was used in this study to gain access to the most up-to-date data. Nevertheless, the data utilized is derived from the year 2019 in terms of impact factors and 2011 in terms of the location of the drivers of biodiversity loss. One of the currently unavoidable downsides of EEIO databases is that the data is accumulating retroactively.

The assessment of carbon and biodiversity footprints based on financial consumption also has some other shortcomings. The categories in EXIOBASE and similar databases in general are relatively limited and only provide a snapshot of the numerous consumption activities of organizations. It is also currently not possible to distinguish between the footprints of two different products in the same sector. This will limit the possibilities for organizations to track the impact of their positive actions on the footprint, especially when actions are taken within a specific sector, for example by procuring more sustainable hardware. Nevertheless, with the currently available methodologies it is very difficult and time consuming to get accurate data about the life cycle impacts of many consumption activities, for example by using the life cycle assessment method (LCA). There is a clear need form more research on the methodologies and databases, as some recent evidence points out that LCA and EEIO databases may produce different results for the same activities(73). Even with these shortcomings, footprints derived from hybrid EEIO-LCA methodology provide valuable information on what sectors an organization should primarily focus on when mitigating its footprints.

In our living lab case, the hybrid EEIO-LCA approach meant that to calculate the carbon footprint we applied LCA approaches to obtain process-based impact factors for five accounts: electricity, heating, water, travel services and travel grants. The carbon footprint of these accounts was calculated based on non-monetary consumption information (e.g. MWh of electricity consumption by electricity generation type and kilometres travelled by different modes of transportation) collected during the preliminary screening of the footprints of the University of Jyväskylä(13, 74). The biodiversity footprint of these accounts was nevertheless calculated with the EEIO methodology because the LCA methodology does not currently offer the opportunity to determine all the environmental impacts needed for biodiversity footprint analysis or the location of the impacts in the supply chain. We used the knowledge used in the carbon footprint assessment about the share of different energy production and travel methods to enhance the accuracy of the analysis and assumed that the costs would be distributed similarly. Nevertheless, differences in calculation methodologies between carbon and biodiversity footprints could explain the differences in the relative importance of energy and water consumption footprints to the total footprint, when looking at the results.

For the carbon footprint of financial consumption, we use the indicator recommended by The International Reference Life Cycle Data System (ILCD)(75), global warming potential during a period of 100 years, which is readily available in EXIOBASE. For the carbon footprint of non-monetary consumption (energy, water, travel), we used impact factors provided by the stakeholders responsible for producing those services (SI Appendix Dataset S5 and S6). For travel grants, we calculated the emissions by utilizing the impact factor (t CO_2e/€) of travel services, which was in turn calculated with process-based impact factors.
We built the biodiversity footprint assessment on estimating the impact of the direct drivers of biodiversity loss, including land use, direct exploitation (water stress), climate change and

pollution. We combined indicators of direct drivers of biodiversity loss from EXIOBASE(50) with the LC-IMPACT life cycle assessment database(42, 76) (SI Appendix Table S5) to calculate the biodiversity footprints of financial accounts, similar to whtat has been previously done(77). The indicator of biodiversity loss in LC-IMPACT is the potentially disappeared fraction of species(42), which we describe in this paper as the biodiversity equivalent (BDe) because it has similar characteristics to the carbon dioxide equivalent indicator (CO_2e). Previous studies on the biodiversity footprints of organizations have mostly used regional indicators of biodiversity loss(12, 15, 42). While it is important to look at both regional and global species loss to cover different viewpoints on biodiversity loss(42), regionally lost species do not necessarily translate to global extinctions. Furthermore, in this context, where we have assessed global supply chains, it is important that we are able to unify the loss of species in different parts of the world under a single indicator that can be used to compare global supply chains with each other. Next, we explain the methodology for calculating the biodiversity footprint of financial accounts.

EXIOBASE contains impact factors (i.e. what is the amount of the driver of biodiversity loss per unit of consumption, such as euro) for land use, blue water consumption (water stress), pollution and greenhouse gas (GHG) emissions associated with the financial consumption of products and services, while the share of the world's species that potentially will go extinct globally if the pressure continues over time is provided by LC-IMPACT. The most recent EXIOBASE datasets can be extracted from the Zenodo repository(71). The impact factors can be found in the satellite accounts folder and multipliers datasheet. However, to determine the share of the world's species that potentially will go extinct globally associated with the direct drivers of biodiversity loss that are driven by consumption (in this case Finnish consumption), the countries of origin where the land use and pollution occur need to be identified. The open-source tool Pymrio can be used to assess the country of origin in the EEIO databases(72).
Following the code provided in Pymrio, we first calculated a global matrix for the country of origin of a driver of biodiversity loss (DR_{origin}):

$$DR_{origin} = \begin{matrix} DR_{1,1,1} & DR_{1,2,2} & \dots & DR_{1,j,k} \\ DR_{2,1,1} & DR_{2,2,2} & \dots & DR_{2,j,k} \\ \vdots & \vdots & \ddots & \vdots \\ DR_{i,1,1} & DR_{i,2,2} & \dots & DR_{i,j,k} \end{matrix}$$

Each cell of the matrix describes the amount of the driver of biodiversity loss (DR) that occurs in region *i* (referred to as impact region) and is driven by consumption in region *j* (referred to as consumption region), product sector *k* (for further clarification see SI Appendix Table S6). The data is from 2011 because running the analysis on data from more recent years, for example 2019, provided non-sensible results, especially in terms of pollution. This might be due to errors in the EXIOBASE satellite account datasets. However, impact factors (impact/euro) from 2019 were used. For the biodiversity footprint assessment, we do not identify the country of origin for climate change because there is no regionalized biodiversity impact data in LC-IMPACT for climate change(42). However, we do assess the country of origin for carbon dioxide emissions in the carbon footprint assessment. The several blue water consumption (water stress) accounts in EXIOBASE were aggregated using the aggregation function in Pymrio. We use the general version of EXIOBASE, with limited land use types and country resolution, rather than the higher-resolution data as it allowed us to include climate change and pollution as biodiversity pressures alongside land use. This somewhat limits the accuracy of the analyses, since it increases the use of averages when connecting EXIOBASE with LC-IMPACT, especially in terms of regional level of detail. In any case it seems the level of detail is sufficient for the purpose of providing a means to influence decision-making in organizations.

As we know the impact and consumption region (in this case Finland) of each driver of biodiversity loss, we can then identify the share of a driver of biodiversity loss in each region (DR_{share}):

$$DR_{share} = \frac{DR_{origin}}{\sum_{i=1}^{n} DR_{i,j,k}}$$

The cells of the new matrix contain the share of the driver of biodiversity loss (*DR*) in impact region *i* from the total amount of the driver that is driven by consumption in consumption region *j*, product sector *k*.

Then we need to harmonize the regional classification between EXIOBASE and LC-IMPACT. EXIOBASE contains 44 countries and five 'rest of the world' regions(50), while LC-IMPACT contains a highly detailed list of the world's countries. The missing countries from EXIOBASE can be harmonized by using the five 'rest of the world' regions. Once the harmonization was done, we allocated the share of the driver of biodiversity loss (DR_{share}) to each respective region. Then we looked into how one unit of a driver of biodiversity loss (DR_{unit}, e.g., 1 kg or 1 m^2) is divided between each impact region *i*:

$$DR_{unit} = DR_{share,i,j,k} / R_i$$

Here *R* represents the frequency of the impact region *i* after harmonization with LC-IMPACT (e.g. EXIOBASE region 'Rest of the World Europe' has been allocated to 23 countries in LC-IMPACT). Given the lack of information on 'rest of the world' regions, we were forced to assume that the drivers of biodiversity loss were shared equally between all countries representing those regions.

At this stage we calculated the impact factors of the driver of biodiversity loss (DR_{factor}) for each impact region *i* driven by consumption in consumption region *j*, product sector *k*:

$$DR_{factor,i,j,k} = DR_{unit,i,j,k} \times DR_{exiobase,j,k}$$

$DR_{exiobase}$ represents the monetary impact factors of the driver of biodiversity loss (impact per euro) from EXIOBASE for consumption region *j*, product sector *k*. Finally, we calculated the biodiversity equivalent factors for the driver of biodiversity loss (*BDe*) for each impact region *i*, driven by consumption in consumption region *j* and product sector *k*, by combining the previous matrix with the biodiversity equivalent factors for each driver of biodiversity loss ($DR_{lc\text{-}impact}$) for each impact region *i* from LC-IMPACT(42, 76):

$$BDe_{i,j,k} = DR_{factor,i,j,k} \times DR_{lc\text{-}impact,i}$$

Total biodiversity equivalent factors (BDe_{factor}) for each consumption region *j* and product sector *k* were derived by summing up the biodiversity equivalent factors of each impact region *i* in consumption region *j*, product sector *k*:

$$BDe_{factor,j,k} = \sum_{i=1}^{n} BDe_{i,j,k}$$

The biodiversity footprint of each financial account was then calculated by simply multiplying the biodiversity equivalent factor (*BDe/euro*) with the harmonized financial accounts (see Step 3).
In terms of the biodiversity impacts of climate change, we take into account carbon dioxide, methane, fossil methane and nitrous oxide. We chose impact factors that take all effects into account for a period of 100 years for both terrestrial and aquatic ecosystems(42). With the spatial component missing from the climate change biodiversity impact analyses, we then multiplied the biodiversity impact factor of each gas with its respective counterpart factor in EXIOBASE. Then we summed the results to derive a total biodiversity footprint factor of climate change for both terrestrial and aquatic ecosystems.

We calculated biodiversity footprint results for each pressure individually first and then merged the results into three impacted ecosystem types: terrestrial, freshwater and marine ecosystems. We then combined the biodiversity footprints of the three ecosystem types by taking a weighted average of biodiversity footprints over ecosystem types. As weights we used the estimated share of all plant and animal species that exist in each habitat type(78). The merged biodiversity footprint (BF_{total}) can then be calculated with the equation:

$$BF_{total} = BF_{terrestrial} \times 0.801 + BF_{freshwater} \times 0.096 + BF_{marine} \times 0.102$$

The Biodiversity Footprint Database can be accessed in https://doi.org/10.5281/zenodo.8369650.

Step 3. Harmonize the accounts

EXIOBASE product classification is based on the Statistical Classification of Economic Activities in the European Community, the so-called NACE classification(50, 79). The financial accounts of the University of Jyväskylä were harmonized with EXIOBASE (SI Appendix Dataset S4), except in the case of two accounts that are general cost accounts ("Compensation of cooperation costs" and "Other costs"), which were considered to represent an average of other cost accounts (excluding depreciation accounts), and in the case of five accounts that were imported as external environmental accounts (heat, electricity, water, travel services and travel grants, see Step 5 for further information). In total, 123 financial accounts were analysed, out of which 12 were excluded because it was not possible to identify their environmental impacts with the current methodologies (e.g. tax-related accounts). Regarding rental accounts, we excluded some space rentals to avoid double-counting of the energy-related environmental accounts.

In the case study, price adjustment due to inflation had to be made only for the financial account data from 2020 because environmental impact multipliers for the year 2019 were used. Prices were adjusted by using the Consumer Price Index from Statistics Finland (2021). For the basic price conversion factors (SI Appendix Dataset S3), we used EXIOBASE supply and use tables(71) for the Finnish economy in the year 2019 (data is nowcasted based on 2016 data points). Value-added tax (VAT) was excluded from calculations because it is invoiced separately in the university accounts (as it is in most Finnish organizations) and thus has already been deducted from the purchaser price. However, if VAT were to be included in the financial account prices, it should be deducted as shown by the formulae in the SI Appendix Table S7.

One of the inevitable limitations of using EEIO data is that it is accumulating retroactively. Thus, inflation between the baseline year of the EEIO database and the financial account data needs to be taken into account. Prices can be adjusted by using national Consumer Price Index data, showing the relative increase of inflation in a given year in relation to a baseline year (i.e. Inflation factor):

$$IAP = FAP - (FAP \times INF)$$

where *IAP* is the inflation-adjusted price, *FAP* is the financial account price and *INF* is the inflation factor. Furthermore, in order to use the impact factors (Step 2) of the EEIO database, financial account prices (i.e. purchaser prices) need to be converted to basic prices, the general unit used in EEIO databases. The System of National Accounts(80) define producer price (*PRP*) as:

$$PRP = BP + TAX - SUB$$

where *BP* is the basic price, *TAX* is the amount of taxes on products excluding invoiced VAT, and *SUB* is the amount of subsidies on products. Consequently, purchaser price (*PUP*) is defined as:

$$PUP = PRP + TTM + VAT$$

where *TTM* refers to the trade and transport margins and *VAT* to the value-added tax not deductible by the purchaser. Finally, the purchaser price (*PUP*) can be defined as:

$$PUP = BP + TAX – SUB + TTM + VAT$$

Then a basic price conversion factor (*BPCF*) can be calculated for each product sector *i* by calculating the share of taxes less subsidies, value-added tax and trade and transport margins from the total supply (*SUP*) values per product sector *i* of the EEIO database (in basic prices):

$$BPCF_i = (TAX_i – SUB_i + VAT_i + TTM_i) / (SUP_i + TAX_i – SUB_i + VAT_i + TTM_i)$$

The required values on taxes less subsidies (excluding VAT) and *TTM*s can be found from national supply and use tables, generally contained within the EEIO database repositories. Harmonized prices (*HP*), including inflation adjustment and basic price conversion, can be calculated with the equation:

$$HP = IAP – (IAP \times BPCF)$$

The conversion formulae and their explanations are summarized in SI Appendix Table S7.

STEP 4. Calculate results

This step can be seen as an optional mid-point step to gain more in-depth insights about the environmental accounts before Step 5, where the results are condensed to meet the financial impact statement criteria. The impact factors from EEIO databases and the footprints of accounts that were calculated with non-monetary impact factors (Step 2) should be assigned to their respective financial account categories (Step 3) and multiplied with the harmonized prices, with the exception of those non-monetary accounts whose results can be directly imported into the accounting scheme.

STEP 5. Assemble the value-transforming financial-environmental impact statement

We made a rough pricing scheme for the purpose of illustrating the principle of how environmental accounts can be used to transform the financial value in the financial-environmental impact statement. To evaluate the offsetting cost of the carbon footprint we used the World Bank carbon pricing statistics for the European Union(51). We converted prices to euros with a currency converter(81). Thus, we multiply the converted pricing factor with the University of Jyväskylä’s carbon footprint.

To estimate the offsetting value of the biodiversity footprint, more assumptions were needed. We used the LC-IMPACT database to determine the biodiversity footprint of intensive forestry land use in Finland and in Brazil(42). By dividing the total biodiversity footprint of the organization (3.66E-08 BDe in 2021) with the characterization factors of intensive forestry land use in Finland (2.65E-17 BDe/m^2)(42) and in Brazil (2.24E-15 BDe/m^2)(42), we assessed how much intensive forestry land should be permanently removed from use if we were to preserve an equivalent amount of global biodiversity (BDe) in Finland. This resulted in 138 423 ha in Finland, and 1636 ha in Brazil. However, protecting an ecosystem from economic demand does not necessarily mean that the demand ends; rather, the economic activity is often shifted elsewhere. To account for this so-called leakage, we derived a correction factor from an existing biodiversity offsetting case report, which calculated the amount of additional forest biodiversity offsets that need to be done when leakage is considered(82). Multiplying this factor (4.15) with the amount of land that needs to be preserved to avoid the BDe loss, we conclude that the total amount of conserved forest land in Finland needs to be 574 455 ha. As we could not find an estimate of potential leakage for Brazil, we utilized the Finland-specific multiplier also for Brazil and conclude that the total amount of conserved forest land in Brazil needs to be 6789 ha.

Acknowledgments

We thank the Strategic Research Council at the Academy of Finland (Kotiaho 345267), Green Carbon Finland Ltd, The Finnish Innovation Fund Sitra and SOK Corporation for funding the development of the methodologies. We thank Māris Grunskis for the illustrations, Andrew Pattison and Annukka Sailo for correcting the language, the administration at the University of Jyväskylä for giving access to the consumption data, the biodiversity footprint team members Veera Vainio and Krista Pokkinen as well as Ulla Helimo, Matti Toivonen, Janne Peljo and Hanna-Leena Pesonen for feedback.

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Supporting Information Text

Supporting Methods

Programming information:
Analyses done with Spyder IDE
* Spyder version: 5.1.5
* Python version: 3.7.6 64-bit
* Qt version: 5.9.7
* PyQt5 version: 5.9.2
* Operating System: Windows 10

Code for finding country of origin for the direct drivers of biodiversity loss, using Pymrio (1)

```
import pymrio
import pandas
exio3 = pymrio.parse_exiobase3(path=''FILE LOCATION'')
#Diagonalize specific stressor account, e.g. et1_diag = exio3.satellite.diag_stressor((''Cropland -–
Cereal grains nec''))
et1_diag = exio3.satellite.diag_stressor((''DRIVER NAME''))
#Connect back to the system
exio3.et1_diag = et1_diag
exio3.calc_all()
#Aggregate to the source drivers
exiostressor = exio3.et1_diag.D_cba.groupby(level=''region'', axis=0).sum()
#Save as a csv-file to given location
exiostressor.to_csv(path_or_buf=''FILE LOCATION'')
```

Code for aggregating drivers (in this study, blue water consumption), using Pymrio (1)

```
import pymrio
import pandas
exio3 = pymrio.parse_exiobase3(path=''FILE LOCATION'')
#Forming the aggregated group(s).
groups = exio3.satellite.get_index(as_dict=True, grouping_pattern = {''Water Consumption
Blue.*'': ''Water Consumption Blue -– Total''})
exio3.satellite_agg = exio3.satellite.copy(new_name=''Aggregated blue water consumption
accounts'')
for df_name, df in zip(exio3.satellite_agg.get_DataFrame(data=False, with_unit=True,
with_population=False),
                       exio3.satellite_agg.get_DataFrame(data=True, with_unit=True,
with_population=False)):
    if df_name == ''unit'':
        exio3.satellite_agg.__dict__[df_name] = df.groupby(groups).apply(lambda x: '' &
''.join(x.unit.unique()))
    else:
        exio3.satellite_agg.__dict__[df_name] = df.groupby(groups).sum()
#Diagonalize specific stressor account, e.g. et1_diag = exio3.satellite.diag_stressor((''Cropland -–
Cereal grains nec''))
et1_diag = exio3.satellite_agg.diag_stressor((''Water Consumption Blue -– Total''))
#Connect back to the system
exio3.et1_diag = et1_diag
exio3.calc_all()
```

```
#Aggregate to the source drivers
exiostressor = exio3.et1_diag.D_cba.groupby(level=''region'', axis=0).sum()
#Save as a csv-file to given location
exiostressor.to_csv(path_or_buf=''FILE LOCATION'')
```

Supporting Discussion

A challenge that remains to be solved when financial and environmental accounts are integrated, is that financial accounting entries do not always include all the relevant information for making an environmental footprint assessment. Thus, in future developments of financial accounting, it would be valuable to consider the needs of environmental accounting. Financial accounting entries should be as detailed as possible revealing the type of the product or service consumed (e.g., travel type: flight vs. train or energy type: coal vs. wind electricity). While more detailed information could be found from individual receipts of purchasing activities, analysis of such information might be cumbersome. Digitalization of receipts would already allow such detailed information to be stored. Second, financial accounting entries could be adjusted to also include physical consumption information, e.g., kilometers travelled, or kilograms of product consumed. Physical consumption information can be found, but it is generally scattered around different units of an organization. Another interesting avenue for further research in the integrated accounting system would be the use of double-entry bookkeeping in environmental accounting and reporting. Double-entry bookkeeping is a common feature of financial accounting used to track financial transactions by keeping book of where money was taken from and to what purpose it was used. In other words, every financial transaction has equal and opposite effects in two different accounts(2). In the future, environmental accounting could take up a similar practice by recording the flows of negative (footprints) and positive (handprints) impacts (impact statement) and consider their accumulation over time (balance sheet). This approach has been mainly discussed in terms of natural capital accounting(3) but could be extended to cover general environmental accounting principles. Double-entry bookkeeping combined with the presented hybrid EEIO-LCA methodology would also allow real-time and automated tracking of carbon and biodiversity footprints in organizations, if environmental accounts would be made at the point of purchasing events, rather than at the end of the year as was done in the case of the University of Jyväskylä. The integration of financial and environmental accounts is one of the important steps to transforming value in organizations. It is high time for equality of accounting. Environmental and financial accounting should be handled with the same level of rigor. To achieve this, changes are not only needed in environmental accounting, but also in financial accounting practices and policy, which play an important role in how organizations currently operate.

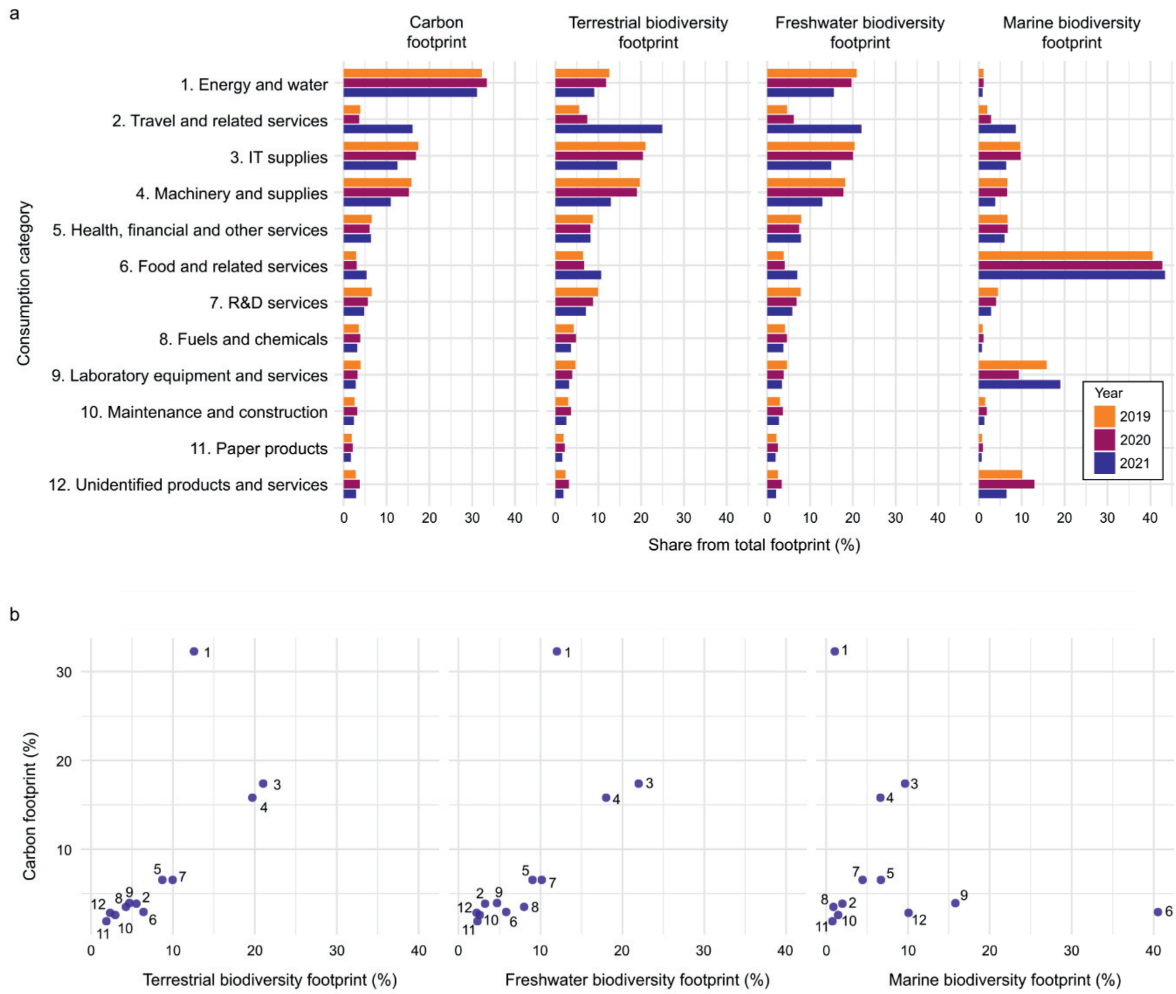

Fig. S1. The composition of the carbon and biodiversity footprints of the University divided by ecosystem types. The relative contribution (%) of different consumption categories of the University of Jyväskylän during 2019-2021 for the carbon and biodiversity footprints (**a**) and scatterplots of the relative carbon footprint of each consumption category on the relative biodiversity footprints of the corresponding consumption category in 2021 (**b**). Small numbers in the scatter plot of panel b refer to the consumption categories in panel a.

Table S1. The carbon footprint (t CO_2e) of the 12 aggregated consumption categories of the University of Jyväskylä 2019-2021.

Consumption category	2019	2020	2021
Unidentified products and services	467.43	509.13	408.45
Paper products	266.49	289.87	271.44
Maintenance and construction	380.45	425.35	373.75
Laboratory equipment and services	451.65	440.28	569.07
Fuels and chemicals	505.63	522.48	506.10
R&D services	775.21	764.96	946.98
Food and related services	858.04	412.50	423.77
Health, financial and other services	1025.78	820.67	946.58
Machinery and supplies	1771.70	2062.65	2293.56
IT supplies	2025.22	2290.85	2523.55
Travel and related services	2596.25	493.49	558.56
Energy and water	5026.58	4535.46	4683.20
Total	**16150.45**	**13567.69**	**14505.01**

Table S2. The biodiversity footprint (BDe) of the 12 aggregated consumption categories of the University of Jyväskylä 2019-2021.

Consumption category	2019	2020	2021
Unidentified products and services	8.49E-10	1.16E-09	9.36E-10
Paper products	6.76E-10	7.34E-10	6.86E-10
Maintenance and construction	1.07E-09	1.22E-09	1.07E-09
Laboratory equipment and services	1.57E-09	1.38E-09	1.84E-09
Fuels and chemicals	1.59E-09	1.67E-09	1.61E-09
R&D services	2.93E-09	2.87E-09	3.53E-09
Food and related services	4.97E-09	2.61E-09	2.72E-09
Health, financial and other services	3.51E-09	2.78E-09	3.20E-09
Machinery and supplies	5.40E-09	6.33E-09	7.08E-09
IT supplies	6.06E-09	6.80E-09	7.58E-09
Travel and related services	9.25E-09	2.20E-09	1.77E-09
Energy and water	3.86E-09	4.02E-09	4.62E-09
Total	**4.17E-08**	**3.38E-08**	**3.66E-08**

Table S3. The biodiversity footprint (BDe) of the 12 aggregated consumption categories of the University of Jyväskylä 2019-2021 in terrestrial, freshwater and marine ecosystems.

	Terrestrial			Freshwater			Marine		
Consumption category	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
Unidentified products and services	9.24E-10	1.25E-09	1.00E-09	2.88E-10	3.89E-10	3.10E-10	8.02E-10	1.15E-09	1.02E-09
Paper products	7.96E-10	8.64E-10	8.08E-10	3.16E-10	3.44E-10	3.23E-10	7.86E-11	8.37E-11	7.74E-11
Maintenance and construction	1.27E-09	1.45E-09	1.27E-09	3.65E-10	4.13E-10	3.63E-10	1.58E-10	1.64E-10	1.49E-10
Laboratory equipment and services	1.60E-09	1.56E-09	2.01E-09	5.12E-10	5.16E-10	6.60E-10	2.35E-09	8.24E-10	1.60E-09
Fuels and chemicals	1.84E-09	1.94E-09	1.86E-09	1.11E-09	1.18E-09	1.12E-09	8.91E-11	9.54E-11	9.06E-11
R&D services	3.47E-09	3.40E-09	4.18E-09	1.19E-09	1.16E-09	1.43E-09	3.51E-10	3.56E-10	4.51E-10
Food and related services	5.33E-09	2.68E-09	2.78E-09	1.60E-09	7.91E-10	8.16E-10	5.36E-09	3.78E-09	4.10E-09
Health, financial and other services	4.12E-09	3.27E-09	3.76E-09	1.40E-09	1.10E-09	1.27E-09	7.38E-10	5.95E-10	6.77E-10
Machinery and supplies	6.45E-09	7.56E-09	8.45E-09	1.99E-09	2.27E-09	2.53E-09	4.74E-10	5.83E-10	6.71E-10
IT supplies	7.18E-09	8.05E-09	8.97E-09	2.47E-09	2.77E-09	3.09E-09	7.87E-10	8.63E-10	9.75E-10
Travel and related services	1.11E-08	2.64E-09	2.13E-09	2.34E-09	5.60E-10	4.54E-10	1.06E-09	2.51E-10	2.01E-10
Energy and water	4.63E-09	4.83E-09	5.55E-09	1.41E-09	1.47E-09	1.69E-09	1.08E-10	9.67E-11	1.08E-10
Total	**4.87E-08**	**3.95E-08**	**4.28E-08**	**1.50E-08**	**1.30E-08**	**1.41E-08**	**1.24E-08**	**8.84E-09**	**1.01E-08**

Table S4. The contribution of the direct drivers of biodiversity loss to the biodiversity footprint (BDe) of the University of Jyväskylä 2019-2021 in terrestrial, freshwater and marine ecosystems.

	Terrestrial			Freshwater			Marine		
Driver type	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
Land use	1.62E-08	1.52E-08	1.67E-08	-	-	-	-	-	-
Climate change	1.49E-08	1.49E-08	1.62E-08	4.64E-09	4.64E-09	5.05E-09	-	-	-
Pollution	2.28E-09	2.15E-09	2.34E-09	3.59E-10	3.18E-10	3.54E-10	1.12E-08	8.51E-09	9.82E-09
Water stress	-	-	-	6.35E-09	6.03E-09	6.56E-09	-	-	-

Table S5. Biodiversity footprint impact categories in EXIOBASE and connecting impact category in LC-IMPACT. In terms of land use, average effects from LC-IMPACT were used, instead of marginal effects.

Stressor name (EXIOBASE)	**Connecting stressor in LC-Impact**
Land use	
Cropland – Cereal grains nec Cropland – Crops nec Cropland – Oil seeds Cropland – Paddy rice Cropland – Plant-based fibers Cropland – Sugar cane, sugar beet Cropland – Vegetables, fruit, nuts Cropland – Wheat	Land stress: Annual crops, permanent crops (average)
Cropland – Fodder crops – Cattle Cropland – Fodder crops – Meat animals Cropland – Fodder crops – Pigs Cropland – Fodder crops – Poultry Cropland – Fodder crops – Raw milk	Land stress: Annual crops
Permanent pastures – Grazing-Cattle Permanent pastures – Grazing-Meat animals Permanent pastures – Grazing-Raw milk	Land stress: Pasture
Forest area – Forestry	Land stress: Intensive forestry, extensive forestry (average)
Forest area – Marginal use (excluded, no data available in EXIOBASE)	-
Infrastructure land (excluded, no data available in EXIOBASE)	-
Other land Use: Total	Average of remaining land use types in LC-Impact (Urban)
Direct exploitation of natural resources	
Water Consumption Blue – Total (aggregated 103 categories)	Water stress
Pollution	
NMVOC – combustion – air Nox – combustion – air	Photochemical ozone formation
Nox – combustion – air NH3 – combustion – air Sox – combustion – air	Terrestrial acidification
P – agriculture – water P – agriculture – soil	Freshwater eutrophication
N – agriculture – water	Marine eutrophication
Climate change	
Climate change midpoint | ILCD recommended CF | Global warming potential 100 years	Terrestrial climate change, aquatic climate change

Table S6. Illustration of the data matrix derived from pymrio analysis of stressor (impact) sources. Regions in the column headers indicate the location of the environmental impact. Regions and sectors in row headers indicate the place of consumption.

	Region A Sector 1	**Region A Sector 2**	**Region B Sector 1**	**Region B Sector 2**
Region A	Impact in Region A driven by consumption in Region A – Sector 1	Impact in Region A driven by consumption in Region A – Sector 2	Impact in Region A driven by consumption in Region B – Sector 1	Impact in Region A driven by consumption in Region B – Sector 2
Region B	Impact in Region B driven by consumption in Region A – Sector 1	Impact in Region B driven by consumption in Region A – Sector 2	Impact in Region B driven by consumption in Region B – Sector 1	Impact in Region B driven by consumption in Region B – Sector 2
Region C	Impact in Region C driven by consumption in Region A – Sector 1	Impact in Region C driven by consumption in Region A – Sector 2	Impact in Region C driven by consumption in Region B – Sector 1	Impact in Region C driven by consumption in Region B – Sector 2

Table S7. Summary of the different operations needed to harmonize purchaser prices (financial account prices) with basic prices (EEIO database prices).

Description	Equation	Legend
Harmonizing financial account prices to take into account inflation between EEIO database baseline year and financial accounting year.	$IAP = FAP - (FAP \times IF)$	IAP = Inflation adjusted price FAP = Financial account price IF = Inflation factor
Definition of producer price.	$PRP = BP + TAX - SUB$	PRP = Producer price BP = Basic price TAX = Taxes on products excluding invoiced VAT SUB = Subsidies on products
Definition of purchaser price.	$PUP = PRP + TTM + VAT$	PUP = Purchaser price PRP= Producer price TTM = Trade and transport margins VAT = VAT not deductible by the purchaser
Definition of purchaser price when producer price is dismantled according to the definition of producer price.	$PUP = BP + TAX - SUB + TTM + VAT$	PUP = Purchaser price BP = Basic price TAX = Taxes on products excluding invoiced VAT SUB = Subsidies on products TTM = Trade and transport margins VAT = VAT not deductible by the purchaser
Basic price conversion factor that can be used to estimate the difference between purchaser price (financial account price) and basic price.	$BPCF = \frac{TAX - SUB + VAT + TTM}{SUP + TAX - SUB + VAT + TTM}$	BPCF = Basic price conversion factor TAX = Taxes on products excluding invoiced VAT SUB = Subsidies on products VAT = VAT not deductible by the purchaser TTM = Trade and transport margins SUP = Total supply per sector
Final harmonization of financial accounting prices including inflation and basic price adjustments.	$HP = IAP - (IAP \times BPCF)$	HP = Harmonized price IAP = Inflation adjusted price FAP = Financial account price BPCF = Basic price conversion factor

Dataset

The full dataset can be accessed in https://doi.org/10.5281/zenodo.8369650.

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