BIODIVERSITY IMPACTS OF COFFEE, TEA AND HOT CHOCOLATE CONSUMED IN FINLAND BASED ON THE IMPACTS OF LAND STRESS, WATER STRESS AND CLIMATE CHANGE

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ABSTRACT

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Biodiversity impacts of coffee, tea and hot chocolate consumed in Finland based on the impacts of land stress, water stress and climate change

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This master's thesis investigated the biodiversity impacts of food products consumed in Finland based on the impacts of land stress, water stress and climate change. The example products chosen in the analysis were coffee, tea and hot chocolate. It was investigated in which life cycle stages and locations the biggest impacts could occur and how the impacts could be reduced. The study was conducted by using LCA and LC-IMPACT was used as an impact assessment method. The impacts were analysed on terrestrial and freshwater ecosystems. The locations of coffee, tea and cocoa production were chosen to be Brazil, Sri Lanka and Ivory Coast respectively. The location of milk and sugar production was chosen to be Finland. The calculation of the impacts was done with openLCA software and MS Excel.

The impacts of coffee, tea and hot chocolate on terrestrial ecosystems were 1.06E-15 PDF*y, 6.11E-16 PDF*y and 1.34E-15 PDF*y respectively and the impacts on freshwater ecosystems were 1.02E-16 PDF*y, 7.38E-17 PDF*y and 3.21E-16 PDF*y respectively. Most of the impacts on terrestrial ecosystems were caused by land stress in the case of coffee and tea. In the case of hot chocolate the impacts of land stress and climate change on terrestrial ecosystems were almost equal. Most of the impacts on freshwater ecosystems were caused by water stress in the case of tea and by the effects of climate change in the case of hot chocolate. The impacts of water stress and climate change on freshwater ecosystems in the case of coffee were almost equal. By far the biggest impacts occurred in primary production in the case of all three products. Also, by far most of the impacts occurred elsewhere than in Finland. Due to limitations and uncertainties the results of this study should be considered indicative.

Potential ways to reduce the impacts of coffee, tea and cocoa are land-sharing, land-sparing and agroforestry. The impacts of milk could be reduced through substituting dairy milk by plant-based milks or by increasing the feed efficiency of cows to get higher milk yield per feed input. Also, application of low-intensity mixed grazing of cattle and sheep or inclusion of woodland and hedges could be potential ways to enhance biodiversity at grazing lands.

TIIVISTELMÄ
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Suomessa kulutetun kahvin, teen ja kaakaojuoman biodiversiteettivaikutukset perustuen maankäytön, vedenkäytön ja ilmastonmuutoksen vaikutuksiin

Ympäristötekniikan diplomityö

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Avainsanat: biodiversiteetti, LCA, LC-IMPACT, kahvi, tee, kaakaojuoma, Suomi

Tässä diplomityössä tutkittiin Suomessa kulutettujen elintarvikkeiden biodiversiteettivaikutuksia perustuen maankäytön, vedenkäytön ja ilmastonmuutoksen vaikutuksiin. Esimerkkituotteiksi valittiin kahvi, tee ja kaakaojuoma. Työssä tutkittiin, missä elinkaaren vaiheissa ja sijainneissa suurimmat vaikutukset voisivat ilmetä ja kuinka vaikutuksia voitaisiin vähentää. Tutkimuksessa käytettiin LCA:ta ja LC-IMPACT-metodia käytettiin vaikutustenarviointimenetelmänä. Vaikutuksia arvioitiin maa- ja makeanveden ekosysteemeille. Sijainniksi kahvintuotannolle valittiin Brasilia, teentuotannolle Sri Lanka, kaakaontuotannolle Norsunluurannikko ja maidon- sekä sokerintuotannolle Suomi. Laskenta suoritettiin openLCA-ohjelmistolla ja MS Excelillä.

Kahvin vaikutukseksi maaekosysteemeille saatiin 1,06E-15 PDF*y, teen vaikutuksiksi 6.11E-16 PDF*y ja kaakaojuoman vaikutuksiksi 1.34E-15 PDF*y. Kahvin, teen ja kaakaojuoman vaikutuksiksi makeanveden ekosysteemeille saatiin 1.02E-16 PDF*y, 7.38E-17 PDF*y and 3.21E-16 PDF*y vastaavasti. Suurin osa kahvin ja teen vaikutuksista maaekosysteemeihin aiheutui maankäytöstä. Maankäytön ja ilmastonmuutoksen vaikutukset maaekosysteemeihin olivat lähes yhtä suuret kaakaojuoman tapauksessa. Suurin osa teen vaikutuksista makeanveden ekosysteemeille aiheutui vedenkäytöstä ja suurin osa kaakaojuoman vaikutuksista ilmastonmuutoksesta. Kahvin tapauksessa vedenkäytön ja ilmastonmuutoksen vaikutukset makeanveden ekosysteemeihin olivat lähes yhtä suuret. Ylivoimaisesti suurin osa vaikutuksista kaikkien kolmen tuotteen kohdalla ilmeni alkutuotannossa ja muualla kuin Suomessa. Rajoitusten ja epävarmuuksien takia tämän työn tuloksia voidaan pitää suuntaa antavina.

Potentiaalisia keinoja vähentää kahvin, teen ja kaakaojuoman vaikutuksia ovat ”land-sharing” ja ”land-sparing” sekä peltometsäviljely. Maidontuotannon vaikutuksia voitaisiin vähentää korvaamalla lehmänmaito kasvipohjaisella vaihtoehdolla tai parantamalla lehmien rehun tehokkuutta, jotta saataisiin tuotettua enemmän maitoa rehun syötettä kohden. Potentiaalisia keinoja parantaa biodiversiteettiä laidunmailla voisivat myös olla matalan intensiteetin nautakarjan ja lampaiden sekalaiduntamisen hyödyntäminen sekä metsämaan ja pensasaitojen sisällyttäminen.

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Jyväskylä 7 August 2023,

Jasmine

SYMBOLS AND ABBREVIATIONS

Symbols

CH_4	methane
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
dl	deciliter
g	gram
G	giga
ha	hectare
kg	kilogram
kWh	kilowatt-hour
l	liter
m^2	square meter
m^3	cubic meter
N_2O	nitrous oxide
NH_3	ammonium
NO_x	nitrogen oxides
*PDF*y*	potentially disappeared fraction of species over time
t	ton
tkm	ton-kilometer
W/m^2	watt per square meter

Abbreviations

AoP	area of protection
BR	Brazil
CF	characterization factor
CI	Ivory Coast
CO	Colombia
DWT	deadweight tons
EF	effect factor
FF	fate factor
FI	Finland
GHG	greenhouse gas
GWP	global warming potential
K	potassium
LCA	life cycle assessment
LCI	fife cycle inventory
LCIA	life cycle impact assessment
LK	Sri Lanka
LULUC	land use and land-use change activities
N	nitrogen
NL	Netherlands
NPP	net primary production
PDF	potentially disappeared fraction of species
P	phosphorous
PM	particulate matter

RoW	rest of world
VS	vulnerability score
XF	exposure factor

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1 Introduction

Food production causes several different significant environmental impacts. Agriculture is the main contributor for exceeding planetary boundaries in biodiversity loss and nutrient flows. It is also the major driver for land-system change and freshwater use zones and a significant driver for climate change zone being at increasing risk. In addition, agriculture is the main or significant contributor to change for many planetary boundaries that are still in a safe operating zone. (Campbell et al. 2017, 1.) Described as numbers, 80 % of deforestation is caused by agriculture and the share of agriculture in freshwater use is 70 %. Drivers linked to food production are responsible for 70 % of terrestrial and 50 % of freshwater biodiversity loss. (WWF 2020, 61.) According to Crippa et al. (2021, 198) food systems cause 34% of global greenhouse gas (GHG) emissions. Thus, it is very important to pay attention to the sustainability of food production.

The environmental impacts of food consumed by Finnish people have been assessed in multiple studies, mostly considering global warming potential (GWP). For example, according to Lettenmeier et al. (2019, 14) the carbon footprint of food consumption of an average Finn is 1750 kg CO_2eq per year which accounts for 17 % of the total annual carbon footprint of an average Finn (10 t CO_2eq). In addition, some other environmental impacts caused by Finnish food consumption have been assessed. According to Sandström et al. (2017, 34, 37) the total land use related to food consumed in Finland was 1.436 million ha in 2010 and blue water consumption which refers to the amount of fresh water used for irrigation of cropland was 117.77 million m^3.

Also, the locations where the environmental impacts from food consumed in Finland occur have been defined in former research. A study conducted by Järviö et al. (2022) shows that most of the biodiversity loss caused by land stress associated with Finnish food consumption occurs outside Finland. The biggest impacts caused by land stress take place in Brazil, Cuba and India (Järviö et al. 2022). An earlier study conducted by Sandström et al. (2017, 37) has found similar results. The study found out that over 93 % of biodiversity impacts related to land use and over 99 % related to freshwater use associated with food consumed in Finland come from imports and therefore occur outside the Finnish borders. The biggest land use related biodiversity impacts were located in Brazil, India, Colombia and Indonesia whereas the biggest freshwater use related biodiversity impacts were located in Spain, USA and Egypt. (Sandström et al. 2017, 37.) In the current average Finn's diet 57 % of GHG emissions come from imported food products and the rest 43 % from domestic food products (Saarinen et al. 2019, 21). However, the effects of climate change are global, so the location of the emission source does not matter in that respect (Verones et al. 2020a, 1203).

There are a lot of differences between the environmental impacts of different food products. In general animal-based products cause bigger environmental impacts compared to plant-based products (Springmann et al. 2018, 452). Studies have found that by reducing the amount of animal-based products in diets, especially food derived from domesticated animals, significant reductions in GHG emissions and eutrophication potential of Finn's diets can be achieved (Saarinen et al. 2019, 22, 26-27; Vieux et al. 2018, 957; Finnish Environment Institute 2020). However, here are also some plant-based food products with relatively high environmental impacts. For instance, coffee has been found to be a hotspot in an average European diet causing significant different environmental impacts despite a low consumption amount of 3.3 kg/year per capita (Crenna et al. 2019, 383-384).

This master's thesis studies the biodiversity impacts of food products consumed in Finland using life cycle assessment (LCA). The analysis has been limited to coffee, tea and hot chocolate. This study is continuation of Järviö et al. (2022) study where the one of the worst food products Finns consume from the point of view of biodiversity loss relativized to the consumption amounts was found to be coffee. Tea and hot chocolate are included because they are similar kind of products and therefore their impacts are easy to compare with the impacts of coffee. The impacts of these products on terrestrial and freshwater ecosystems are assessed at endpoint level based on land stress, water stress and climate change impact categories by using LC-IMPACT method. The aim of this thesis is to identify the stages of product lifecycle that cause the largest impacts and ways to reduce the impacts. The aim is also to find hotspots about the locations where biodiversity loss caused by the products is the highest.

The research questions of this study are:

- What are the biodiversity impacts of coffee, tea and hot chocolate based on land stress, water stress and climate change impact categories?

- What are the lifecycle stages where the most significant impacts occur and how could the impacts be reduced?
- In which locations do the highest biodiversity impacts occur?

In this thesis there is a theory part that first considers the biodiversity impacts of food systems in more detail. After that, methodology of this study is presented focusing on LCA and LC-IMPACT method. After the theory part there is a calculation part where the biodiversity impacts of the chosen three food products are defined. Then, an analysis part is conducted where the results of this study are interpreted and measures to reduce biodiversity impacts of the products are considered. Finally, at the end of this thesis there are conclusions.

2 Biodiversity impacts of food

Nature is crucial for human existence and well-being. It supports our quality of life by providing basic conditions for living, material goods as well as inspiration and recreational opportunities. These nature's contributions to people include for example food, medicine and regulation of environmental processes such as pollination, climate and quality of water. Many things that nature provides for humans are essential for health and therefore a good quality of life becomes threatened as they decline. (IPBES 2019, XXVI-XXVII.)

The world population is constantly growing. In November 2022 the world population reached 8 billion people and it has been estimated to reach 9,7 billion in 2050 and 10,4 billion in 2100. (United Nations 2023.) Humanity as being the largest influence on life on earth globally has caused decline in natural terrestrial, freshwater and marine ecosystems. The global rate of species extinction is accelerating all the time and it is already now at least tens to hundreds of times faster than the average rate during the past 10 million years. (IPBES 2019, XXVIII.)

As the population grows so does the demand of food which has been estimated to grow by 36-56 % between 2010-2050 (van Dijk et al. 2021, 49). Food production has enormous effects on biodiversity. Land use change mainly driven by agriculture together with forestry and urbanization has the biggest impact on terrestrial and freshwater ecosystems. For marine ecosystems direct exploitation of fish and seafood causes the biggest impact. So far climate change, pollution and invasive species have had a smaller relative impact on biodiversity. However, their effects are also accelerating. (IPBES 2019, XXXII.)

In this chapter it is described how food systems affect biodiversity through land use and degradation, water scarcity and quality as well as climate change (sections 2.1-2.3). In section 2.4 also some other biodiversity impacts of food production are presented. Section 2.5 discusses the role of international trade, displaced impacts and how the environmental impacts of food production are distributed in different supply chain stages.

2.1 Land use and degradation

In 2019 there was 4,75 billion hectares agricultural land in the world which accounts for 37 % of the total land area of the globe (FAO 2022, 254). Agriculture also accounts for 80 % of all global land use change (Benton et al. 2021, 16). Between 1961-2019 the agricultural land area grew by 6 % and most of it was gained by deforesting. Because of unsustainable agricultural practises, natural degradation, urban expansion as well as development of infrastructure and extractive industries some of the land also became unsuitable for agriculture and thereby was lost. (FAO 2022, 253.)

Agriculture affects biodiversity through land use change by destroying habitats. Wild animals, plants and other organisms lose their habitat as land is converted for crop production or cleared for grazing which threatens the species populations. Crops and farmed animals also compete from the same resources as wildlife. In recent decades the greatest loss of undamaged ecosystems has occurred through clearing of forests to make way for soy, palm oil and cattle production in the tropics where biodiversity is the richest. (Benton et al. 2021, 16-17.)

At farm and landscape scale agriculture affects biodiversity by creating homogeneous areas covered by a single crop (e.i. monocultures) thus replacing the heterogeneity of the natural environment. The spatial and temporal uniformity of habitat deteriorates the ability of land to provide versatile habitat for different kind of ecosystems and viable populations as many species may need different habitats at different times of the day or year, e.g. for reproducing, foraging or sheltering. (Benton et al. 2021, 17-18.)

Also, the quality of agricultural land is degrading which causes loss in productivity, biodiversity and ecosystem services. Land degradation is a phenomenon which has several forms including for example erosion, acidification and soil carbon depletion and the processes related to it are usually the result of sequential series of interactions. One third of soils has damaged due to land degradation caused by human activities. Unsustainable forestry and agricultural practices and the expansion of crop and grazing lands through deforestation are among the main reasons for soil degradation. (FAO 2022, 256.)

Soil erosion means all the processes that remove and move soil from its original location to another place mainly through wind, water and tillage. 80 % of agricultural land and 10-20

% of pasturelands have been estimated to suffer from a serious erosion. This is a matter of concern because erosion remarkably reduces crop yields and the ability of soil to store and cycle water, nutrients and carbon. (FAO 2022, 256-257.)

Land use change and the intensification of agricultural production are the main causes for soil organic carbon loss. Soils have a big influence on the concentration of CO_2 in the atmosphere as they are the main terrestrial storage of carbon. Therefore, soil organic carbon loss causes CO_2 emissions. Soil organic carbon is also crucial for soil health and for several soil functions that provide important ecosystem services. (FAO 2022, 257, 259.)

It has been estimated that over 1,1 billion hectares of soils are subjected to salinity and sodicity. Salination has caused the losing of 76 million hectares of mostly irrigated land. The causes for soil salinization are often either poorly managed irrigation or fertilization or intrusion of salt water from the sea, groundwater, river or mining. These result in a rapid decline of soil health and as a consequence, the soil loses its ability to produce necessary ecosystem functions such as carbon sequestration, natural filtration and biomass production. Soil acidification in turn is caused by atmospheric pollutants and overuse of fertilizers which also results in soil health declining. (FAO 2022, 258-259.)

2.2 Water scarcity and quality

Irrigated agriculture is the major user of freshwater as it accounts for over 70 % of global withdrawals of water (FAO 2022, 259). Biodiversity can be affected through irrigation when water is abstracted from groundwater flows which may pose a threat to aquatic populations that depend on those flows (Benton et al. 2021, 19). In many regions the management of water resources is unsustainable because water withdrawals are bigger than the amount of renewable water resources or because of the use of fossil groundwater. Currently 35 % of irrigation is done with groundwater and the share has been estimated to increase due to decreases in surface water availability. In most regions water levels in aquifers are declining already now because of overexploitation, pollution and poor management. Many countries suffer from water scarcity which means that the demand of water is bigger than the available water supply. (FAO 2022, 259-261.)

Irrigated agriculture has been prioritized over rainfed agriculture especially since 1980s which has led to an enormous expansion of irrigated area, reservoir constructions and intensification of agricultural production. Simultaneously it has helped to develop a more reliable agriculture that is less dependent on meteorological conditions. On the other hand, this has also resulted in a stronger dependence on freshwater resources which are currently under increasing pressure. The current situation has been caused by poor water governance, insufficient water conservation measures and not understanding the economic value of water. (FAO 2022, 261.)

Along with quantity also the quality of freshwater is an important issue to consider. Increasing human activities are the main reason for water quality degradation. Some pollutants remain active for a long time which has also decreased the capacity of receiving freshwater to dilute them. The anthropogenic freshwater pollution is caused by nutrient overloading (nitrogen and phosphorous), pathogens, plastics, heavy metals and emerging pollutants. (FAO 2022, 261-262.) Emerging pollutants refer to natural or synthetic chemicals that are typically not monitored in the environment but may enter there and potentially cause known or suspected harm for the environment or human health and therefore they cause emerging concern (Kumar et al. 2022, 2).

Intensive agriculture is a major cause for water degradation as it has resulted in extensive eutrophication of lakes, rivers, dams as well as wetland systems mainly caused by fertilizer overuse and also by industrial livestock production (FAO 2022, 263). Intensive large scale animal farming with a large number of animals on a relatively small area of land creates a big amount of manure from which nutrients leak into the soil and water bodies in harmful amounts (Benton et al. 2021, 17). Losses of nitrate from agriculture also cause coastal eutrophication in marine waters (Andersen et al. 2014, 906). Wide areas of water can be polluted by fertilizers, and they end up in waterbodies when excess nutrients wash into rivers from poorly managed soils during rain periods (Benton et al. 2021, 17, 19).

Eutrophication means excessive plant and algae growth which is caused by increased availability of one or more limiting factors for photosynthesis, for example nutrients, CO_2 or sunlight (Chislock et al. 2013). The increased algae growth may cause a change in species composition to faster growing algae species and a shift from long lived macroalgae to species that are more harmful. As a secondary impact the excess algae growth reduces the availability of sunlight deeper in the water thus reducing the depth distribution of sea grasses and macroalgae. (European Commission 2023.) Also, when plants and algae die, they decompose which consumes oxygen from the water (European Environment Agency 2023). As a consequence, the affected area of water becomes lifeless due to lack of oxygen caused by decomposition of the excess algae growth (European Environment Agency 2023; Chislock et al. 2013). By that way aquatic and marine biodiversity deteriorates. Channelization and damming along with other waterway modifications in order to support agriculture worsen these impacts. (Benton et al. 2021, 19.) For freshwaters phosphorous is the main nutrient causing eutrophication whereas for salt waters it is nitrogen (European Environment Agency 2016).

2.3 Climate change

The role of food production contributing to climate change is significant. According to Crippa et al (2021, 198) food systems released 18 Gt CO_2eq emissions in 2015 thus accounting for 34 % of global GHG emissions. Expressed as CO_2eq the share of carbon dioxide (CO_2) from the food system emissions was 52 %, the share of methane (CH_4) 35 %, the share of nitrous oxide (N_2O) 10 % and the share of fluorinated gases 2 %. Compared to 1990 the GHG emissions have increased by 12,5 % (2 Gt CO_2eq). However, between 1990-2015 global food production grew by over 40 % so the emission intensity of food production has decreased. (Crippa et al. 2021, 199, 201.)

Land-based sector accounts for 71 % of the emissions from food systems including agriculture as well as associated land use and land-use change activities (LULUC). The share of LULUC from the total food system emissions is approximately 32 % and they come mostly from carbon losses caused by deforestation and degradation of organic soils including peatlands. The biggest share of emissions (39 %) comes from the production stages until “farm gate” excluding LULUC and including agriculture, aquaculture, fishing and emissions from the production of inputs, e.g. fertilizers. (Crippa et al. 2021, 198-199, 201.)

The rest 29 % of food system emissions are caused by distribution (transport, packaging and retail), processing, consumption and end-of-life. Most of these emissions are linked to energy use. (Crippa et al. 2021, 199, 201.)

Climate change affects biodiversity in many ways. It alters species population dynamics and causes changes in species distribution, the composition of species assemblage as well as ecosystem functions and structures. It has been estimated that at least to some extent climate change has already affected negatively to the distribution of almost a half of threatened terrestrial mammals, excluding bats, and a quarter of threatened birds. From species rapidly advancing climate change requires either capability to evolve, disperse or follow their shifting habitats due to changing climate conditions. Many species are not able to adapt to the rapid changes which leads to large reductions or even local extinctions of populations. (IPBES 2019, XXXIII.)

2.4 Other impacts

One significant issue affecting biodiversity loss in agriculture is pesticide use. Pesticides may not only kill the targeted pests but other insects in the nearby, too. (Benton et al. 2021, 17).

Manure and synthetic fertilizers cause air pollution as nitrogen oxides (NO_x) and ammonium (NH_3). Both contribute to formation of secondary particulate matter (PM) that decreases air quality and causes smog. (Benton et al. 2021, 18-19.) In addition, increased reactive nitrogen concentrations in the atmosphere can be deposited in rain resulting in ecosystem changes as a consequence of nutrient enrichment and soils becoming more acidic (Benton et al. 2021, 19; Sutton and Grinsven 2011, xxx). These changed circumstances favour plants that prefer more acidic conditions or higher nitrogen supply which in turn can lead to the displacement of a larger number of more sensitive species thus threatening biodiversity (Sutton and Grinsven 2011, xxx).

The impact of fishing on biodiversity is significant. In the past 50 years fishing has had the greatest impact for marine ecosystems and the marine fish stocks are increasingly overfished. In 2015 33 % of fish stocks were overfished, 60 % were maximally sustainably fished and only 7 % were underfished. (IPBES 2019, XXXIII.)

Food production may also affect biodiversity at a genetic level. Gene introgression, meaning gene pollution, can occur from crop plants into wild populations and from non-native fish that escape from aquaculture farms and mate with wild fish. In both cases the natural genetic composition in the location or ecosystem becomes altered. (Benton et al. 2021, 21.)

Food transportations can affect biodiversity by introduction of invasive alien species as transportation of people and goods promotes their distribution. It has been found out that trade was one of the most significant reasons for the wide spreading of invasive alien species in terrestrial and freshwater ecosystems in 20th and 21st centuries. (IPBES 2019, 114.)

2.5 Impacts along food supply chains

There are several stages included in the life cycles of agri-food products in which different environmental impacts occur. Thus, it is important to assess the environmental impacts of food production throughout the whole supply chain. By that way detailed evidence about environmental impacts of food production can be collected which has many benefits. The life cycle stages with largest impacts can be identified and thus focus on improving environmental performance can be directed to those stages. It is possible to find out whether specific food products cause higher impacts or even compare impacts between producers, production systems or technologies. This in turn can help companies to adopt more sustainable production practices and to compare their own performance with competitors. With the help of detailed information governments can target their policies better or even impose direct incentives for companies. In addition, consumers are increasingly demanding information about environmental impacts of food supply chains. (Deconinck and Toyama 2022, 6-7.)

It is important to recognize the essential share of international trade in the formation of environmental impacts of food products. Typically, the environmental impacts of countries have been measured and reported production-based which means that the impacts are thought to belong to the producer country. This approach, however, does not tell the whole truth as a country can have a good production-based environmental performance whereas a considerable share of environmental impacts may be embodied in imported products. Thus, it is important to consider consumption-based environmental performance which links the environmental impacts of the imported products to the country where the final consumption takes place. This helps in identifying which measures are most effective when improving environmental performance in food supply chains. It is inefficient to target policies on domestic products if the biggest share of impacts are embodied in imported products. On the other hand, if most demand of products produced in a country occurs abroad informing citizens about sustainable consumption choices only has a limited impact. (Deconinck and Toyama 2022, 7.)

2.5.1 Displaced impacts

Globally the role of international trade in environmental impacts of food systems is significant. According to Hong et al. (2022, 597) 22 % of agricultural land and 27 % of GHG emissions from land use are embodied in agricultural products that are consumed elsewhere than the region where they are produced. Transfers form low-income countries e.g. Indonesia, Argentina and Brazil to more industrialized regions e.g. China, United States and Europe are the largest (Hong et al. 2022, abstract). According to Pendrill et al. (2019, 1) and Pendrill et al. (2020) approximately 13 % of GHG emissions from food consumption in EU countries come from deforestation emissions. According to Sandström et al. (2018, 48, 51) in an average EU-28 country 64 % of GHG emissions from food production and trade come from domestic food products or imports from other European countries and the rest from elsewhere in the world when emissions from primary production, land use change and international trade are included. The share of Latin America is 25 % followed by Asia (7 %) and Africa (3 %) (Sandström et al. 2018, 51).

It has been found out that in general the biggest GHG emissions occur at the beginning of food supply chains in land use and agricultural production phases. According to Crippa et al. (2021, 198) 71 % of the food systems GHG emissions are formed in these two stages globally. However, the relative share of different supply chain stages varies between countries. Similar results have been found when considering the GHG emissions of single food products as land use change and on-farm emissions typically cause the biggest share of GHG emissions. As in the case of country specific food system GHG emissions the impacts of food products vary significantly even within same product categories. (Deconinck and Toyama 2022, 10, 14-15.)

Sandström et al. (2017) have investigated global land use, water use and biodiversity impacts resulting from food consumption in Finland between 1986-2011. Biodiversity impacts were assessed based on land use and water use. It was found out that in 2010 more than 93 % of land use related biodiversity impacts and over 99 % of water use related biodiversity impacts resulting from Finnish food consumption occurred outside Finland. The most serious biodiversity impacts from crop imports related to land use took place in Brazil, Indonesia, Colombia and India. From single crop imports the biggest impacts were caused by coffee, cocoa, sugar, rubber and soybeans. Imports of coffee from Mexico, Brazil, Colombia and India had the highest land use related biodiversity impacts. The biggest water consumption related biodiversity impacts were caused by citrus fruits and rice from USA, Egypt and Spain. Global biodiversity loss in Finland is small because in Northern Europe endemic species richness is low. (Sandström et al. 2017, 34-35, 37.)

A study conducted by Järviö et al. (2022) found similar results. In the study biodiversity impacts of food consumed in Finland were analysed based on land stress. The preliminary results of the study found that even though most of the land use takes place in Finland the largest biodiversity impacts occur outside of EU. Most of the biodiversity impacts linked to food consumption in Finland were caused by production of coffee and sugar cane as well as grazing. (Järviö et al. 2022.) The results represent the total consumption instead of impacts per unit (Järviö, email 24 March 2023). Brazil, Cuba and India were the locations where the biggest impacts seemed to occur (Järviö et al. 2022).

3 Methodology

In this chapter the methodology of this thesis is explained. As an introduction to this chapter the most common research methods for assessing the environmental impacts of food are presented in section 3.1. In this study LCA and LC-IMPACT method are used in analysing the biodiversity impacts of coffee, tea and hot chocolate. The principles of LCA are presented in section 3.2 mainly based on standards ISO 14040 and ISO 14044. LC-IMPACT method is explained in section 3.3.

3.1 Assessment methods used in analysing environmental impacts of food

The environmental impacts of food production have been assessed by downscaled estimates, LCA (discussed in section 3.2) and trade-based approaches. In downscaled estimates the share of food is defined from the environmental impacts in certain sectors where the overall impacts are known. For example, when the GHG emissions of transport sector as a whole are known the share of food in transport activities can be estimated to define transport related emissions of food. When this method is applied for different supply chain stages an overview of the contribution of different supply chain stages to the impacts is gotten. Downscaled estimates have been so far used mainly in assessing GHG emissions and water use. (Deconinck and Toyama 2022, 10-11, 24.) For example, Crippa et al. (2021) have used downscaling in their study (Crippa et al. 2021, 204-206).

Trade-based approaches use information about economic flows to trace product flows in order to link environmental impacts from the place of production to the place where the final consumption of the products happens. In these approaches input-output tables are used that tell how outputs of one sector are used as inputs in other sectors. Input-output approach is often used together with LCA. Usually input-output tables are compiled based on monetary values of trade flows. When this kind of tables are used the environmental impacts are economically allocated assuming that the impacts are embodied in product flows relative to their monetary value. This assumption may give misleading results. (Deconinck and Toyama 2022, 24, 27.)

Input-output approaches can also be based on physical product flows. One example is the Food and Agriculture Biomass Input-Output Model (FABIO) developed by Bruckner et al. (2019). FABIO is a set of tables from where supply, use, inputs and outputs of the agricultural and food product flows in the world economy can be seen in physical units. (Bruckner et al. 2019, 11302.) These tables are multiregional and they include 191 countries and 125 products from agriculture, food and forestry between 1986-2013 (Bruckner and Kuschnig 2020; Bruckner et al. 2019, 11302.) For example, Järviö et al. (2022) have used FABIO database in their study.

3.2 Life Cycle Assessment

LCA is a method developed to analyse the potential environmental impacts of a product (or a service) throughout its life cycle from raw material acquisition to recycling and disposal. By conducting LCA studies it is possible to identify possibilities to reduce environmental impacts of products in different stages of their life cycle, to provide information for decision-makers and to select essential indicators of environmental performance. Results of an LCA study can be also beneficial for marketing, for example in ecolabelling. (SFS-EN ISO 14040: 2006, v.)

There are four phases in an LCA study: goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA) and life cycle interpretation. In goal and scope definition phase the aim of the study as well as the extent and level of detail are defined. In LCI phase data is collected and essential inputs and outputs for a product are calculated. In LCIA phase the significance of the potential environmental impacts is analysed in certain previously defined impact categories based on LCI results. (SFS-EN ISO 14040: 2006, v, 11, 13-14.) In this step environmental flows are translated to impact categories by using characterization factors (CFs) (SFS-EN ISO 14044:2006, 20). Finally, in life cycle interpretation phase the results from LCI and LCIA phase are evaluated, conclusions are drawn and recommendations are given (SFS-EN ISO 14040: 2006, v, 16).

When defining the goal of an LCA study the intended application, reasons for conducting the study, intended audience and whether the results are intended to be used in publicly presented comparative claims are determined. The scope must include the product system under study with its functions, functional unit and system boundaries. Functional unit is a reference unit to which input and output data of a product system are scaled. When defining the functional unit, also the reference flow must be defined which means the amount of the outputs from the product system required to fulfil the function of the functional unit. System boundaries, in turn, include the unit processes examined in the study. In the scope definition also allocation procedures, impact assessment methods, types of impacts, type of interpretation, data requirements, assumptions, limitations, initial data quality requirements, value choices and optional parts, type of critical assessment if used as well as the type and format of the report are considered. LCA is an iterative study and thus the scope may need to be modified later during the study. (SFS-EN ISO 14044:2006, 4-5, 7, 8.)

LCI phase is an iterative process where the essential inputs and outputs of a product system are quantified through data collection and calculation procedures. When collecting data and familiarizing oneself deeper with the system new data requirements or limitations may arise which require changing data collection methods so that the goal of the study will still be achieved. It is also possible that such things are recognized that require redefining the goal and scope of the study. (SFS-EN ISO 14040: 2006, 13.)

Qualitative and quantitative data included in the inventory must be collected for every unit process inside the system boundaries. The collected data can be either measured, calculated or estimated. The most important titles under which data is classified are “energy inputs, raw material inputs, ancillary inputs, other physical inputs”, “products, co-products and waste”, “releases to air water and soil” and “other environmental impacts”. (SFS-EN ISO 14044:2006, 11-12.) After collecting the data inventory results for every unit process as well as for the functional unit of the product system under study are formed by applying calculation procedures such as data validation and relativizing data to unit processes and/or to the reference flow of the functional unit (SFS-EN ISO 14040: 2006, 13). All calculation procedures must be documented unambiguously and assumptions must be clearly reported and explained. (SFS-EN ISO 14044:2006, 13.)

In LCIA phase inventory data is associated with environmental impact categories and category indicators to understand the environmental impacts. This phase also gives information for interpretation phase. It is critical that LCIA is conducted and reported transparently because for instance selection, modelling and evaluation of impact categories can bring subjectivity to this phase. It is also important to take into account that LCIA covers only those environmental issues that have been defined in goal and scope definition and therefore it does not consider comprehensively all environmental issues of the product system under study. (SFS-EN ISO 14040: 2006, 14-15.)

The mandatory parts that LCIA must include are (SFS-EN ISO 14044:2006, 16):

- selection of impact categories, category indicators and characterization models
- classification which means assignment of LCI results to the selected impact categories
- characterization which means calculation of indicator results

Impact category is a class that represents the environmental impacts under study to which LCI results can be assigned, for example climate change. Category indicator is a quantitative measure that represents the impact category, which is for example in the case of climate change infrared radiative forcing (W/m^2). Characterization model presents the environmental mechanism by describing the relation of LCI results, category indicators and in some cases category endpoints. In the case of climate change the characterization model can be for example the baseline model of 100 years of the Intergovernmental Panel on Climate Change. Environmental mechanism, in turn, is a system functioning in each impact category formed by physical, chemical and biological processes and it combines the results of LCI to category indicators and category endpoints. Category endpoint refers to a natural environment, health or natural resources related phenomenon that is used to express environmental issue under concern. (SFS-EN ISO 14044:2006, 5-6, 18.)

In LCIA phase midpoint or endpoint approach can be used which are characterization models offering indicator results at different levels. In the midpoint approach environmental impacts are analysed at a cause-effect chain level from consumption of a resource or the release of a substance to the level of endpoint. (Dong and Ng 2014, 1410.) During characterization LCI results are converted to common units by using CFs and these modified results are combined inside each impact category. The final result of characterization is a numeric indicator result. In climate change impact category, for example, the CF is GWP_{100} as kg CO_2eq/kg gas and the category indicator result is expressed as kg CO_2eq per functional unit. (SFS-EN ISO 14044:2006, 18, 20.)

In the endpoint approach, in turn, environmental impacts are assessed at the level of areas of protection (AoP), such as ecosystem, resource and human health (Dong and Ng 2014, 1410).

In this thesis endpoint approach is used to assess the impacts of food products on biodiversity. More information about the chosen endpoint methodology is given in section 3.2.

After characterization a compilation about different category indicator results of LCIA (LCIA profile) can be made. Voluntary additional steps of LCIA include normalization, grouping, weighting and data quality analysis. (SFS-EN ISO 14044:2006, 20-21.)

Finally, in the interpretation phase the results from both LCI and LCIA are considered together. This phase should produce such results based on which conclusions and recommendations can be made and limitations be explained. The aim of interpretation is also to present the results of the LCA study in an easily understandable, complete and consistent form. Interpretation should be consistent with the goal and scope of the study. (SFS-EN ISO 14040: 2006, 16.)

3.3 LC-IMPACT method

There are several different LCIA methods available for assessing biodiversity impacts. However, a generally accepted method does not yet exist. (Crenna et al. 2020, 9715.) LC-IMPACT was chosen in this study because of consistency as it was also used in Järviö et al. (2020) study. In addition, LC-IMPACT performed well in the inclusion of pressures, ecosystems and taxonomic groups in Damiani et al. (2023, 7-8) study that evaluated different biodiversity impact assessment methods based on how well biodiversity has been considered in the methods.

In this section LC-IMPACT is first described in general in section 3.3.1. After that in sections 3.3.2-3.3.4 the cause effect pathways, taxonomic groups included and types of CFs available for climate change, land stress and water stress impact categories are presented.

3.3.1 LC-IMPACT in general

LC-IMPACT is an LCIA method developed by Verones et al. (2020a) in their study *LC-IMPACT: A regionalized life cycle damage assessment method*. As the title states LC-IMPACT includes a spatial detail for environmental impacts that occur on a local or regional scale. When considering the impact categories chosen in this study land use and water use need regionalization whereas the impacts of climate change are global despite the location of emission. (Verones et al. 2020a, 1203, 1205.)

LC-IMPACT has an endpoint approach where three AoPs have been chosen: human health, ecosystem quality and natural resources. Ecosystem quality has been further divided into terrestrial, freshwater and marine ecosystems. In total 11 impact categories have been linked to the three AoPs: climate change, ozone depletion, ionizing radiation, photochemical ozone formation, particulate matter formation, acidification, eutrophication, toxicity, land stress, water stress and mineral resources scarcity. From all of these climate change, photochemical ozone formation, acidification, eutrophication, toxicity, land stress and water stress are linked to ecosystem quality as shown in Figure 1. (Verones et al. 2020b, 7.)

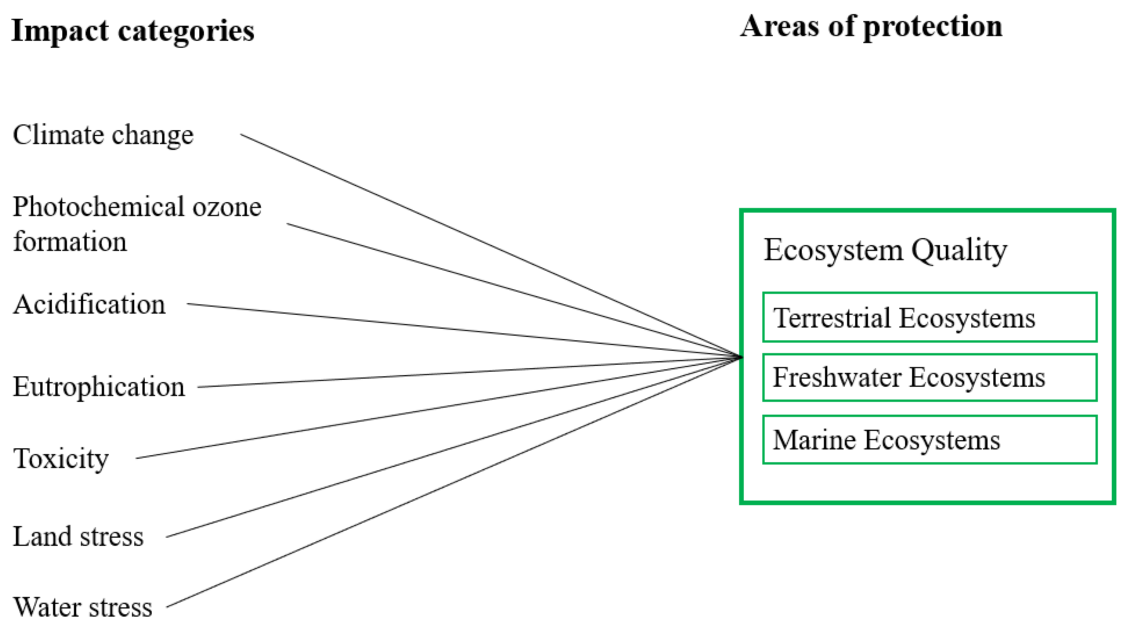

Figure 1. Impact categories linked to ecosystem quality AoP. Adapted from: (Verones et al. 2020b, 7).

The endpoint unit for ecosystem quality AoP is potentially disappeared fraction of species (PDF) (Verones et al. 2020b, 9). When quantifying impacts in LCIA the damage for ecosystem quality is expressed as PDF over time (PDF·y) per functional unit. In LC-IMPACT method PDF is defined on a global level instead of local or regional and thus it refers to irreversible extinction of species on a global scale. This is because a regionally extinct species is not necessarily lost on a global level and it may be possible to be recovered through repopulation. Thus, regional extinction of a species is not irreversible. (Verones et al. 2020a, 1206.)

The loss of species is considered in relation to species occurring globally which thus leads to “a globally normalized PDF of species” (Verones et al. 2020b, 9). The time unit (y) does not mean that the species is lost during a certain time period but rather indicates that more weight is given to long-lasting interferences rather than short-lasting ones. For example, a PDF of 0,03 would mean that 3 % of global species will go extinct if the pressure continues. Impact scores should not either be interpreted as immediate loss of species but as an increase in risk of global extinction over a specific exposure time. (Verones et al. 2020a, 1206.)

The basic equation based on which all ecosystem CFs in LC-IMPACT have been calculated is shown in the equation 1 below (Verones et al. 2020b, 8):

$$CF_{ecosystem\ quality} = FF \cdot XF \cdot EF \cdot VS \tag{1}$$

where FF is a fate factor, XF is an exposure factor, EF is an effect factor and VS is a vulnerability score. In some impact categories (e.g. land stress) XF has been omitted because it equals to 1. VS varies between 0-1 and the bigger the value the more threatened the species is or the species is probably endemic. (Verones et al. 2020b, 7-8.) Different taxonomic groups can have different values for VS and EF (Verones et al. 2020a, 1206).

LC-IMPACT provides CFs for all impact categories included in the method (Verones et al. 2020a, 1215). The CFs are defined by following either a marginal or an average/linear approach. In the marginal approach the reference state is the current situation and it is investigated how big additional impact is caused by a small increase of pressure or concentration. In a cause effect curve the impact is defined as a derivative at the point of current situation. In the average approach the reference state is also the current situation but the change is related to a state of zero effect, a preferred state or a possible future state. The average impact per unit of change is calculated based on the difference between the current situation and one of the three last mentioned states. A linear approach is used when information about the current state is not available. The reference situation in linear approach is assumed to be 0.5 (50 %) which is compared to a state of zero effect similarly as in average approach. Table 1 below shows the approaches available for the impact categories chosen in this study. The approach of climate change is a mix of marginal and average approaches. (Verones et al. 2020a, 1203-1204, 1206; Verones et al. 2020b, 10-11.)

Table 1. Approaches covered by the impact categories chosen in this study (Verones et al. 2020b, 11).

Environmental mechanism	**Marginal**	**Average**
Climate change	x	x
Land stress	x	x
Water stress (ecosystems)	x	

Both approaches have their own strengths. By using the marginal approach small changes in resource use or emissions can be calculated whereas by using the average approach impacts of larger changes can be assessed. When possible, it is recommended to use CFs consistently so that either marginal or average/linear factors are used in all of the impact categories chosen in the study. (Verones et al. 2020b, 10-11.)

LC-IMPACT method includes some value choices. These are time horizon and the level of evidence of impacts. The impacts can be considered either on a short-term (100 years) or on a long term and all impacts can be included or only certain impacts with a high level of scientific evidence. (Verones et al. 2020a, 1207.) Thus, four different types of CFs are available: all impacts, 100 years; all impacts, long-term; certain impacts, 100 years; certain impacts, long-term (Verones et al. 2020b, 11-12). From these four types "all impacts, long-term" and "certain impacts, 100 years" differ from each other the most and therefore it is recommended to include at least these two scenarios to an LCA study (Verones et al. 2020a, 1207). To understand the full extent and nature of the impacts it is also recommendable to calculate the results by using all the four types of CFs (Verones et al. 2020b, 12).

3.3.2 Climate change

The cause effect pathway of climate change affecting on ecosystem quality according to Verones et al. (2020b, 21) is illustrated in Figure 2. Climate change affects terrestrial and freshwater ecosystems. The cause effect pathway begins when GHG emissions are released to the atmosphere which results in an increase in GHG concentration of the atmosphere. This increased concentration causes increased radiative forcing in the atmosphere which leads to a bigger part of the solar energy remaining there. As a result, the global temperature increases which affects the natural ecosystems. (Verones et al. 2020b, 21.)

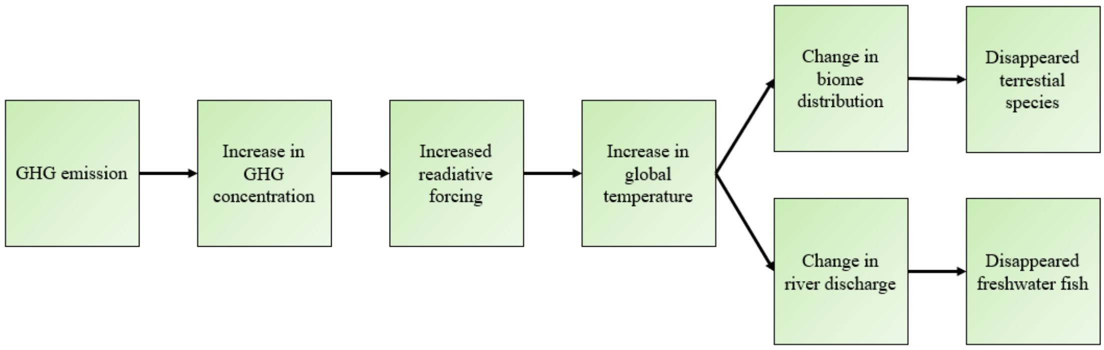

Figure 2. The cause effect pathway of climate change affecting on ecosystem quality. Adapted from: (Verones et al. 2020b, 21).

As a result of increased temperatures the distribution of terrestrial ecosystems will shift. All species will not be able to migrate fast enough to follow the change in vegetation essential for them which will lead to extinctions. Climate change can decrease river discharges which may affect freshwater ecosystems. A decrease in a river discharge will likely cause several different species to go extinct in that river system because rivers with lower discharges cannot sustain as much different species of fish as rivers with larger discharges. (Verones et al. 2020b, 22.)

For ecosystem quality the unit for the endpoint CFs for climate change is PDF*y/kg GHG and the factors represent the "potentially disappeared fraction of species over a period of time due to the emission of 1 kg of GHG". In the climate change CFs there is no spatial resolution. The terrestrial species included are birds, mammals, reptiles, frogs and butterflies. All these species are included in all the four types of CFs for terrestrial ecosystems. Fish in global river basins below 42º latitude are included in the freshwater ecosystem "all impacts" CFs. In norther regions river discharge and the number of fish species are not proportional to each other. In the "certain impacts" CFs freshwater ecosystems are not considered due to uncertainty. The response of fish representing all aquatic species is unlikely which causes uncertainty. The types of CFs available for climate change impact category and the ecosystems included in them are compiled in Table 2. (Verones et al. 2020b, 12, 15, 22, 24-27, 31.)

Table 2. The CFs available for climate change impact category and the ecosystems included in them (Verones et al. 2020b, 12).

Included ecosystems	**All impacts, long-term (1000 years)**	**All impacts, 100 years**	**Certain impacts, long-term (1000 years)**	**Certain impacts, 100 years**
Terrestrial ecosystems	x	x	x	x
Freshwater ecosystems	x	x		

3.3.3 Land stress

In LCI and LCIA land transformation (i.e. land use change) and land occupation are usually considered. Land transformation means modifying of land in order to make it suitable for a certain purpose, for example making space for agriculture through deforesting. Land occupation, in turn, means using land in the certain productive way and thus the development of the land towards a natural reference state is prevented. This happens for instance when the land is used for agriculture and the regrowth of forest is avoided. (Verones et al. 2020b, 135.)

Figure 3 presents the cause effect pathway of land use affecting on ecosystem quality according to Verones et al. (2020b, 136). Land transformation and occupation cause physical changes to local flora and fauna through habitat loss. As a result, the species composition and richness changes on the modified land area. This leads to extinctions of species on regional or global scales if too much of their suitable habitat is lost which thus causes damage to ecosystem quality. (Verones et al. 2020b, 136.) Land stress impact category considers terrestrial ecocystems (Verones et al 2020a, 1206).

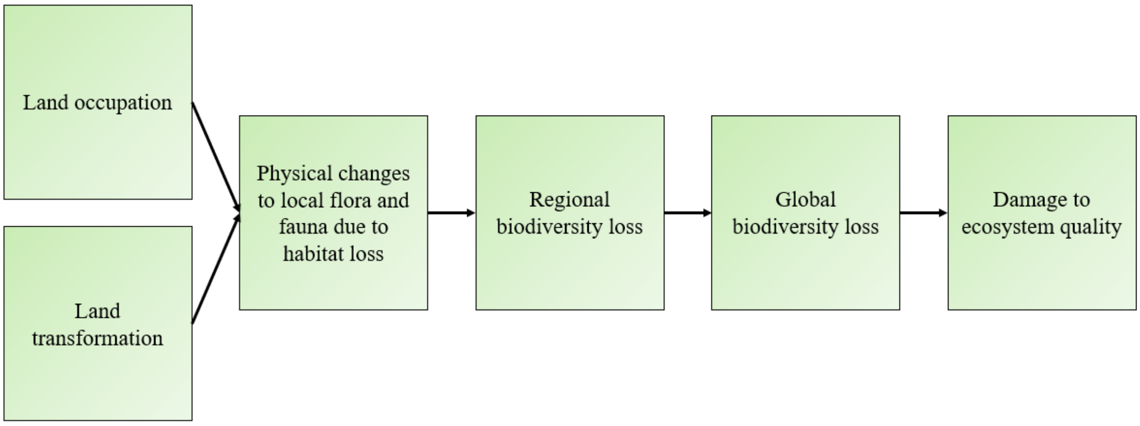

Figure 3. The cause effect pathway of land stress affecting on ecosystem quality. Adapted from: (Verones et al. 2020b, 136).

In LC-IMPACT model CFs have been calculated for six land use types (annual crops, permanent crops, pastures, urban, extensive forestry and intensive forestry) and five taxa have been included (mammals, birds, reptiles, amphibians and vascular plants). Both unweighted and weighted CFs are available. In the weighted values VS as an indicator of global extinction risk of the taxonomic groups has been considered and aggregation of different taxa as well as equal weighting of animal and plants taxa has been made. For land transformation the unit of weighted and aggregated CFs is PDF*y/m^2 and for land occupation PDF*y/m^2*a. (Verones et al. 2020b, 137, 139-140, 142-143.)

CFs for land transformation and occupation are available for 804 different size ecoregions as well as for continents and 245 countries as average values based on the share of ecoregions inside their borders. CFs are defined by using both marginal and average approach. Also, global averages are available for background processes where the locations of land use are unknown and they have been calculated with average approach. (Verones et al. 2020b, 137, 141-142.)

Time horizon for land occupation is not relevant and for all the four types of CFs the included effects are occupation of six land use types. Therefore, for land occupation there are actually only one type of CFs from the perspective of time horizon and level of certainty. For land transformation the time horizon is either 100 years on short-term or total recovery time (up to 1200 years) on long-term. The recovery time of biodiversity in a region ranges approximately between 80-1200 years after human land use has ended. It depends on prior land use, ecosystem and taxa. Also, in the case of land transformation the included effects are the transformation of six land use types for all four types of CFs. Thus, there are two types of CFs for land transformation from the perspective of time horizon (100 years "core" CFs and total recovery time "after 100 years" CFs) which both have the same level of certainty. The different CFs available for land stress with their time horizons and included effects are compiled in Table 3. (Verones et al. 2020b, 14, 142.)

Table 3. Time horizons and included effects of the occupation and transformation CFs (Verones et al 2020b, 14).

	Occupation	**Transformation, short-term**	**Transformation, long-term**
Time horizon	not relevant	100 years	Up to 1200 years depending on ecosystem
Included effects	6 land use types	6 land use types	6 land use types

3.3.4 Water stress

LC-IMPACT considers the impacts of water consumption on biodiversity including aquatic and riparian habitat as well as vascular plants that represent more terrestrial systems. The analysis has been limited to freshwater systems thus excluding marine and coastal waterbodies that are affected by saltwater. The focus is on physical availability of water. In LC-IMPACT word "wetland" is used to describe water, peatland, marsh and fen areas. (Verones et al. 2020b, 160.) Five taxonomic groups have been included: birds, mammals, amphibians and reptiles as proxies for freshwater and riparian ecosystems as well as vascular plants as a proxy for more terrestrial ecosystems. (Verones et al. 2020b, 160-161). Water stress impact category considers freshwater ecosystems (Verones et al. 2020a, 1206).

LC-IMPACT includes two impact pathways that describe the impacts of water consumption on biodiversity. Figure 4 shows the cause effect pathway of water consumption affecting on terrestrial and freshwater species. Terrestrial species in this cause effect chain refer to riparian habitats. The chain begins with an increase in water consumption which changes either surface water volume or groundwater table. Because of this also wetland area changes which can lead to loss of terrestrial and freshwater species. This impact pathway considers birds, mammals, reptiles and amphibians. (Verones et al. 2020b, 160-161.)

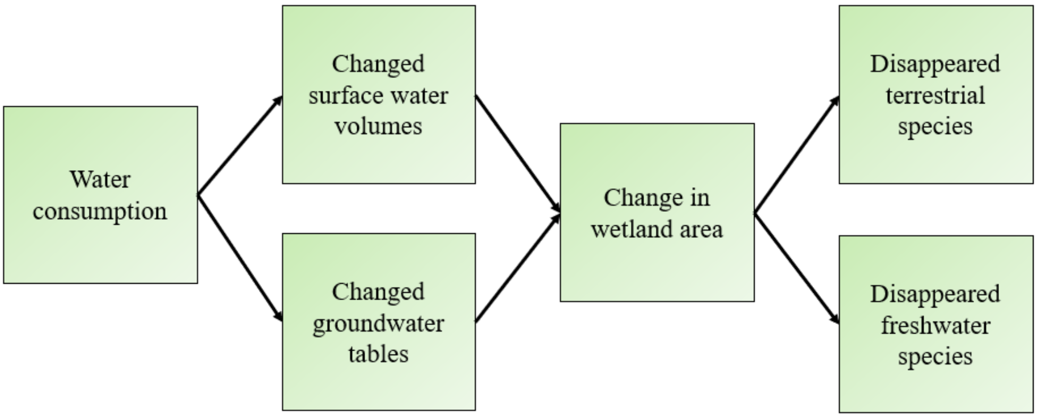

Figure 4. The cause effect pathway of water use affecting on terrestrial and freshwater species. Adapted from: (Verones et al. 2020b, 161).

Figure 5 presents the cause effect chain of water consumption affecting on terrestrial habitat. Water consumption leads to diminishing of water limited net primary production (NPP) of plants and thereby may cause loss of vascular plant species. (Verones et al. 2020b, 161.) This is based on that water consumption on areas where the growth of plants is water limited can reduce the availability of water to plants thus diminishing vegetation and the diversity of plants (Pfister et al. 2009, 4100).

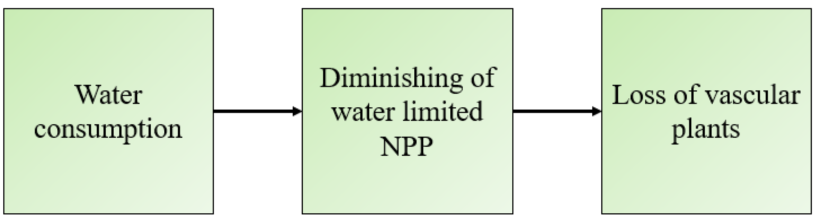

Figure 5. Cause and effect pathway of water use affecting on vascular plants. Adapted from: (Verones et al. 2020b, 161).

The time horizon of the CFs is not relevant. All impact CFs include both the surface water and groundwater impacts on waterbodies and certain impacts CFs include only the impacts of surface water consumption because groundwater-fed waterbodies have bigger uncertainties and significantly less data available. Thus, there are two types of CFs available. The CFs have been defined using marginal approach and they are available with a 0.5º x 0.5º resolution. Country and continental averages for the CFs are also available. The unit of the CFs is PDF*y/m^3. (Verones et al. 2020b, 14, 162, 168.)

4 Assessing biodiversity impacts of selected food products

In this chapter the biodiversity impacts of coffee, tea and hot chocolate consumed in Finland are calculated according to the principles of LCA. First, the goal and scope of this study is defined in section 4.1. After that inventory analysis is conducted in section 4.2. Finally, LCIA phase is done in section 4.3. Due to clarity some inventory data is presented already in goal and scope definition.

4.1 Goal and scope definition

The goal of this thesis is to investigate the biodiversity impacts of coffee, tea and hot chocolate consumed in Finland. It is studied in which supply chain stages and locations the biggest impacts occur. It is also discussed how the biodiversity impacts could be reduced. The intended audience of this thesis is academic. The results of the thesis are not intended to be used in comparative assertions intended to be disclosed to the public.

Biodiversity impacts are defined based on the impacts of land stress, water stress and climate change by using LC-IMPACT method as described in sections 3.3-3.3.4. The modelling of the impacts is conducted by using openLCA software and Agribalyse 3.0.1 database as well as MS Excel.

The functional unit of this study is 2 dl of each prepared drink. The system boundaries include primary production, oversea transportation and consumption phase in the case of all three drinks. Depending on the product also processing of the product may be included. Transportation inside the borders of countries is not considered because its impacts are assumed to be small compared to the oversea shipping. The primary production of each product is also considered on an average country level and thus the exact locations of the farms are not defined. Packaging and retail are excluded as they are assumed to have a minimal impact. It has been found out that the share of package and retail from the total carbon footprint of food products is small (Ritchie 2020). In consumption phase dish washing is not considered because its effect is the same for all the chosen products. Food waste and end-of-life are also excluded. More detailed system boundaries for all three drinks are presented in sections 4.1.1-4.1.3.

In the inventory analysis cut-off criteria is used in calculating the flows related to land transformation and occupation so that all the flows that contribute at least 1 % of the total land use are taken into account. This is done because the flows contributing to less than 1 % can be assumed to have a minimal impact on the results. All land transformation and occupation flows included in the calculations are assumed to be located in the country where the process in question takes place due to lack of other information and to simplify the calculations.

In LC-IMPACT there is no CF available for all land use types that appear in the inventory flows. Those flows are considered if their contribution to total land flows is at least 5 % because excluding all of them would cause too much uncertainty to the results. Mineral extraction site land flows are considered as urban land flows whereas unknown forest and secondary (non-use) forest land flows are considered as extensive forestry land flows. Land flows related to waterbodies and seabed are left out because they are not close to any land use type to which CFs are available in LC-IMPACT method.

In all the processes chosen from the Agribalyse 3.0.1 database water use related to energy production (cooling or turbine use) covers most of the water flows. However, it has been assumed that these water flows do not represent consumptive water use but are water flows going through energy production processes and thus the water is released back to where it has been taken from. The cut-off criteria for water flows depends on the process and therefore is defined separately in each case.

In climate change impact category all CO_2, CH_4 and N_2O outputs are considered except for biogenic CO_2. This is because LC-IMPACT method does not cover biogenic CO_2 emissions (Verones, email 7 June 2023).

In transportation phase only the impacts of climate change are considered because land use and water use are assumed to be minimal in this life cycle stage. It would also be difficult to trace the locations of land and water use associated with oversea transportation. Consumption of the beverages is assumed to take place in Helsinki, Finland.

In the LCIA phase marginal approach for CFs is chosen because it was also used in Järviö et al. (2022) study. In addition, CFs defined by the marginal approach are available for all impact categories chosen in this thesis but average/linear CFs are not available for environmental mechanism considering water stress from the point of view of ecosystems (Verones et al. 2020b, 11). Therefore, it is more logical to use marginal approach.

Because of the limited time available to complete this thesis not all four types of CFs from the point of view of time horizon and level of evidence of impacts are included. In Järviö et al. (2020) study the 100-year time horizon was used. Thus, in this thesis impacts are assessed based on short-term 100 years CFs, too. In terms of the level of evidence of impacts the included effects under consideration in CF types “all impacts, 100 years” and “certain impacts, 100 years” differ in climate change category considering impacts on freshwater ecosystems and in water stress impact category (Verones et al. 2020b, 12, 14). In this thesis all impacts are included.

So, when considering the available CFs presented in sections 3.3.2-3.3.4 in climate change impact category marginal CFs for 100-year time horizon with all impacts are used. In land use impact category weighted values for marginal country specific CFs are used for transformation and occupation. In addition, for transformation 100-year time horizon is used. In water use impact category country specific CFs with all impacts are used.

When interpreting the results of this thesis charts are drawn to compare the three products with each other and to demonstrate the contribution of different life cycle stages to the overall impacts of each product. Charts are also drawn to demonstrate the locations where the biggest impacts occur. The interpretation section also includes discussion about the reliability of the results including a sensitivity analysis about how changing the location of coffee, tea and cocoa bean production will affect the results.

4.1.1 The scope of coffee

Arabica and robusta are the two main commercial coffee varieties from which arabica is the most used in Finland (Paulig 2023). In 2020 Brazil produced approximately 37 % of all coffee in the world therefore being the biggest coffee producer country. Also, more than a half of all arabica coffee in the world was produced in Brazil in 2020. (International Coffee Organization 2021.) For these reasons arabica coffee produced in Brazil is chosen to represent coffee consumed in Finland.

Coffee is transported to Finland from the country of origin by a ship to Hamburg, Antwerp or some other big European port from where it is brought to Helsinki by a smaller cargo ship (Kahvi- ja paahtimoyhdistys 2023). Therefore, the transport route is chosen to be from Brazil to Antwerp and from Antwerp to Helsinki in this study. The location of the port in Brazil is not defined precisely because the exact location of the coffee plantation is not known either.

The system boundaries include the production of arabica coffee beans, transportation of the coffee beans from Brazil to Finland, roasting and grinding of the coffee beans in Finland and the consumption phase of coffee. The system boundaries for the coffee modelling are presented in Figure 6. The waste generated in consumption phase is used coffee powder.

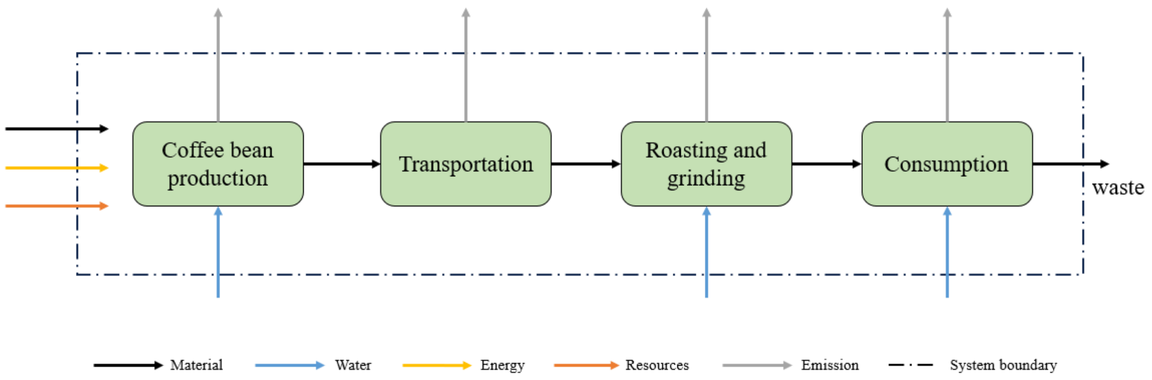

Figure 6. The system boundaries of coffee.

The chosen production system of green coffee beans in Agribalyse is ‘coffee green bean production, arabica - BR’. The data represents an average situation in Brazil for the production of the coffee beans for export market. The establishment phase of the orchard as well as all activities during a year in the productive phase are included. The included activities start from the nursery production of fruit tree seedlings and end to the waste treatment after the clearing of the orchard. The lifetime of the orchard is 20 years. Tree nursery, soil cultivation, planting of trees, planting of trellis system and irrigation have been included to the establishment phase. In the productive phase machine operations, corresponding infrastructure, sheds and fuel use have been included. Machine operations include soil cultivation, application of fertilizers and pesticides, irrigation and harvesting. Orchard is cleared by rooting up the trees at the end of the productive phase. Wood fuel is used in the drying of the coffee beans. Land use change and direct field emissions are considered. The packaging of fertilizers and pesticides as well as the inputs of fertilizers, pesticides and seedlings have also been taken into account. (Guignard and Peano 2016a.) The production of fertilizers has not been mentioned in the description of the process, so it is uncertain whether it has been included in the data or not.

The average yield used in the coffee bean production process is from years 2001-2014 and it is 1800 kg/ha. The amount of water used for irrigation is 1987 m^3/ha. The input of nitrogen (N) fertilizer is 173 kg/ha, phosphorous (P) fertilizer 35 kg/ha and potassium (K) fertilizer 247 kg/ha. The amount of applied pesticides is 7.8 kg/ha. In a year of the establishment phase the pesticide and fertilizer use has been assumed to be half of the amount used per year in productive phase. (Guignard and Peano 2016a.)

The chosen transportation process of the green coffee beans from Brazil to Finland 'transport, freight sea, transoceanic ship' represents the whole lifecycle of transport. It includes the construction of the port as well as the production, operation and maintenance of the ship that has a tank size of 50 000 deadweight tons (DWT) and an average propulsion of slow speed engine and steam turbine. (Spielmann 2012.) This process is used to model transportation along the whole shipping route from Brazil via Antwerp to Helsinki because no other suitable ship transportation processes were available in the Agribalyse database. The transportation distance is mentioned later in inventory analysis (section 4.2.1).

The roasting and grinding process is chosen to take place in Finland. The chosen process in Agribalyse database 'Roasting and grinding, green coffee (WFLDB 3.1) – GLO' includes the direct emissions related to roasting as well as the inputs of water, energy and the factory building (Guignard 2020c). Packaging of the finished product has been excluded (Guignard 2020c). The original process includes coffee beans and transportation in the input flows but those were deleted as coffee bean production and transportation are considered as separate processes in this thesis. The original process is global but the location was changed to Finland by substituting the original electricity input with 'Electricity, medium voltage {FI}| market for | Cut-off, S – Copied from Ecoinvent – FI'. Also, in LCIA phase the inventory flows of land and water are multiplied by Finland specific CFs.

The consumption phase includes water consumption in coffee making as well as emissions and land use related to electricity use of a coffee machine. The impact of coffee filter is not considered. The impacts of electricity use in coffee making are modelled using a process ‘market for electricity, medium voltage – FI’. The dataset is based on statistics from 2014 (Treyer 2015). It includes electricity inputs produced domestically or imported as well as their transformation to medium voltage (Treyer 2015). The transmission network, direct emissions to air and transmission losses have also been considered (Treyer 2015).

In coffee bean production water flows from river and well located in Brazil are considered. These flows contribute to more than 1 % of all water flows of the process. In roasting and grinding direct water use in the process is considered with a share of 0.02 % from all water flows. In the consumption phase water use consists of water added in coffee making.

4.1.2 The scope of tea

Agricultural tea production processes are available in Agribalyse database for Kenya, Sri Lanka and China. Of these three the biggest amount of tea imported to Finland in 2021 came from Sri Lanka measured as monetary value (2.95 million dollars) (OEC 2023b). Also, in 2016 Sri Lanka was the second biggest exporter of tea to Finland (257 tons) after Poland that re-exported 355 tons (Finnpartnership 2017, 6). Therefore, tea produced in Sri Lanka is chosen to represent tea consumed in Finland. The tea ending up to consumer is assumed to be loose tea.

The system boundaries of tea include the production of dried tea leaves in Sri Lanka, transportation of tea to Finland and consumption of tea. The system boundaries are presented in Figure 7. The waste generated in consumption phase is used tea leaves. Tea blending is not considered due to lack of suitable process in Agribalyse 3.0.1 database. Its impact on the total results are also assumed to be small.

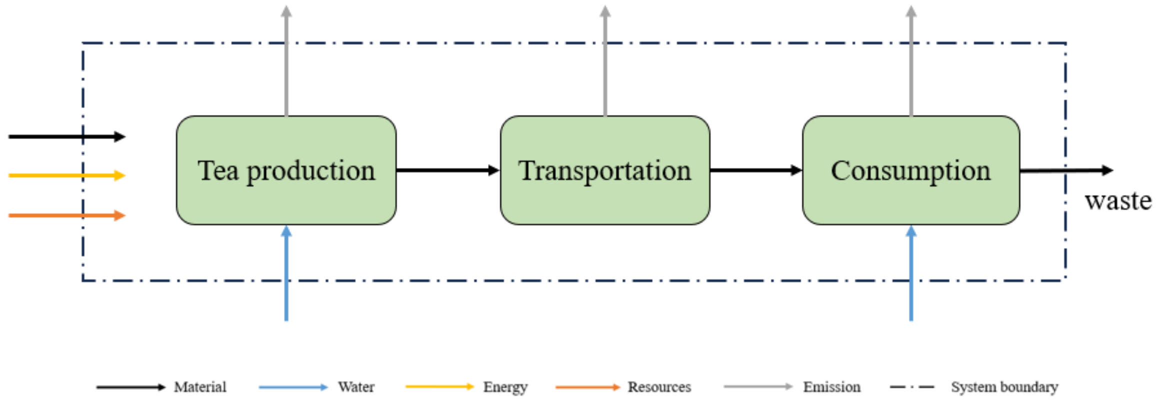

Figure 7. The system boundaries of tea.

The production system of tea ‘tea production, dried – LK’ in Agribalyse database represents the production of dried tea leaves for the export market. The included activities start with the nursery that produces tea tree seedlings and end with the waste treatment after rooting up the trees when clearing up the orchard. The lifetime of the orchard is 20 years. Tree nursery, soil cultivation, planting of trees, grass sowing, irrigation and installation of trellis system consisting of posts and wires have been included in the establishment phase of the orchard. Sheds, machine operations, corresponding infrastructure and fuel use have been included in the productive phase of the orchard. The machine operations are irrigation and fertilizer and pesticide application. Land use and direct field emissions have been considered. The productive phase ends with clearing of the orchard. The dataset includes the inputs of seedlings, pesticides and fertilizers and also the packaging of pesticides and fertilizers. Emissions of manure storage have been excluded. (Mouron and Riedener 2016b.) The production of fertilizers has not been mentioned in the description of the process, so it is uncertain whether it has been included in the data or not.

The average yield from 2009-2012 has been used in the dataset of the tea production process and it is 1.4 kg/ha. The input of mineral N fertilizer is 62 kg. Liquid manure is used as an organic fertilizer 2.46 m^3/ha and solid manure 2.35 t/ha. The amount of pesticide input is 6.92 kg/ha. In a year of the establishment phase the pesticide and fertilizer use has been assumed to be half of the amount used per year in productive phase. (Mouron and Riedener 2016b.)

It is assumed that tea is transported from Sri Lanka to Finland by a ship. The same transportation process is used as in the case of coffee. The transportation distance is mentioned later in inventory analysis (section 4.2.2).

The consumption phase of tea includes water consumption and electricity use in boiling of the water. The same electricity process is used as in coffee consumption phase.

In tea production process there are not any water flows for Sri Lanka, so it is assumed that water flows from river and well in rest of the world (RoW) are located in Sri Lanka. Those contribute more than 1 % from all water flows in the process.

4.1.3 The scope of hot chocolate

In Eneroth et al. (2022, 29) study cocoa drink consists of dairy/oat milk, cocoa powder and sugar. The same assumption is done in this thesis and the milk is assumed to be dairy milk.

A lot of milk is produced in Finland. For example, 2193 million liters of milk was produced there in 2022 (Natural Resources Institute Finland 2023). Therefore, Finland is chosen to be the production country for milk.

Ivory Coast is the biggest cocoa bean producer country and it produced approximately 2.1 million tons of cocoa beans in crop year 2021/2022 (Statista 2023). Thus, Ivory Coast is chosen as the country of origin for cocoa beans in this thesis. The processing and industrialization of cocoa typically takes place elsewhere than the region where it is produced, for example in Europe (37 %) (Guirlanda et al. 2021, 2). Finland imported cocoa powder the most from Netherlands in monetary value in 2021 (OEC 2023a). Therefore, the processing of cocoa beans is chosen to take place in Netherlands.

A little less than a half of the demand for sugar in Finland is covered by domestic sugar production from sugar beet. The rest is imported either as raw cane sugar from developing countries or as white sugar from Germany, Denmark and Sweden. (Lavonen 2021.) There is one sugar factory in Finland located in Säkylä (Pukkila 2021). It produces cane sugar from domestic sugar beet (Sucros Oy 2023a). Raw sugar imported in Finland is treated at a sugar refinery in Porkkala, Kirkkonummi (Sucros 2023b). In this thesis sugar beet production as well as sugar production from sugar beet are chosen to take place in Finland.

The system boundaries of hot chocolate include the production and pasteurisation of milk, the production and processing of sugar beet, the production and oversea transportation of cocoa beans and cocoa powder as well as the consumption phase where the ingredients of hot chocolate are prepared to a drink. The transportation of milk and sugar is not considered as it only takes place in Finland. The system boundaries of hot chocolate are presented in Figure 8.

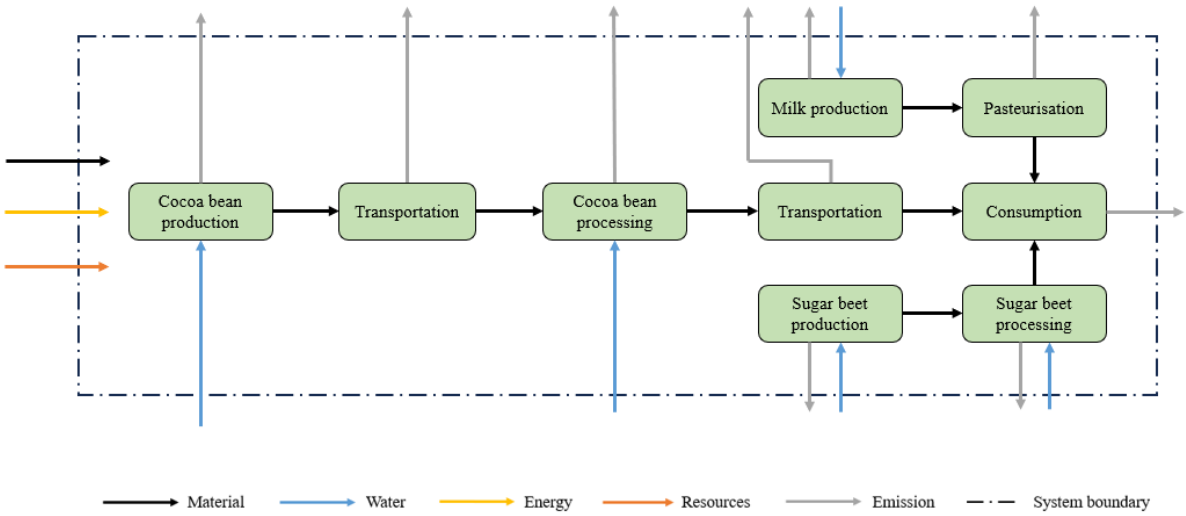

Figure 8. The system boundaries of hot chocolate.

The chosen milk production process ‘Cow milk, conventional, highland milk system, grass fed, at farm gate - FR’ in Agribalyse 3.0.1 database includes all activities of a cattle farm. Inputs as livestock, feeds, straw, water, energy, fuels and transport to the farm, infrastructure for milking as well as the buildings and housings have been included. Also, enteric emissions of the cows and emissions from the effluent management have been included in the inventory. The chosen process represents a highland milk system for grass fed cows in France. (Gac 2020) There were no grass fed processes available for lowland milk systems and because of that this process was chosen. In LCIA phase Finland specific CFs are applied to land and water flows of the process.

The chosen pasteurisation process for milk ‘Pasteurisation; from raw milk, at 72¡C for 30 s; French production mix, at plant; 1 kg of pasteurised milk (PGi) - FR’ in Agribalyse database includes electricity use, heat and burning of propane and it represents the situation in France

(Barrucand 2020). Water flows of this process are not considered in the calculations as there is no direct water use and the water amounts are very small. The input flow of milk was deleted as milk production is modelled as a separate process in this thesis. There are two empty pasteurizer inputs in the process. To include their contribution to the calculations they should have been replaced by flows of own choice which was not done in this case. The location was changed to Finland by substituting electricity input to ‘Electricity, medium voltage {FI}| market for | Cut-off, S – Copied from Ecoinvent – FI’. Also, in LCIA phase land flows are multiplied with Finland specific CFs.

The activities in the chosen sugar beet production process ‘sugar beet production – CH’ in Agribalyse database start after the harvest of previous crop and end after the harvest of the current crop at farm gate. The sugar beet root yield is 77640 kg/ha based on the average yield from years 2000, 2005 and 2008. Inputs of fertilizers, pesticides and seeds have been included as well as direct field emissions from manure as an organic fertilizer. Other direct field emissions have also been included. All machine operations, corresponding infrastructure and sheds have also been considered. The machine operations include cultivation of soil, sowing, pest management, weed control, harvest and transportation of sugar beets from field to farm over a distance of 1 km. Also, the cultivation of green manure before sowing of beets is considered. (Kägi and Nemecek 2016.) The production of mineral fertilizers has not been mentioned in the description of the process, so it is uncertain whether it has been included in the data or not. In LCIA phase land and water flows of the process are multiplied by Finland specific CFs.

The chosen process for sugar production from sugar beet ‘Sugar, from sugar beet, at sugar refinery, (WFLDB 3.1) – GLO’ includes the processing of sugar beets to sugar, pulp and molasses as well as the treatment of waste effluents. Packaging of sugar has been excluded. (Bengoa 2020.) The input of sugar beet was deleted because sugar beet production is modelled as a separate process in this thesis. Also, the inputs of transportation with a lorry and a train were deleted because in the case of other products transportation inside country borders has been excluded, too. However, transport with a tractor and trailer was not deleted. The original process was modelled at a global scale but the location was changed to Finland by changing the location of tap water input and by substituting electricity input by ‘Electricity, medium voltage {FI}| market for | Cut-off, S – Copied from Ecoinvent – FI’.

Also, CFs specific for Finland are used when calculating results for land stress and water stress in LCIA phase.

The data in the chosen production system of cocoa beans ‘Cocoa beans, sun-dried, at farm (WFLDB 3.1)/kg – CI’ in the Agribalyse 3.0.1 database represents the production of cocoa beans in Ivory Coast for the export market. The production system includes planting, pesticide application, fertilization, harvest, fermentation and drying. Most of the work is assumed to be manual work so machine use and infrastructure have been excluded. Inputs of planted trees, irrigation, pesticides and fertilizers have been included. Direct field emissions from land use change as well as from activities related to crop production have been taken into account. The lifetime of the trees from planting to clearing is 50 years. The system boundaries include an average year of the productive phase, emissions calculated per year of lifetime for nursery, planting materials, establishment phase as well as clearing phase with waste treatment. An average yield from 2009-2012 has been used which is 613 kg/ha. The amount of water used for irrigation is 985 m^3/ha. (Guignard 2020b.) The production of fertilizers has not been mentioned in the description of the process, so it is uncertain whether it has been included in the data or not.

The chosen cocoa beans processing process ‘Cocoa beans processing, at plant (WFLDB 3.1) – RER’ in Agribalyse includes the processing of cocoa beans into cocoa butter, cocoa liquor, cocoa cake, cocoa shells and cocoa powder. Energy and water inputs have been included and the packaging of final products is excluded. (Guignard 2020a.) The process includes transportation of cocoa beans but the transportation inputs were deleted because transportation is considered as a separate process in this thesis. The location of the process is changed to Netherlands by substituting electricity input with ‘Electricity, medium voltage {NL}| market for | Cut-off, S – Copied from Ecoinvent – NL’ and by changing the location of water input to Netherlands. Also, in LCIA phase land and water flows of the process are multiplied by Netherlands specific CFs.

Cocoa powder is produced as a final step of cocoa beans processing when cocoa cakes are broken up and ground into cocoa powder (European Cocoa Association 2023). Therefore, cocoa butter, cocoa liquor, cocoa, cake and cocoa shells are produced in earlier stages of processing. As the cocoa beans processing process has five outputs the impacts of the process have to be divided between the co-products to define the impacts of cocoa powder. The division is conducted based on the masses and prices of the products.

The transportation of cocoa beans from Ivory Coast to Netherlands as well as the transportation of cocoa powder from Netherlands to Finland is assumed to happen by a ship. The same transportation process by a transoceanic ship is used as in the case of coffee and tea. The transportation distance is mentioned later in inventory analysis (section 4.2.3).

In cocoa beans production all water consumption from river located in Ivory Coast is assumed to be used for irrigation and is included in the calculations contributing more than 1 % of all water flows. Water use in pasteurization is excluded because it is very small and there is no direct water use in that process. In cocoa bean processing and sugar beet processing direct water use in the process is included in the calculations. In cocoa bean processing it contributes more than 1 % and in sugar beet processing less than 1 %. In sugar beet production water flows contributing at least 1 % and located in Switzerland (the original location of the process) are included in the calculations. In milk production all water flows that are located in Europe as well as water from river without specification about origin that contribute to at least 0.01 % of all water use are included. This is because all other water flows than those related to energy production contribute to less than 1 %.

4.2 Inventory analysis

The inventory data for all life cycle stages is collected mostly using openLCA which is an open source LCA software. This means that anyone has access to the source code of the software and the creator of the code is identified by the licence accompanying every distributed file of the software. (GreenDelta 2022.) The inventory data withing openLCA software is collected from Agribalyse 3.0.1 database which is a French LCI database developed by ADEME and it provides data about food and agricultural products consumed in France (Cilleruelo 2022). The inventory flows of process are copied from openLCA to Excel where the flows relevant for the study (land, water and GHG) are grouped and summed up.

4.2.1 Coffee inventory

To make 1 liter of black coffee 65 grams (g) of roasted and ground coffee is needed (Usva et al. 2020, 1). To produce 1 kg of roasted and ground coffee 1.23 kg of green coffee beans are needed (Guignard 2020c). As the functional unit of this study is 2 dl of prepared drink, 13 g of roasted and ground coffee and 15.99 g of green coffee beans are needed. Thus, 15.99 g is entered as the target amount for the green coffee bean production process and 13 g for the roasting and grinding process in openLCA.

The shipping route from Brazil to Antwerp is approximately 10 000 km long depending on the location of the port in Brazil. The shipping route from Antwerp to Helsinki is approximately 2000 km long. (Fluent Cargo 2023.) Thus, the total shipping distance is approximately 12 000 km. As 15.99 g of coffee beans are transported over a distance of 12 000 km it makes 0.19 ton-kilometers (tkm) which is entered as the target amount for the transportation process in openLCA.

Making 2 dl of coffee consumes 2 dl of water and 0.14-0.18 kWh electricity (Usva et al. 2020, 1). An average of 0.16 kWh is used in the calculations of this study. Therefore, the electricity consumption in coffee making per functional unit is 0.032 kWh. Possible evaporation of water during coffee making is not considered.

The inventory results of land transformation for coffee are presented in Table 4. The results indicate that most of the land transformation happens in coffee bean production phase.

Table 4. The inventory results of land transformation for coffee.

Land flow type	**Coffee bean production**	**Roasting and grinding**	**Consumption**
Transformation, from annual crop [m^2]	2.7919E-04	7.9317E-08	1.1012E-06
Transformation, from extensive forestry [m^2]		1.0910E-07	
Transformation, from intensive forestry [m^2]	2.4289E-04	3.7700E-06	5.7076E-05
Transformation, from pasture [m^2]	1.4322E-03		
Transformation, from permanent crop [m^2]	4.4417E-03		
Transformation, to annual crop [m^2]	4.0055E-04	1.8674E-07	9.0507E-07
Transformation to intensive forestry [m^2]	2.6575E-04	3.9000E-06	5.7076E-05
Transformation, to pasture [m^2]	1.3205E-03		
Transformation, to permanent crop [m^2]	4.4417E-03		

The inventory results of land occupation for coffee are presented in Table 5. The results indicate that coffee bean production covers most of the land occupation and permanent crop has the biggest share from different land use types.

Table 5. The inventory results of land occupation for coffee.

Coffee bean production (BR)			**Roasting and grinding (FI)**	**Consumption phase (FI)**
Occupation, permanent crop [m^2*a]	Occupation, pasture [m^2*a]	Occupation, intensive forestry [m^2*a]	Occupation, intensive forestry [m^2*a]	Occupation, intensive forestry [m^2*a]
8.9073E-02	2.6296E-02	2.1255E-02	3.1174E-04	4.5900E-03

The inventory results of water consumption are 1.7651E-02 m^3 in coffee bean production phase (BR), 3.3800E-06 m^3 in roasting and grinding phase (FI), and 2.0000E-04 m^3 in consumption phase (FI). The results indicate that most of the consumption happens in coffee bean production phase and the consumption in other life cycle stages is minimal.

The inventory results for GHG emissions for coffee are presented in Table 6. By far the majority of all different types of GHG emissions are generated in the coffee bean production phase.

Table 6. The inventory results GHG emissions for coffee.

Emission	**Coffee bean production**	**Transportation**	**Roasting and grinding**	**Consumption**	**Total**
CO_2 [kg]	6.3309E-02	3.3901E-04	2.6592E-03	7.0282E-03	7.3335E-02
CH_4, biogenic [kg]	8.1869E-05	6.2815E-09	1.2009E-06	9.2211E-07	8.3998E-05
CH_4, fossil and land transformation [kg]	1.7703E-04	5.2790E-14	5.2726E-06	1.5578E-05	1.9788E-04
N_2O [kg]	4.4386E-05	4.6640E-13	4.4322E-08	5.9784E-07	4.5028E-05

4.2.2 Tea inventory

Eneroth et al. (2022, 32) have estimated that 1.6 g tea leaves are needed per 2 dl of prepared tea. That amount is also used in this study and it is entered as the target amount for the tea production process in openLCA.

The shipping route from Sri Lanka to Finland is approximately 15 000 km long (Fluent Cargo 2023). As 1.6 g of tea leaves are needed it makes 0.024 tkm which is entered as the target amount for the transportation process in openLCA.

Making 2 dl of tea consumes 2 dl of water and the electricity consumption in boiling of the water is assumed to be the same as in coffee making, 0.032 kWh. Eneroth et al. (2022, 27, 32) have also made the same assumption. Possible water evaporation during water boiling is not considered.

The inventory results of land transformation for tea are presented in Table 7. The results indicate that land transformation is the largest in tea production phase. However, the flows “transformation, from annual crop” and “transformation, to annual crop” are equal, so they cancel each other out. The land transformation flows of consumption phase are equal to the coffee consumption phase flows of coffee in Table 4 because they originate from electricity use which is the same for both coffee making and tea preparing.

Table 7. The inventory results of land transformation for tea.

Land flow type	**Tea production (LK)**	**Consumption (FI)**
Transformation, from annual crop [m^2]		1.1012E-06
Transformation, from intensive forestry [m^2]		5.7052E-05
Transformation, from permanent crop [m^2]	5.5600E-04	
Transformation, to annual crop [m2]		9.0507E-07
Transformation, to intensive forestry [m^2]		5.7076E-05
Transformation, to permanent crop [m^2]	5.5600E-04	

The inventory results of land occupation are presented in Table 8. The results indicate that permanent crops in production phase cover most of the land occupation. The occupation results of consumption phase are identical to the results of coffee consumption in Table 5 they originate from electricity use which is the same for both coffee making and tea preparing.

Table 8. The inventory results of land occupation for tea.

Tea production (LK)		**Consumption (FI)**
Occupation, intensive forestry [m^2*a]	Occupation, permanent crop [m^2*a]	Occupation, intensive forestry [m^2*a]
1.7400E-04	1.1138E-02	4.5900E-03

The inventory results of water consumption for tea are 3.0260E-03 m^3 in tea production phase (LK) and 2.0000E-04 m^3 in consumption phase (FI). Thus, most of the water consumption happens in production phase.

The inventory results of GHG emissions for tea are presented in Table 9. Consumption phase covers most of the CO_2 emissions and CH_4 emissions from fossil sources and land transformation. Production phase, in turn, covers most of the biogenic CH_4 emissions and N_2O emissions. The emissions from consumption phase originate from electricity consumption and are therefore identical to the emissions from coffee consumption (Table 6).

Table 9. The inventory results of GHG emissions for tea.

Emission	**Tea production**	**Transportation**	**Consumption**	**Total**
CO_2 [kg]	1.5120E-03	3.4659E-05	7.0282E-03	8.5748E-03
CH_4, biogenic [kg]	5.5751E-06	6.3876E-10	9.2211E-07	6.4978E-06
CH_4, fossil and land transformation [kg]	4.0132E-06	3.0879E-08	1.5578E-05	1.9622E-05
N_2O [kg]	2.6975E-06	9.4258E-10	5.9784E-07	3.2963E-06

4.2.3 Hot chocolate inventory

In Eneroth et al. (2022, 32) study 2 dl of hot chocolate consists of 2 dl of milk, 8 g of cocoa powder and 8 g of sugar. The same assumption is made in this thesis.

It is assumed that 2 dl of milk equals to 0.2 kg. Thus, 0.2 kg has been set as the target amount in milk production and pasteurisation processes.

According to Ntiamoah and Afrane (2007, 1737) by processing of 1 kg of cocoa beans in Ghana 75 g of cocoa powder, 268.75 g of cocoa cake, 310.48 g of cocoa liquor, 231.25 g of cocoa butter and 98 g of cocoa shells are gotten. It is assumed that this is also the case in cocoa bean processing in Netherlands. Cocoa powder is produced by breaking up cocoa cakes and grinding them into powder (European Cocoa Association 2023). It is assumed that cocoa cake from the cocoa beans processing is further processed to cocoa powder and therefore the mass of cocoa powder is the sum of the mass of the actual cocoa powder and the mass of cocoa cake which makes in total 343.75 g.

The division of the biodiversity impacts of cocoa processing for cocoa powder is made based on the masses and monetary value of the co-products. Cocoa shell is not utilized very well and usually rather considered as waste (Okiyama et al. 2017, 103). Thus, it is assumed that cocoa shells do not have any monetary value and their price is 0. The average prices of cocoa powder, coca liquor and cocoa butter are calculated from the prices of these products (without value added tax) in cocoasupply.eu webstore at the moment of conducting the calculations due to lack of other data. The average price of cocoa powder is 9.78 €, the average price of cocoa liquor is 9.15 € and the average price of cocoa butter is 11.88 € (Cocoa Supply 2023). Products that were in sale have been excluded from the calculations. The share of the biodiversity impacts of cocoa powder from the impacts of cocoa bean processing is calculated in equation 2 below.

$$Share\ of\ cocoa\ powder\ impacts\ =$$
$$\frac{0.34375\ kg*9.78\ €/kg}{0.34375*9.78\frac{€}{kg}+0.31048\cdot 9.15\frac{€}{kg}+0.23125\ kg*11.88\frac{€}{kg}+0.098\ kg*0\ €/kg}*100\ \%\approx 37.56\% \qquad (2)$$

So, 37.56 % of the biodiversity impacts of cocoa bean processing can be divided to cocoa powder. The amount of cocoa beans needed to get 8 g of cocoa powder and the other co-products of the cocoa beans processing process is assumed to be 1000 g/343.74 g times the amount of needed cocoa powder (8 g) which makes 23.27 g and is entered as the target amount in the cocoa beans processing process. As 37.56 % of the impacts of cocoa bean processing belong to cocoa powder the inventory flows of cocoa bean processing are multiplied by that percentage.

The total mass of all the co-products from the processing of 1 kg of cocoa beans is 983.48 g so a small fraction of the mass of cocoa beans is lost. It is assumed that the mass of cocoa beans needed for the production of cocoa powder is 1000 g/983.48 g times the needed amount of cocoa powder. Therefore, to produce 8 g of cocoa powder needed for 2 dl of hot chocolate 8.134 g of cocoa beans are needed which is entered as the target amount for cocoa bean production process.

The shipping route from Ivory Coast to Netherlands is approximately 7000 km long and from Netherlands to Helsinki approximately 2000 km long (Fluent Cargo 2023). As 8.134 g of cocoa beans are transported to Netherlands it makes 0.0569 tkm. From Netherlands 8 g of cocoa powder is transported to Helsinki which makes 0.0160 tkm. As a sum 0.0729 tkm is gotten. This is the target amount entered in the transportation process in openLCA.

From the inputs of sugar beet processing process in Agribalyse 3.0.1 database it can be seen that approximately 5.846 kg of sugar beets are needed to produce 1 kg of sugar (Bengoa 2020). Therefore 46.767 g of sugar beets are needed to produce 8 g of sugar and it is entered as the target amount for the sugar beet production process and it is also the reference flow of sugar beets. 8 g is entered as the target amount for sugar beet processing.

The inventory results of land transformation for hot chocolate are presented in Table 10. It can be seen that the biggest share of land transformation happens in sugar beet production and cocoa bean production phases.

Table 10. The inventory results of land transformation for hot chocolate.

Land flow type	Milk production (FI)	Pasteurisa-tion (FI)	Sugar beet production (FI)	Sugar processing (FI)	Cocoa bean production (CI)	Cocoa bean processing (NL)	Consump-tion (FI)
Transformation, from annual crop [m²]	2.4400E-05	2.6966E-07	1.2074E-02	2.1906E-07	2.9907E-03	2.9684E-08	1.1012E-06
Transformation, from extensive forestry [m²]	1.0502E-05			6.5163E-08	1.1418E-03	7.1255E-07	
Transformation, from intensive forestry [m²]	2.0000E-05	1.3162E-05		3.0770E-06		5.0766E-07	5.7052E-05
Transformation, from pasture [m²]	3.0000E-05			2.4554E-07			
Transformation, from permanent crop [m²]	1.4261E-06				7.2483E-03		
Transformation, from urban [m²]	2.8877E-05						
Transformation, to annual crop [m²]	2.5428E-05	3.9224E-07	1.2078E-02	2.6249E-07	2.4105E-03	5.2684E-08	9.0507E-07
Transformation, to intensive forestry [m²]	2.4000E-05	1.3182E-05		3.1338E-06		5.1200E-07	5.7076E-05
Transformation, to pasture [m²]	4.6258E-06						
Transformation, to permanent crop [m²]	1.6814E-06				9.0323E-03		
Transformation, to urban [m²]	3.5067E-05			9.3930E-08		6.9327E-07	

The inventory results of land occupation for hot chocolate are presented in Table 11. It can be seen that most of land occupation happens in milk production and cocoa bean production phases.

Table 11. The inventory results of land occupation for hot chocolate.

Land flow type	Milk production (FI)	Pasteurisation (FI)	Sugar beet production (FI)	Sugar processing (FI)	Cocoa bean production (CI)	Cocoa bean processing (NL)	Consumption (FI)
Occupation, annual crop [m²*a]	5.6060E-02		6.8900E-03				
Occupation, intensive forestry [m²*a]		1.0740E-03		2.5200E-04		4.1319E-05	4.5900E-03
Occupation, pasture [m²*a]	4.0876E-01						
Occupation, permanent crop [m²*a]					1.3298E-01		
Occupation, urban [m²*a]				4.7155E-06			

The inventory results of water consumption for hot chocolate are presented in Table 12. Water consumption seems to be the biggest in cocoa bean production phase.

Table 12. The inventory results of water consumption for hot chocolate.

	Milk production (FI)	Sugar beet production (FI)	Sugar beet processing (FI)	Cocoa bean production (CI)	Cocoa bean processing (NL)
Water consumption [m³]	1.2398E-03	2.7000E-04	5.2000E-05	1.3064E-02	4.5075E-05

The inventory results of GHG emissions for hot chocolate are presented in Table 13. The biggest share of CO_2 emissions and emissions of CH_4 from fossil sources and land transformation are generated in cocoa bean production phase and the biggest share of biogenic CH_4, as well as N_2O is generated in milk production.

Table 13. The inventory results of GHG emissions for hot chocolate.

Emission	Milk production	Pasteurisation	Sugar beet production	Sugar beet processing	Cocoa bean production	Cocoa bean processing	Cocoa transportation	Consumption
CO_2 [kg]	2.2758E-02	3.0440E-03	7.7263E-04	1.4902E-03	9.5197E-02	2.5208E-03	1.0469E-04	7.0282E-03
CH_4, biogenic [kg]	6.8165E-03	2.0743E-07	1.7330E-07	1.0760E-07	5.5040E-07	6.5788E-08	1.9402E-09	9.2211E-07
CH_4, fossil and land transformation [kg]	3.0067E-05	5.0643E-06	1.2066E-06	3.0180E-06	6.1916E-05	2.0903E-06	9.3794E-08	1.5578E-05
N_2O [kg]	1.6072E-04	1.3595E-07	4.4067E-06	5.7222E-08	2.0024E-05	9.4586E-08	2.8631E-09	5.9784E-07

4.3 Life cycle impact assessment

The calculation of the indicator results is done in Excel by multiplying the inventory results of GHG emissions, land transformation and occupation as well as water consumption with the related CFs taken from Verones et al. (2020b, 31), lc-impact.eu website and SimaPro. The indicator results for coffee, tea and hot chocolate are presented in sections 4.3.1-4.3.3.

From the CFs of land transformation used in the calculations ‘transformation, from’ flows have positive CFs whereas ‘transformation, to’ flows have negative CFs. The CFs of Sri Lanka have the biggest absolute values indicating that land transformation per m^2 has the highest biodiversity impacts in Sri Lanka. The CFs of Finland, in turn, have the lowest absolute values indicating that land transformation per m^2 in Finland has the lowest impact on biodiversity. (SimaPro 2023; LC-IMPACT 2023a.)

From the CFs of land occupation used in the calculations the CFs of Sri Lanka have the biggest values indicating that land occupation per m^2*a in Sri Lanka has the biggest impact on biodiversity. Land occupation per m^2*a in Finland, in turn, has the lowest impact on biodiversity because the CFs of Finland have the smallest values. (LC-IMPACT 2023a.)

From the CFs of water stress used in the calculations the CF of Sri Lanka has the biggest value indicating that water consumption per m^3 in Sri Lanka has the biggest impact on biodiversity. The CF of Netherlands has the smallest value indicating that water consumption per m^3 in Netherlands has the lowest impact on biodiversity. (LC-IMPACT 2023b.)

From the CFs of climate change used in the calculations for both terrestrial and freshwater ecosystems the CFs of N_2O have the biggest values which indicates that N_2O emissions have the biggest impact on biodiversity per kg. The CFs of CO_2 are the smallest which means that CO_2 emissions have the lowest impact on biodiversity per kg. (Verones et al. 2020b, 31; SimaPro 2023.)

4.3.1 Coffee results

The indicator results of the biodiversity impacts of coffee based on land transformation are presented in Table 14. The total results are negative in coffee bean production phase and roasting and grinding phase which would indicate that those life cycle stages have a positive impact on the biodiversity. However, that is quite improbable and it is more likely that the negative results are caused by cut-off criteria of the land flows.

Table 14. The indicator results of coffee based on land transformation.

Land flow type	**Coffee bean production (BR) [PDF*y]**	**Roasting and grinding (FI) [PDF*y]**	**Consumption (FI) [PDF*y]**
Transformation, from annual crop	1.68E-16	1.43E-21	1.99E-20
Transformation, from extensive forestry		1.67E-21	
Transformation, from intensive forestry	9.84E-17	7.06E-20	1.07E-18
Transformation, from pasture	5.57E-16		
Transformation, from permanent crop	1.96E-15		
Transformation, to annual crop	-2.41E-16	-3.38E-21	-1.64E-20
Transformation to intensive forestry	-1.08E-16	-7.31E-20	-1.07E-18
Transformation, to pasture	-5.13E-16		
Transformation, to permanent crop	-1.96E-15		
Total	**-3.87E-17**	**-2.71E-21**	**3.11E-21**

The indicator results of coffee based on land occupation are presented in Table 15. Clearly the biggest impacts from land occupation occur in coffee bean production phase and they are caused by occupation of permanent crop.

Table 15. The indicator results of coffee based on land occupation.

Land flow type	**Coffee bean production (BR) [PDF*y]**	**Roasting and grinding (FI) [PDF*y]**	**Consumption (FI) [PDF*y]**
Occupation, intensive forestry	1.34E-16	6.02E-20	8.86E-19
Occupation, pasture	1.66E-16		
Occupation, permanent crop	6.33E-16		
Total	**9.33E-16**	**6.02E-20**	**8.86E-19**

The indicator results of coffee based on water stress are 5.03E-17 PDF*y in coffee bean production phase, 3.04E-21 PDF*y in roasting and grinding phase, and 1,80E-19 PDF*y in consumption phase. Thus, the biggest impacts of water stress are caused by coffee bean production.

The indicator results of the impacts of coffee on biodiversity based on climate change impacts for both terrestrial ecosystems and freshwater ecosystems are presented in Table 16. The biggest impacts of climate change for both ecosystem types are caused by coffee bean production phase and the impacts of transportation are the lowest.

Table 16. The biodiversity impacts of coffee based on climate change. TE means terrestrial ecosystems and FE freshwater ecosystems.

Emission	**Coffee bean production**		**Transportation**		**Roasting and grinding**		**Consumption**	
	TE [PDF*y]	FE [PDF*y]	TE [PDF*y]	FE [PDF*y]	TE [PDF*y]	FE [PDF*y]	TE [PDF*y]	FE [PDF*y]
CO_2	1.11E-16	3.46E-17	5.97E-19	1.85E-19	4.68E-18	1.45E-18	1.24E-17	3.84E-18
CH_4, biogenic	4.03E-18	1.25E-18	3.10E-22	9.62E-23	5.92E-20	1.84E-20	4.54E-20	1.41E-20
CH_4, fossil and land transformation	9.35E-18	2.90E-18	1.60E-20	4.98E-21	2.78E-19	8.65E-20	8.22E-19	2.56E-19
N_2O	2.07E-17	6.43E-18	4.32E-21	1.34E-21	2.07E-20	6.42E-21	2.79E-19	8.66E-20
Total	**1.46E-16**	**4.52E-17**	**6.17E-19**	**1.92E-19**	**5.04E-18**	**1.57E-18**	**1.35E-17**	**4.20E-18**

4.3.2 Tea results

The indicator results of tea based on land transformation are presented in table 17. The impacts in tea production phase seem to be net zero and therefore land transformation in consumption phase has the biggest impact. The impacts in consumption phase are identical to the impacts in coffee consumption phase.

Table 17. The indicator results of tea based on land transformation.

Land flow type	**Tea production (LK) [PDF*y]**	**Consumption (FI) [PDF*y]**
Transformation, from annual crop		1.99E-20
Transformation, from intensive forestry		1.07E-18
Tranformation, from permanent crop	2.23E-15	
Transformation, to annual crop		-1.64E-20
Transformation, to intensive forestry		-1.07E-18
Tranformation, to permanent crop	-2.23E-15	
Total	**0**	**3.11E-21**

The indicator results of tea based on land occupation are presented in Table 18. Most of the impacts of land occupation are caused by occupation of permanent crop in tea production phase. The results of consumption phase are identical to the results of coffee consumption phase.

Table 18. The indicator results of tea based on land occupation.

Land flow type	**Tea production (LK) [PDF*y]**	**Consumption (FI) [PDF*y]**
Occupation, intensive forestry	6.46E-18	8.86E-19
Occupation, permanent crop	5.86E-16	
Total	**5.92E-16**	**8.86E-19**

The indicator results of tea based on water stress are 6.80E-17 PDF*y for tea production phase (LK) and 1,80E-19 PDF*y for consumption phase (FI). The impact of consumption phase is the same as for coffee because the amount of water used is the same.

The indicator results of tea based on climate change for both terrestrial and freshwater ecosystems are presented in Table 19. The biggest impacts seem to occur in consumption phase for both ecosystem types and the lowest impacts in transportation phase. The impacts of consumption phase are equal to the impacts in coffee consumption phase.

Table 19. The indicator results of tea based on climate change. TE means terrestrial ecosystems and FE freshwater ecosystems.

Emission	**Tea production**		**Transportation**		**Consumption**	
	TE [PDF*y]	FE [PDF*y]	TE [PDF*y]	FE [PDF*y]	TE [PDF*y]	FE [PDF*y]
CO_2	2.66E-18	8.27E-19	6.10E-20	1.90E-20	1.24E-17	3.84E-18
CH_4, biogenic	2.75E-19	8.54E-20	3.15E-23	9.79E-24	4.54E-20	1.41E-20
CH_4, fossil and land transformation	2.12E-19	6.59E-20	1.63E-21	5.07E-22	8.22E-19	2.56E-19
N_2O	1.26E-18	3.91E-19	4.40E-22	1.37E-22	2.79E-19	8.66E-20
Total	**4.41E-18**	**1.37E-18**	**6.31E-20**	**1.96E-20**	**1.35E-17**	**4.20E-18**

4.3.3 Hot chocolate results

The indicator results of land transformation for hot chocolate are presented in Table 20. The biggest impacts seem to occur in milk production phase. The total results of pasteurisation, sugar beet production, cocoa bean production and cocoa bean processing are negative. This would indicate that land transformation in these life cycle stages causes positive impact on biodiversity but as in the case of coffee land transformation results it is more likely that the negative results are caused by cut-off criteria of the land flows. The results of consumption phase are equal to the results of coffee and tea consumption phase.

Table 20. The indicator results of land transformation for hot chocolate.

Land flow type	Milk production (FI) [PDF*y]	Milk pasteurisa-tion (FI) [PDF*y]	Sugar beet production (FI) [PDF*y]	Sugar beet processing (FI) [PDF*y]	Cocoa bean production (CI) [PDF*y]	Cocoa bean processing (NL) [PDF*y]	Consump-tion (FI) [PDF*y]
Transformation, from annual crop	4.41E-19	4.88E-21	2.18E-16	3.96E-21	1.43E-15	3.49E-21	1.99E-20
Transformation, from extensive forest	1.61E-19			9.97E-22	1.25E-16	1.38E-20	
Transformation, from intensive forest	3.75E-19	2.47E-19		5.77E-20		1.57E-20	1.07E-18
Transformation, from pasture	8.43E-19			6.90E-21			
Transformation, from permanent crop	5.33E-20				2.65E-15		
Transformation, from urban	1.62E-18						
Transformation, to annual crop	-4.60E-19	-7.09E-21	-2.18E-16	-4.75E-21	-1.15E-15	-6.19E-21	-1.64E-20
Transformation, to intensive forest	-4.50E-19	-2.47E-19		-5.87E-20		-1.58E-20	-1.07E-18
Transformation, to pasture	-1.30E-19						
Transformation, to permanent crop	-6.28E-20				-3.30E-15		
Transformation, to urban	-1.97E-18			-5.28E-21		-8.96E-20	
Total	**4.23E-19**	**-2.60E-21**	**-7.23E-20**	**7.73E-22**	**-2.50E-16**	**-7.87E-20**	**3.11E-21**

The indicator results of land occupation for hot chocolate are presented in Table 21. The biggest impact seems to occur in cocoa bean production phase from occupation of permanent crop. Cocoa bean processing seems to have the lowest impacts of land occupation. The results of consumption phase are equal to the results of coffee and tea consumption phase.

Table 21. The indicator results of land occupation for hot chocolate.

Land flow type	Milk production (FI) [PDF*y]	Milk pasteurisa-tion (FI) [PDF*y]	Sugar beet production (FI) [PDF*y]	Sugar beet processing (FI) [PDF*y]	Cocoa bean production (CI) [PDF*y]	Cocoa bean processing (NL) [PDF*y]	Consump-tion (FI) [PDF*y]
Occupation, annual crop	1.16E-17		1.43E-18				
Occupation, intensive forestry		2.07E-19		4.86E-20		1.32E-20	8.86E-19
Occupation, pasture	1.18E-16						
Occupation, permanent crop					7.89E-16		
Occupation, urban				2.84E-21			
Total	**1.30E-16**	**2.07E-19**	**1.43E-18**	**5.15E-20**	**7.89E-16**	**1.32E-20**	**8.86E-19**

The indicator results of water stress for hot chocolate are presented in Table 22. The biggest impact seems to occur in cocoa bean production phase and the lowest impact in cocoa bean processing.

Table 22. The indicator results of water stress for hot chocolate.

Milk production (FI) [PDF*y]	Sugar beet production (FI) [PDF*y]	Sugar beet processing (FI) [PDF*y]	Cocoa bean production (CI) [PDF*y]	Cocoa bean processing (NL) [PDF*y]
1.11E-18	2.43E-19	4.67E-20	1.13E-16	2.40E-20

The indicator results of the impacts of climate change on terrestrial ecosystems are presented in Table 23. The biggest impact seems to result from milk production and the lowest impact from cocoa transportation. The results of consumption phase are equal to the results of coffee and tea consumption phase.

Table 23. The indicator results of the impacts of hot chocolate on terrestrial ecosystems based on climate change impacts.

Emission	Milk production	Pasteurisa-tion	Sugar beet production	Sugar beet processing	Cocoa bean production	Cocoa bean processing	Cocoa transpor-tation	Consump-tion
CO_2	4.01E-17	5.36E-18	1.36E-18	2.62E-18	1.68E-16	4.44E-18	1.84E-19	1.24E-17
CH_4, biogenic	3.36E-16	1.02E-20	8.54E-21	5.30E-21	2.71E-20	3.24E-21	9.56E-23	4.54E-20
CH_4, fossil and land transfor-mation	1.59E-18	2.67E-19	6.37E-20	1.59E-19	3.27E-18	1.10E-19	4.95E-21	8.22E-19
N_2O	7.50E-17	6.34E-20	2.06E-18	2.67E-20	9.34E-18	4.41E-20	1.34E-21	2.79E-19
Total	**4.53E-16**	**5.70E-18**	**3.49E-18**	**2.81E-18**	**1.80E-16**	**4.59E-18**	**1.91E-19**	**1.35E-17**

The indicator results of the impacts of climate change on freshwater ecosystems are presented in Table 24. It seems that the biggest impact also on freshwater ecosystems results from milk production and the lowest impact from cocoa transportation. The results of consumption phase are equal to the results of coffee and tea consumption phase.

Table 24. The indicator results of the impacts of hot chocolate on freshwater ecosystems based on the impacts of climate change.

Emission	**Milk production**	**Pasteurisa-tion**	**Sugar beet production**	**Sugar beet processing**	**Cocoa bean production**	**Cocoa bean processing**	**Cocoa transpor-tation**	**Consump-tion**
CO_2	1.24E-17	1.67E-18	4.23E-19	8.15E-19	5.21E-17	1.38E-18	5.73E-20	3.84E-18
CH_4, biogenic	1.04E-16	3.18E-21	2.65E-21	1.65E-21	8.43E-21	1.01E-21	2.97E-23	1.41E-20
CH_4, fossil and land transfor-mation	4.93E-19	8.31E-20	1.98E-20	4.95E-20	1.02E-18	3.43E-20	1.54E-21	2.56E-19
N_2O	2.33E-17	1.97E-20	6.39E-19	8.29E-21	2.90E-18	1.37E-20	4.15E-22	8.66E-20
Total	**1.41E-16**	**1.77E-18**	**1.08E-18**	**8.75E-19**	**5.60E-17**	**1.43E-18**	**5.92E-20**	**4.20E-18**

5 Interpretation

The comparison of the impacts of coffee, tea and hot chocolate on terrestrial and freshwater ecosystems is presented in Figure 9. It seems that hot chocolate has the biggest impacts on both ecosystem types whereas tea has the lowest impacts. The impacts of tea on terrestrial ecosystems (6.11E-16 PDF*y) are less than half of the impacts of hot chocolate (1.34E-15 PDF*y) and the impacts of tea on freshwater ecosystems (7.38E-17 PDF*y) are a bit more than a fifth of the impacts of hot chocolate (3.21E-16 PDF*y). The total impacts of coffee on terrestrial ecosystems are 1.06E-15 PDF*y and on freshwater ecosystems 1.02E-16 PDF*y.

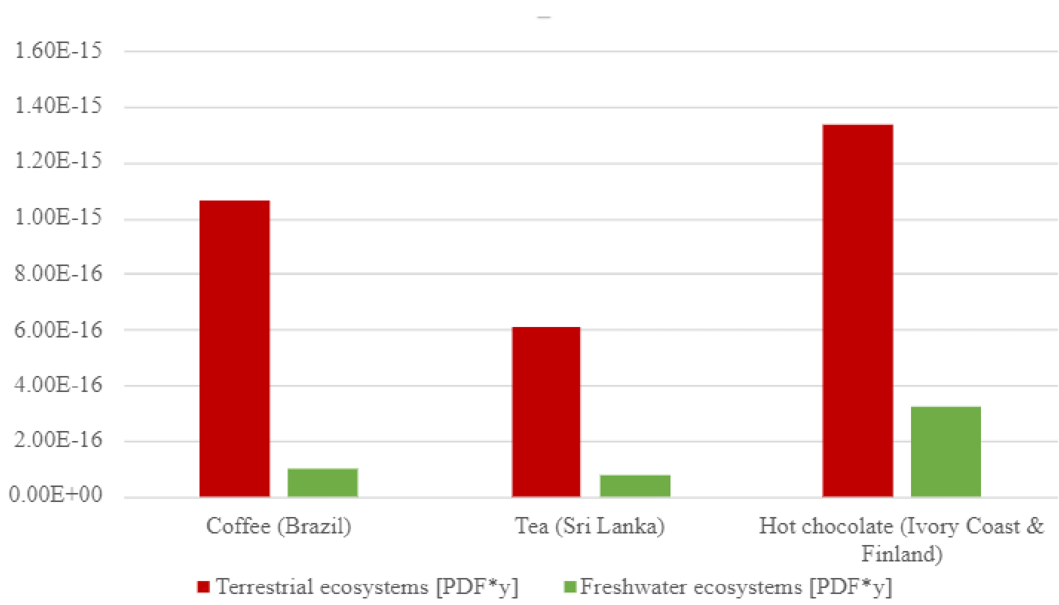

Figure 9. Comparison of the biodiversity impacts of coffee, tea and hot chocolate.

The impacts of coffee on terrestrial ecosystems in different life cycle stages based on the impacts of land stress and climate change are presented in Figure 10. The total impacts caused by land stress are 8.95E-16 PDF*y and by climate change 1,65E-16 PDF*y. It seems that by far the majority of the impacts of land stress and climate change are generated in coffee bean production phase, 8.94E-16 PDF*y and 1.46E-16 respectively.

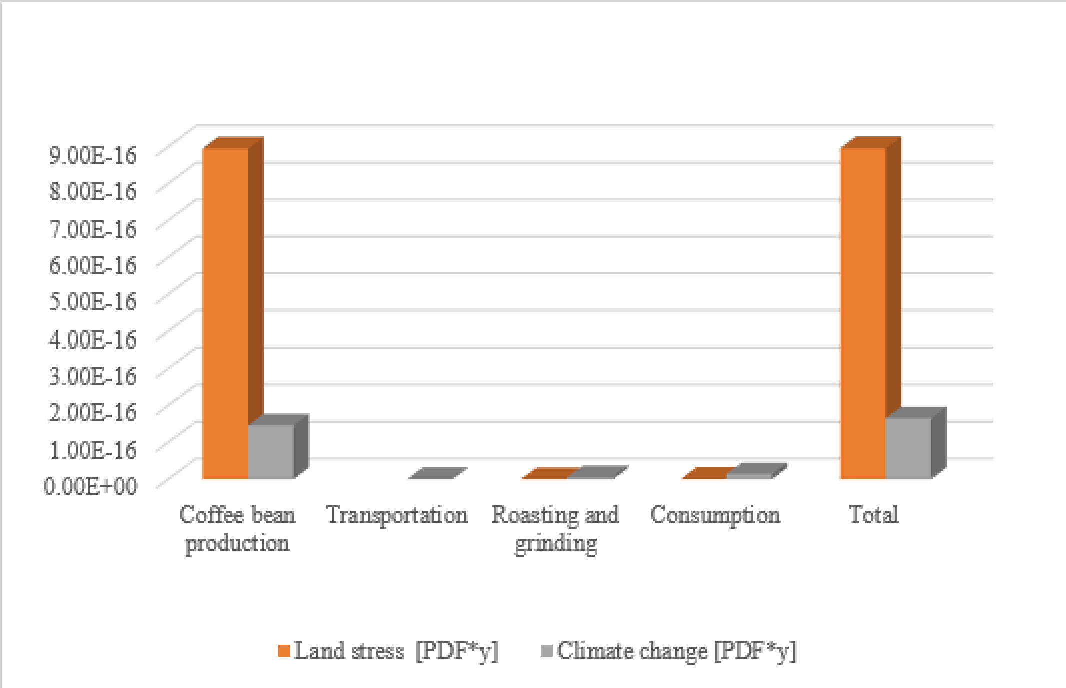

Figure 10. The impacts of coffee on terrestrial ecosystems in different life cycle stages based on the impacts of land stress and climate change.

When looking at the indicator results of coffee based on land occupation (Table 15) it can be seen that the occupation of permanent crop covers most of the impacts of land stress (6.33E-16 PDF*y) and when looking at the inventory results of land occupation for coffee (Table 5) it can be seen that also the area used in occupation of permanent crop is clearly the highest. In Table 15 it can also be seen that the total land stress impact from land occupation in coffee bean production phase is a bit higher than the total impact of land stress in that life cycle stage (Figure 10). This is caused by the net negative result of land transformation in coffee bean production phase (Table 14) which slightly lowers the total land stress result of coffee. However, the effect of this on the overall result is small. In Table 14 it can also be seen that the net impact of land transformation in roasting and grinding is negative which also lowers the total impact of land stress but in a much smaller magnitude. The biggest impacts of climate change on terrestrial ecosystems in coffee bean production results from CO_2 emissions (Table 16). In Table 6 it can be seen that also the absolute amount of CO_2 emissions in coffee bean production phase is higher than the amounts of other emissions but the relative difference of magnitudes in indicator results is smaller. This is because the other GHGs have much bigger CFs (Verones et al. 2020b, 31; SimaPro 2023).

The impacts of coffee on freshwater ecosystems in different life cycle stages based on the impacts of water stress and climate change are presented in Figure 11. The total impacts of water stress (5.04E-17 PDF*y) and climate change (5.12E-17 PDF*y) seem to be almost equal. By far the majority of the impacts of both water stress and climate change seem to be generated in coffee bean production phase, 5.02E-17 PDF*y and 4.52E-17 respectively.

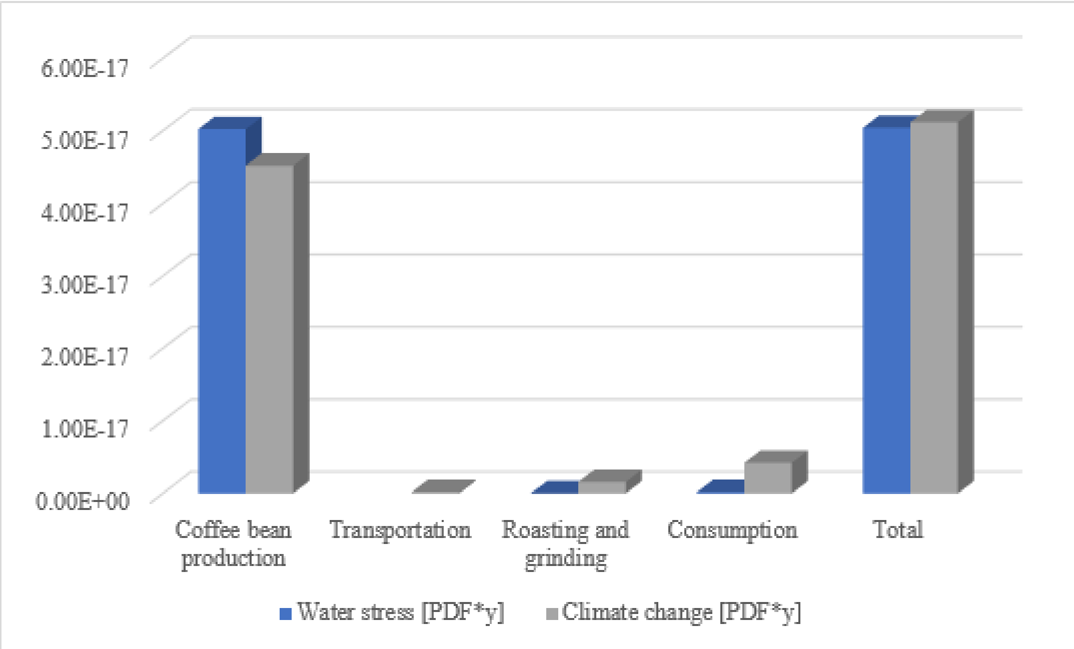

Figure 11. The impacts of coffee on freshwater ecosystems in different life cycle stages based on the impacts of water stress and climate change.

Based on the inventory results of coffee water consumption in coffee bean production phase is by far the biggest. Also, the water stress CF of Brazil is bigger than the CF of Finland (LC-IMPACT 2023b). As in the case of terrestrial ecosystem impacts, CO_2 emissions seem to also cover most of the impacts of climate change on freshwater ecosystems (Table 16) but the relative difference in magnitude between CO_2 and other GHGs is smaller in indicator results compared to inventory results (Table 6). This is because also the freshwater ecosystem CFs of other gases are much bigger than the CF of CO_2 (Verones et al. 2020b, 31; SimaPro 2023).

Figure 12 shows the locations where the impacts of coffee on terrestrial (on the left) and freshwater (on the right) ecosystems occur. Climate change impacts have not been included as they do not depend on the location of the emissions. It can be seen that over 99 % of the impacts of coffee on both terrestrial and freshwater ecosystems are located in Brazil and only a very small fraction in Finland.

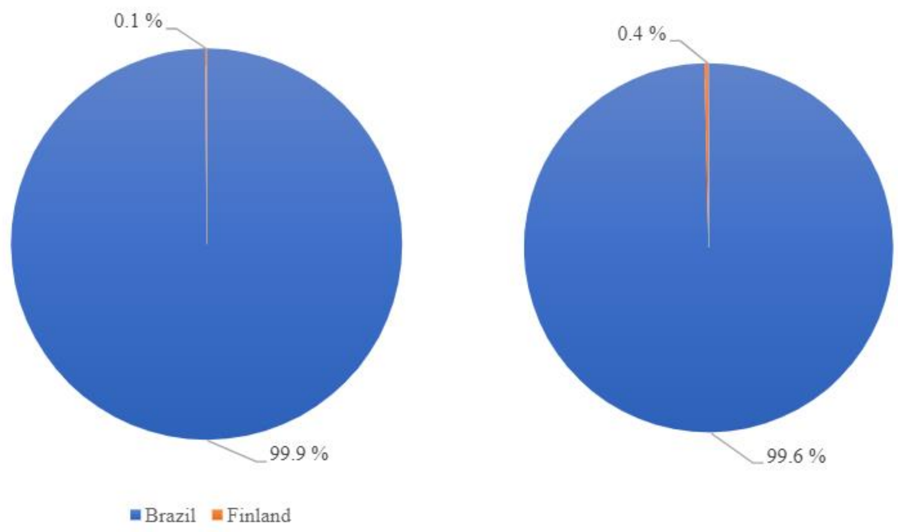

Figure 12. Locations of the impacts of coffee on terrestrial ecosystems based on land stress (on the left) and on freshwater ecosystems based on water stress (on the right).

The impacts of tea on terrestrial ecosystems in different life cycle stages based on the impacts of land stress and climate change are presented in Figure 13. The total impacts of land stress are 5.93E-16 PDF*y and the total impacts of climate change are 1.80E-17 PDF*y. Thus, the impacts of climate change are only a fraction of the impacts of land stress. Almost all of the impacts of land stress seem to occur in tea production phase (5.92E-16 PDF*y) and almost all of the impacts of climate change in consumption phase (1,35E-17 PDF*y).

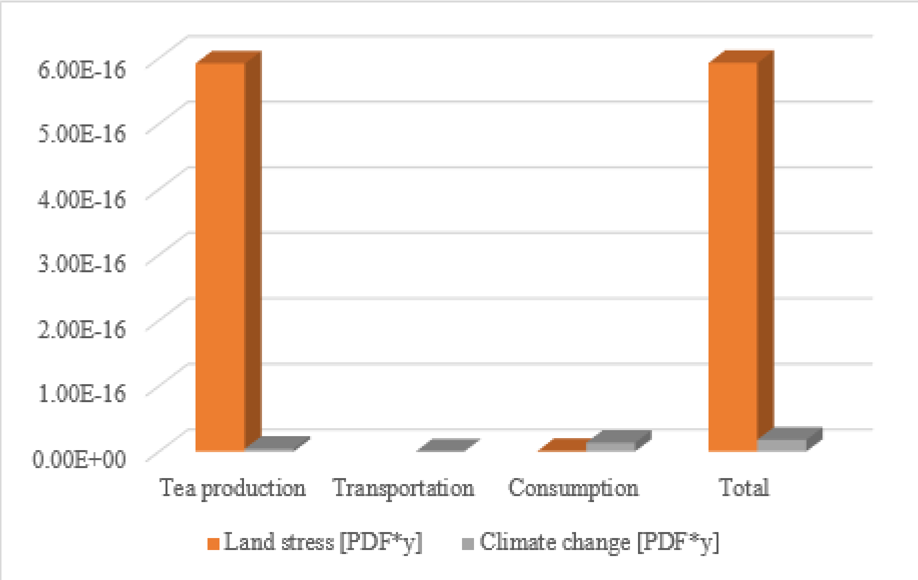

Figure 13. The impacts of tea on terrestrial ecosystems in different life cycle stages based on the impacts of land stress and climate change.

Most of the land use and the land stress impacts in tea production phase result from occupation of permanent crop (Table 8 and Table 18). The impacts of climate change in consumption phase result mostly from the impacts of CO_2 emissions (Table 19). As in the case of coffee the relative difference between the magnitude of CO_2 emissions and emissions of other gases is smaller in indicator results than in inventory results (Table 9 and Table 19).

The impacts of tea on freshwater ecosystems in different life cycle stages based on the impacts of water stress and climate change are presented in Figure 14. The total impacts of water stress are 6.82E-17 PDF*y and the total impacts of climate change are 5.59E-18 PDF*y. Thus, the impacts of climate change are only a fraction of the impacts of water stress. Almost all of the impacts of water stress (6.80E-17 PDF*y) occur in tea production phase and most of the impacts of climate change (4.20E-18 PDF*y) occur in consumption phase.

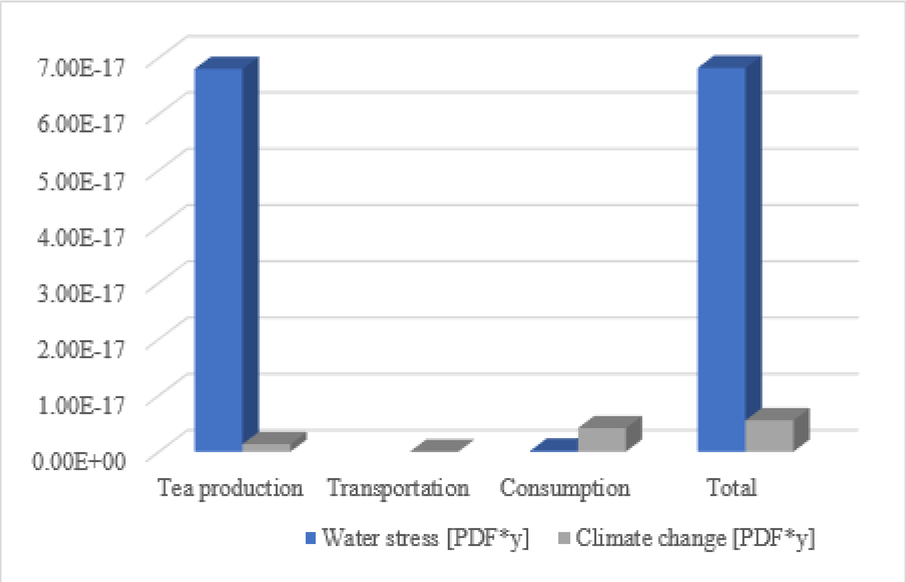

Figure 14. The impacts of tea on freshwater ecosystems in different life cycle stages based on the impacts of water stress and climate change.

According to the inventory results water consumption in tea production phase covers almost all of the water consumption. In addition, the water stress CF of Finland is minimal compared to the CF of Sri Lanka (LC-IMPACT 2023b). In the case of freshwater ecosystems the relative difference between the magnitude of CO_2 emissions and emissions of other gases is smaller in indicator results than in inventory results (Table 9 and Table 19) as in the case of terrestrial ecosystems.

Figure 15 shows the locations where the impacts of tea on terrestrial (on the left) and freshwater (on the right) ecosystems occur. The impacts of climate change were left out for the same reason as in the case of coffee. It can be seen that over 99 % of the impacts of tea on both terrestrial and freshwater ecosystems are located in Sri Lanka and only a very small fraction in Finland.

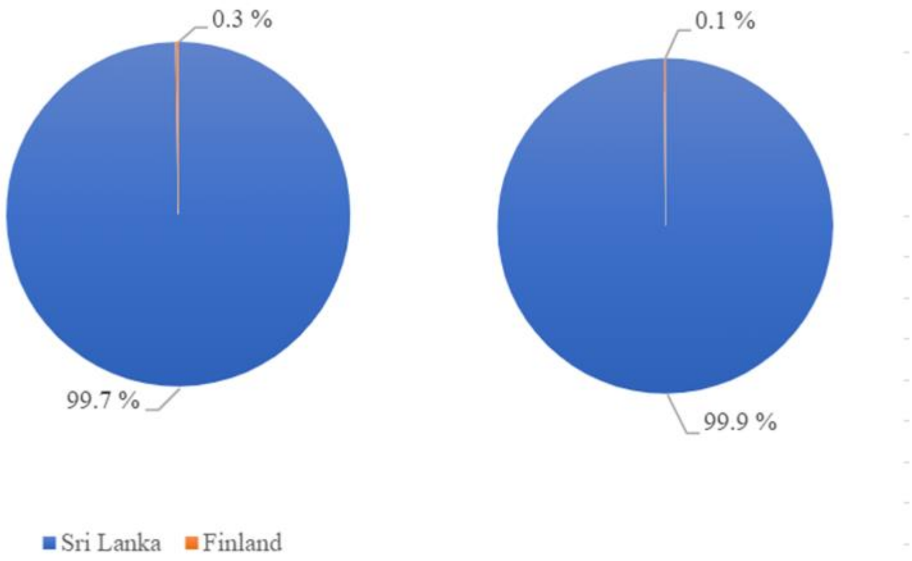

Figure 15. Locations of the impacts of tea on terrestrial ecosystems based on land stress (on the left) and on freshwater ecosystems based on water stress (on the right).

The impacts of hot chocolate on terrestrial ecosystems in different life cycle stages based on the impacts of land stress and climate change are presented in Figure 16. The impacts of land stress and climate change are almost equal, 6.72E-16 PDF*y and 6.63E-16 PDF*y respectively. Most of the impacts of land stress occur in cocoa bean production phase (5.40E-16 PDF*y) and most of the impacts of climate change occur in milk production phase (4.53E-16 PDF*y). A significant share of the impacts of land stress occurs also in milk production phase (1.30E-16 PDF*y) and a significant share of the impacts of climate change occur also in cocoa bean production phase (1.80E-16 PDF*y).

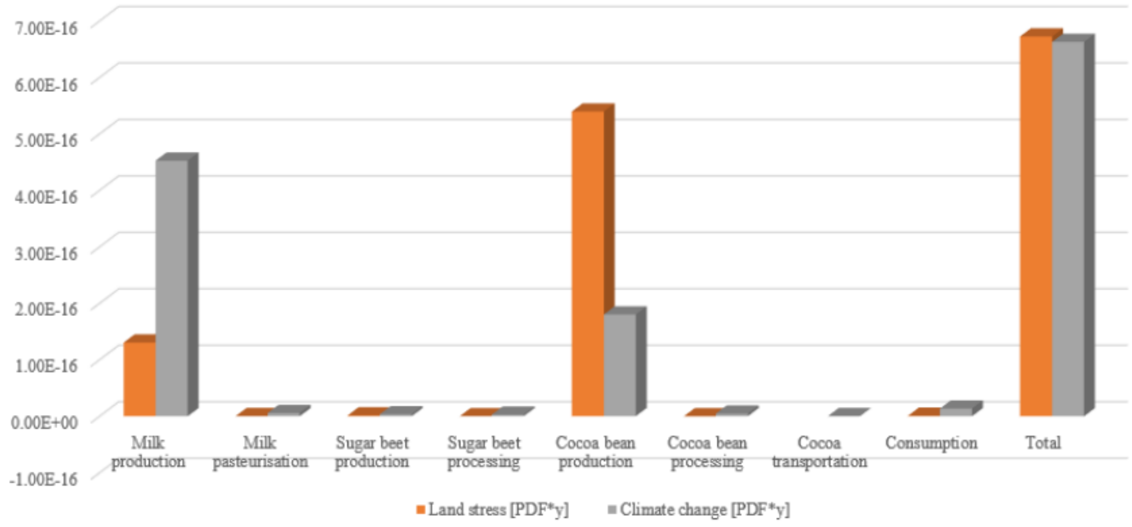

Figure 16. The impacts of hot chocolate on terrestrial ecosystems in different life cycle stages based on the impacts of land stress and climate change.

The land stress impact in cocoa bean production phase results mostly from occupation of permanent crop (Table 21). The net impacts of land transformation, in turn, are negative (Table 20) which reduces the total impact of cocoa bean production to some extent. In Table 20 it can be seen that the net impacts of land transformation seem to be negative also in pasteurisation, sugar beet production and cocoa bean processing. The total land stress impact of cocoa bean processing stage seems to go negative because the net positive impact of land occupation (Table 21) in that life cycle stage is smaller than the absolute value of land transformation. However, the impact of that negative value on the overall land stress results remains non-existent. In milk production phase most of the land stress impacts result from occupation of pasture (Table 21) and the impact of land transformation seems to be minimal (Table 20).

By far the biggest share of the impacts of climate change on terrestrial ecosystems in milk production result from biogenic CH_4 emissions (Table 23) even though the absolute amount of CO_2 emissions (Table 13) is much bigger. Also, the impact of N_2O seems to be higher than the impact of CO_2 even though the amount of N_2O is minimal compared to the amount of CO_2. These differences between the inventory results and indicator results are explained by the differences between the CFs of the GHGs (Verones et al. 2020b, 31; SimaPro 2023). By far the majority of the climate change impacts of cocoa bean production are caused by

CO_2 emissions because the amount of other GHG emissions is non-existent compared to the amount of CO_2 (Table 13 and Table 23).

The impacts of hot chocolate on freshwater ecosystems in different life cycle stages based on the impacts of water stress and climate change are presented in Figure 17. The impacts of climate change (2.06E-16 PDF*y) seem to be almost twice as big as the impacts of water stress (1.15E-16 PDF*y). Almost all of the impacts of water stress occur in cocoa bean production phase (1.13E-16 PDF*y). The biggest impacts of climate change occur in milk production phase (1.41E-16 PDF*y) and the second biggest impacts occur in cocoa bean production phase (5.60E-17 PDF*y).

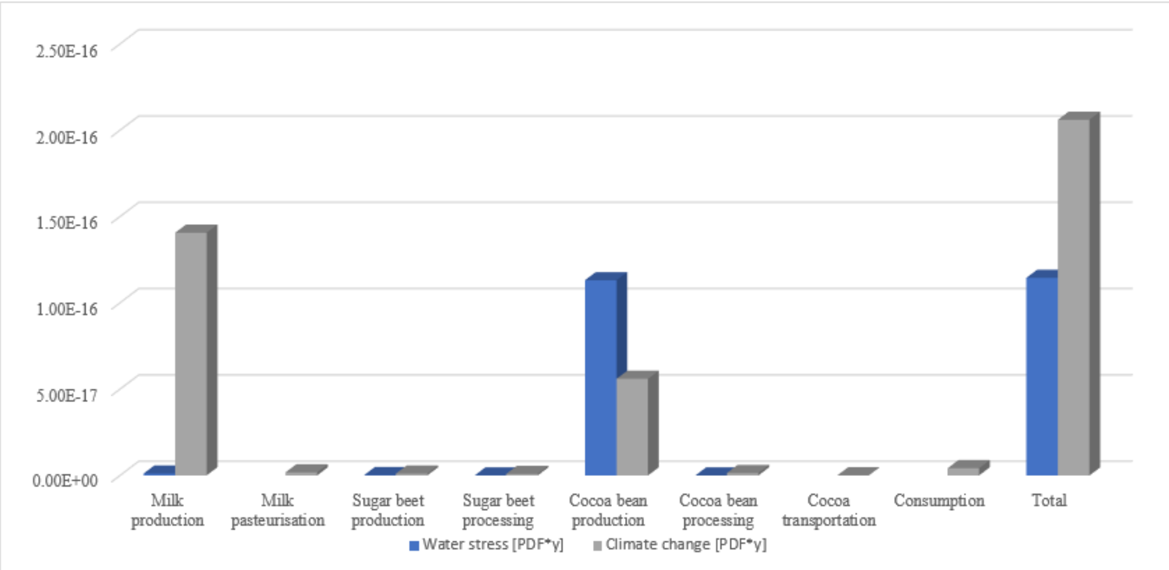

Figure 17. The impacts of hot chocolate on freshwater ecosystems in different life cycle stages based on the impacts of water stress and climate change.

Cocoa bean production phase covers almost all of the water consumption (Table 12). Also, the water stress CF of Ivory Coast is much higher than the water stress CFs of Finland and Netherlands (LC-IMPACT 2023b). The climate change impacts of hot chocolate on freshwater ecosystems are explained by the same things as the climate change impacts on terrestrial ecosystems. The only difference is that the CFs of freshwater ecosystems are smaller (Verones et al. 2020b, 31; SimaPro 2023).

Figure 18 shows the locations where the impacts of hot chocolate on terrestrial (on the left) and freshwater (on the right) ecosystems occur. The impacts of climate change are left out for the same reason as in the case of coffee and tea. It can be seen that approximately 80 % of the impacts on terrestrial ecosystems occur in Ivory Coast and the rest 20 % in Finland. Netherlands was left out from the comparison of terrestrial ecosystem impacts because the land stress impacts of cocoa bean processing are negative. It seems that almost 99 % of the impacts on freshwater ecosystems occur in Ivory coast. 1.2 % of the impacts occur in Finland and only a minimal amount of 0.02 % of the impacts occur in Netherlands.

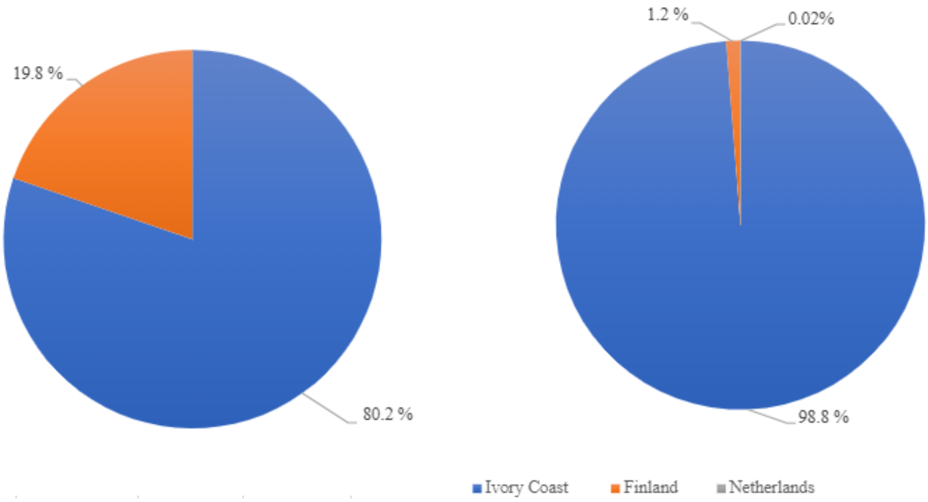

Figure 18. Locations of the impacts of hot chocolate on terrestrial ecosystems based on land stress (on the left) and on freshwater ecosystems based on water stress (on the right).

Most of the impacts in the case of all products occur in primary production which was also expected. Also, the locations of the impacts are in line with previous research by Sandström et al (2017 and Järviö et al. (2022) (presented in section 2.5.1) as by far the majority of the biodiversity impacts of food products consumed in Finland occur outside the borders of Finland.

5.1 The reliability of the results

There are several factors that affect the reliability of the results. In this section those issues and their significance for the results are discussed.

Choosing other impact assessment method could have possibly resulted in different kind of results. It was noticed during the calculations that LC-IMPACT does not cover everything.

As biogenic CO_2 emissions are not considered in the method it is possible that the impacts of climate change are bigger in reality. Also, the method does not have CFs for all land use types. Because of that some land flows were entirely excluded from the calculations and for some land flows CFs of the closest land use type were applied. This can affect significantly on the results as the impacts of land stress had the biggest contribution to the impacts on terrestrial ecosystems in the results of this thesis.

The biodiversity impacts were calculated based on land stress, water stress and climate change but other impact categories such as eutrophication were left out. Therefore, the results of this thesis would likely be higher if more impact categories were considered.

The used cut-off criteria may have affected the results of this thesis. In water inventory flows the cut-off criteria was mostly either 0.01 % or 1 % depending on how big share the water flows related to other than energy production were from the total amount of water. In the case of water flows the cut-off criteria has likely not caused significant uncertainty. For land flows the cut-off criteria was 1 % except for land flows without corresponding CF that had a cut-off criteria of 5 %. The cut-off criteria of land flows may have affected significantly on the results as CFs for 'transformation, to' flows are negative. Therefore, it is possible that at least some of the negative indicator results from land transformation are caused by cut-off criteria instead of the process in question having a positive biodiversity impact.

The exclusion of some life cycle stages, such as retail and end-of-life affects the results but not very significantly as their impacts were assumed to be small. Including dishwashing to the consumption phase would have made the impacts of that life cycle stage bigger but it would not have affected the impacts of the products under study in relation to each other as the energy and water consumption in dishwashing could have been assumed to be the same for each product.

Data quality may have affected on the results of this thesis. One issue causing uncertainty is that the processes chosen from Agribalyse 3.0.1 database represent the situation in a certain time and thus they are not necessarily representative for the situation of today. Also, possible uncertainties and assumptions related to the datasets of the processes can cause uncertainty. In the processes where the original location was changed the data may not represent the circumstances of the other location very well which can be considered as a significant uncertainty factor especially in the case of milk production that had a big contribution to the impacts of hot chocolate.

A large amount of data was handled manually in Excel due to which calculation mistakes are possible. Also, in general the analysing of input and output data of the processes was challenging so it is possible that something has been neglected.

Because of site specific data and differences between country specific CFs the chosen locations may affect the results significantly. This issue is considered more in detail in section 5.1.1.

As a conclusion, there are several issues that cause uncertainty in the results of this thesis. Therefore, the results should be considered indicative.

5.1.1 Sensitivity analysis

In the sensitivity analysis it is investigated how much the changing of the location of coffee, tea and cocoa bean production affects the results. If the location of primary production changes so will the transportation distance. However, transportation is not modelled again because its impact on the overall results is minimal.

In addition to Brazil there is an arabica coffee bean production process available for Colombia, Honduras and India in Agribalyse 3.0.1 database. From these three Colombia produced the most coffee beans in 2020 (International Coffee Organization 2023) and because of that it has been chosen as the location of coffee bean production in this sensitivity analysis. The chosen process is called 'coffee, green bean production, arabica - CO'. In water flows all flows from river, well and unspecified natural origin located in Colombia and RoW that contribute at least 0.01 % of total water flows are considered. RoW is considered because the coffee bean production process includes a unit process 'market for irrigation – RoW' (Guignard and Peano 2016b).

In addition to Sri Lanka there is a tea production process available for Kenya and RoW in Agribalyse 3.0.1 database. From these two Kenya is chosen as the location of tea in this sensitivity analysis. The process is called 'tea production, dried - KE'. In land transformation flows transformation from primary forests (non-use) and secondary forests (non-use) have been assumed to be extensive forestry. In water flows water from river and well in RoW has been considered because there are no specific flows for Kenya and the process includes a unit process ‘market for irrigation – RoW’ (Mouron and Riedener 2016a). These flows contribute to more than 1 % from all water flows.

In crop year 2021/22 Ghana was the second largest cocoa bean producer country in the world (Statista 2023). Therefore, Ghana is chosen as the location of cocoa bean production in this sensitivity analysis. The chosen process in Agribalyse 3.0.1 database is ‘Cocoa beans, sun-dried, at farm (WFLDB 3.1)/kg - GH’. In land transformation calculations secondary forest (non-use) is assumed to be extensive forestry and natural grassland (non-use) is assumed to be pasture. From water flows water from river and well in Ghana have been included in the calculations and those flows contribute to more than 1 % of total water flows.

The results of sensitivity analysis compared to the original results of primary production phase of coffee, tea and cocoa are presented in Table 25. It can be seen that by changing the location of coffee bean production from Brazil to Colombia (CO) the impact on terrestrial ecosystems grows from 1.04E-15 PDF*y to 9.04E-15 PDF*y (769 %) and the impact on freshwater ecosystems grows from 9.55E-17 PDF*y to 2.05E-16 PDF*y (115 %). By changing the location of tea production from Sri Lanka to Kenya (KE) the impact on terrestrial ecosystems decreases from 5.97E-16 PDF*y to 3.35E-17 PDF*y (94 %) and the impact on freshwater ecosystems decreases from 6.94E-17 PDF*y to 3.10E-17 PDF*y (55 %). By changing the location of cocoa bean production from Ivory Coast to Ghana (GH) the impact on freshwater ecosystems decreases from 1.69E-16 PDF*y to 1.21E-16 PDF*y (28 %). The impact on terrestrial ecosystems seems to turn negative because the impacts of land transformation in the case of Ghana are negative. This would indicate that cocoa bean production in Ghana has a positive impact on the diversity of terrestrial ecosystems (which is unlikely) or that cut-off criteria together with assumptions considering land transformation calculations distort the results.

Table 25. A comparison of the biodiversity impacts of coffee bean, tea and cocoa bean production in the original location and in the locations chosen in the sensitivity analysis.

Ecosystem type	Coffee bean production (BR)	Coffee bean production (CO)	Tea production (LK)	Tea production (KE)	Cocoa bean production (CI)	Cocoa bean production (GH)
Terrestrial ecosystems [PDF*y]	1.04E-15	9.04E-15	5.97E-16	3.35E-17	7.20E-16	-4.06E-16
Freshwater ecosystems [PDF*y]	9.55E-17	2.05E-16	6.94E-17	3.10E-17	1.69E-16	1.21E-16

A comparison of the biodiversity impacts of coffee tea and hot chocolate when the location of coffee bean, tea and cocoa bean production has been changed is presented in Figure 19. The locations of other life cycle stages have not been changed, nor has the location of primary production of milk and sugar. Transportation distances have not been modified either. It can be seen that now coffee has by far the largest impact on terrestrial ecosystems, so it rises past hot chocolate that had the greatest impact in the original results (Figure 9). The impact of coffee is so high that the negative result of cocoa bean production in Ghana does not distort the order. The order of the impacts on freshwater ecosystems remains the same as in the original results (Figure 9) as hot chocolate has a slightly higher impact than coffee.

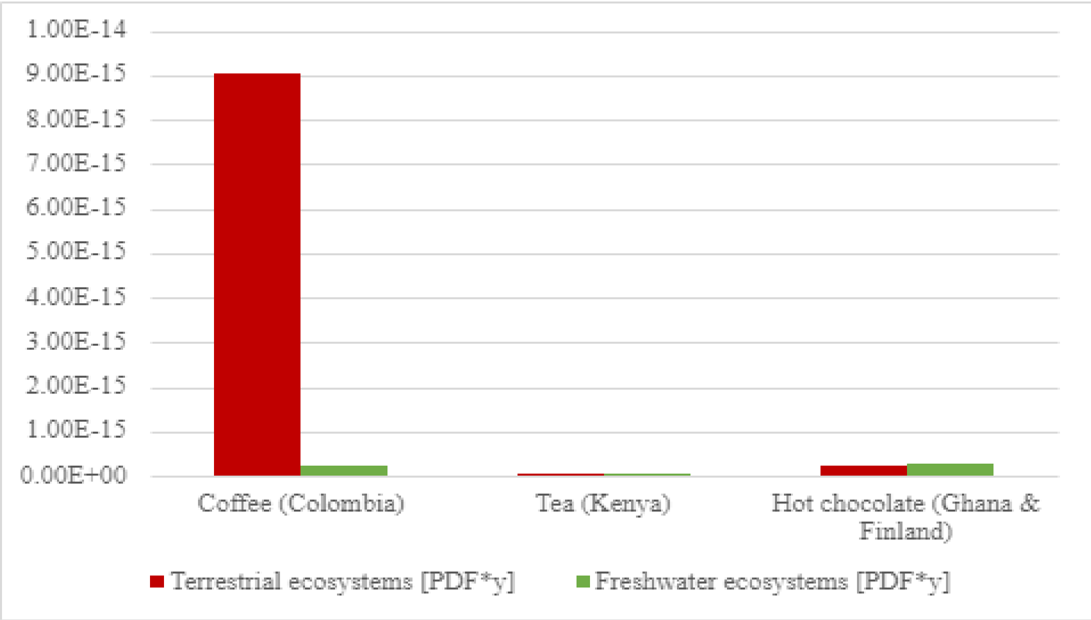

Figure 19. Comparison of the biodiversity impacts of coffee, tea and hot chocolate when the locations of primary production have been changed.

As a conclusion it can be said that the location of primary production has an enormous impact on the results and that should be considered when interpreting the results of this thesis. It must also be kept in mind that the products chosen in this study are imported to Finland from various different countries and thus the locations chosen do not represent all coffee, tea and hot chocolate consumed in Finland. Milk and sugar beet production were not considered in the sensitivity analysis but based on the results it can be assumed that changing the location of the production could have a substantial impact on the results also in the case of these two products.

6 Reduction of biodiversity impacts

Based on the results of this thesis it seems that drinking tea instead of coffee would decrease biodiversity impacts. As Finnish people drink a lot of coffee and tea consumption is much lower (Valsta et al. 2018, 53) this could have a significant impact. However, there are also many ways to reduce the biodiversity impacts of coffee, tea and hot chocolate throughout their life cycles. As most of the impacts seem to occur in primary production the analysis will focus on that life cycle stage.

One way of reducing biodiversity impacts in agriculture is to practice land-sharing or land-sparing. Land-sharing means that wildlife and agriculture are integrated together on the same area of land. In practice this kind of farming means avoiding of intensive farming practices as well as leaving field margins and some small uncropped areas on the land. Food outputs are lower in land-sharing systems but also biodiversity impacts are smaller. In land-sparing systems, in turn, wildlife and agriculture are separated from each other so that there are smaller areas of intensive agriculture and areas spared for biodiversity. So, smaller area of land is farmed in a more intensive way. Land-sparing has been recognized to be a more effective way to protect biodiversity compared to land-sharing and it may also be better when considering other aspects of sustainability as for example less GHG emissions per unit of production are generated in this kind of system. However, there is a risk that the intensive agriculture affects biodiversity in the spared areas for example through nutrient leakages. The spared land areas cannot either be too small or fragmented or otherwise the existence of viable wildlife populations is prevented. (Benton et al. 2021, 60-61.) Also, as intensive agriculture degrades the ability of soil to provide food in the long term through soil degradation (Kopittke et al. 2019, 1) more land may have to be eventually obtained for food production.

According to a study conducted by Valente et al. (2022, 1) land-sharing and land-sparing systems can complement each other in coffee growing landscapes when protecting biodiversity of birds. From different bird species groups generalists and open area specialists seem to prefer land-sharing landscapes whereas forest specialists seem to prefer land-sparing landscapes. The overall bird species richness varies between the two systems also temporally as species richness is higher in land-sharing systems during breeding season whereas during non-breeding season biodiversity is higher in land-sparing systems. (Valente et al. 2022, 1.) Bennett et al. (2021, 1) have gotten similar results when investigating the impacts of cocoa farming on biodiversity of birds through a meta-analysis. Land-sharing and land-sparing are both beneficial ways in protecting bird biodiversity in cocoa farming as these systems benefit different kind of bird species (Bennett et al. 2021, 1, 8). From the point of view of tree species richness, it seems that land-sparing systems are better for biodiversity in cocoa growing landscapes (Wade et al. 2010, 324).

Organic farming has several benefits. Less synthetic fertilizers and pesticides are used and certain kind of fertilizers and pesticides are not allowed to be used. Organic farming focuses on the fertility of soil and closing of nutrient cycles and it also supports crop rotation. Diversity has been included as an organizing principle. The downside of organic farming, however, is that the yields are lower which means that more land area is needed to produce the same amount of food compared to intensive farming. (Benton et al. 2021, 64.)

One promising way to mitigate biodiversity impacts in coffee, tea and cocoa cultivation is agroforestry. Agroforestry means integration of woody vegetation (trees and shrubs) with agricultural crops and/or animals (Mahmud et al. 2021, 83). This kind of farming enables the combining of several crops and opportunities for cropping all year round as fruits, nuts and wood are produced by tree polycultures (Benton et al. 2021, 65). Agroforestry was practiced for thousands of years in the tropics as the major food production way until agriculture was specialized and monoculture practices were brought into use (Eneroth et al. 2022, 24; Mahmud et al. 2021, 83).

Agroforestry has several benefits. For example, trees can provide useful shading for food crops. Agroforestry can help in protecting soils from erosion and improve the natural recharging of groundwater which in turn limits further deterioration of biodiversity and improves the productivity of the land over a longer period of time. It also provides natural pollination and pest control and can thus reduce the need for chemical inputs. (Benton et al. 2021, 65.) Applying of agroforestry can both mitigate climate change as trees sequester carbon and provide resilience against the impacts of climate change on variable and unstable crop productivity (Mahmud et al. 2021, 85).

The impacts of agroforestry on biodiversity in case of coffee and cocoa have been investigated in multiple studies. It has been found out that the species richness decreases by

46 % when turning agroforests into plantations and provision of ecosystem services in turn decreases by 27 %. Therefore, it is beneficial in terms of biodiversity and ecosystem provisioning to protect agroforest from further intensification and on the other hand to diversify monocultural coffee and cocoa plantations. However, the magnitude of impacts when turning agroforest into plantation differs between continents. This can result from both differences in sensitivity of species and different kind of farming practices between the locations. (De Beenhouwer et al. 2013, 1, 5.)

Agroforestry practices can be applied also in the case of tea to reduce biodiversity impacts. Monocultural plantations are the major tea production practice currently. However, among the biggest threats to biodiversity have been the expansion of the plantations together with conventional agricultural practices. By applying traditional tea cultivation methods such as agroforestry biodiversity can be supported in tea production. (Chowdhury 2021, 1, 14.)

According to the results of this thesis a significant share of the biodiversity impacts of hot chocolate are caused by milk production, especially because of climate change impacts (Figure 16 and Figure 17). One option to reduce the impacts from milk could be replacing dairy milk by plant-based options such as oat milk (Ritchie 2022). The GHG emissions throughout the life cycle of oat milk (0.9 $kgCO_2eq/l$) seem to be only a fraction compared to those of milk (3.15 $kgCO_2eq/l$) (Ritchie 2022). Also, land use of oat milk (0.76 m^2) seems to be very small compared to the land use of dairy milk (8.95 m^2) (Ritchie 2022). Therefore, also the land stress impacts of milk could be reduced by substituting dairy milk.

CH_4 emissions represent approximately a half of the carbon footprint of milk produced in Finland. During 1960-2020 the CH_4 emissions from dairy cows in Finland have reduced 56 % due to decreased number of cows and higher milk yield per cow. Per unit of product the reduction of CH_4 was 36 %. The emissions per unit have decreased because of improved efficiency of milk production resulting from breeding, management and feeding. The trends during the 60-year time period are likely to continue also in the future but more slowly. The most promising way to further reduce GHG emissions from Finnish milk production per unit is to increase the feed efficiency of cows by breeding which would result in higher milk yield per same feed input. (Huhtanen et al. 2022, 1, 9.) As the carbon footprint of dairy milk decreases so do the biodiversity impacts.

There are also ways to enhance and support biodiversity in grassland-based livestock farms. One example is to apply low-intensity mixed grazing of cattle and sheep to control dominant plant species in botanically diverse pastures/grazing lands. This enables less abundant species to compete thus promoting botanical richness and enhancing biodiversity. Another way to improve biodiversity in livestock farms could be to include woodland and hedges which would support a wider variety of species within different taxa by providing a different kind of habitat. (Fraser et al. 2022, 1, 4, 10.)

7 Conclusions

The objectives of this thesis were well achieved. The biodiversity impacts of coffee, tea and hot chocolate on terrestrial ecosystems were 1.06E-15 PDF*y, 6.11E-16 PDF*y and 1.34E-15 PDF*y respectively and the impacts on freshwater ecosystems were 1.02E-16 PDF*y, 7.38E-17 PDF*y and 3.21E-16 PDF*y respectively. Thus, the impacts of hot chocolate on both ecosystem types were the highest whereas the impacts of tea were the lowest. By far the largest share of the biodiversity impacts in the case of all three products and both ecosystem types occurred in primary production.

Most of the impacts on terrestrial ecosystems were caused by land stress in the case of coffee and tea. In the case of hot chocolate the impacts of land stress and climate change on terrestrial ecosystems were almost equal. Most of the impacts on freshwater ecosystems were caused by water stress in the case of tea and the effects of climate change in the case of hot chocolate. The impacts of water stress and climate change on freshwater ecosystems in the case of coffee were almost equal.

From the impacts of coffee on both terrestrial and freshwater ecosystems over 99 % were located in Brazil and the rest in Finland. Also, from the impacts of tea on both ecosystem types over 99 % occurred in Sri Lanka and the rest in Finland. From the impacts of hot chocolate on terrestrial ecosystems approximately 80 % occurred in Ivory Coast and the rest 20 % occurred in Finland. From the impacts of hot chocolate on freshwater ecosystems almost 99 % occurred in Ivory Coast, a bit over 1 % occurred in Finland and a very small share (0.02 %) occurred in Netherlands. The results indicate that by far the majority of the biodiversity impacts occur outside Finland which is in line with previous research of Sandström et al (2017) and Järviö et al (2022).

The biggest potential for reducing biodiversity impacts is in primary production as that is the life cycle stage where the largest share of the impacts occur. In coffee, tea and cocoa bean production land-sharing, land-sparing and agroforestry are examples about promising solutions. The impacts of milk could be reduced by substituting dairy milk by plant-based options or by reducing the impacts of dairy milk through increasing the feed efficiency of cows which would lead to higher milk yield per same feed input. Also, application of low-intensity mixed grazing of cattle and sheep or inclusion of woodland and hedges are potential ways to enhance biodiversity at grassland-based livestock farms.

Based on this study it is important to consider the displaced biodiversity impacts of food products consumed in Finland which is also in line with previous research of Sandström et al. (2017) and Järviö et al. (2022). Whereas the previous studies focused on analysing the overall impacts of food products consumed in Finland, in this study the focus was on the life cycles of single food products. Therefore, this study provided information about the contribution of different life cycle stages which in turn can help to target impact reduction measures to the life cycle stages where they are most effective. In addition, as this study compared the impacts of three similar kind of products, information about how impacts change by substituting one product with another was gotten.

There were several limitations and uncertainties in this study of which one of the most important was the choice of the locations. In sensitivity analysis it was seen that changing the location of primary production of coffee beans, tea and cocoa beans had an enormous impact on the results of that life cycle stage. Also, the order from best to worst changed when the impacts of coffee, tea and hot chocolate were compared without modifying other factors. The impacts of coffee seemed to rise past the impacts of hot chocolate. The exclusion of other impact categories than land stress, water stress and climate change was also one of the most essential limitations. Because of that the results of this study do not represent the biodiversity impacts in a completely comprehensive way. Also, the choice of impact assessment method, limitations related to LC-IMPACT, cut-off criteria, data quality as well as exclusion of some life cycle steps affect the reliability of the results. As a big amount of data was handled manually in Excel also calculation mistakes are possible. Because of all the limitations and uncertainties, the results of this study should be considered indicative.

However, despite the limitations and uncertainties, the results of this thesis can help to steer consumption and production in a more biodiversity friendly direction. In future research more impact categories could be included to get a more comprehensive analysis of the biodiversity impacts. Also, different impact assessment methods could be applied to see how the results differ. To get a more holistic view on the possibilities to reduce the impacts of food products consumed in Finland more different kind of products as well as locations of production could be included in future research. Also, biodiversity impact assessment methods should be developed further as there is no generally accepted method available currently.

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