YRKESHÖGSKOLAN NOVIA

Urban Ecological Footprint Assessment of the City of Vaasa with Open Access Data

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I would like to thank all of my friends and family, especially my parents for supporting me in everything I do. Special thanks to my classmates who not only supported me in my studies but with whom I also had the chance to share my free time.

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Also, special thanks to Roger Mäntylä and Frank Späte who both made my stay in Finland possible.

Finally, I would like to address the importance of working towards a more sustainable world community, fighting human-made climate change, and preserving natural resources for future generations.

BACHELOR'S THESIS

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Abstract

This thesis was commissioned by Novia University of Applied Sciences. The aim of this thesis was to calculate the Urban Ecological Footprint (UEF) of the city Vaasa and to develop a repeatable methodology for future assessment of other cities in Finland.

With respect to the methodology, input-output analysis was conducted, and the identified data were computed into a value representing the UEF of Vaasa. Data was collected from FAOstat, LUKE, SYKE, Statistics Finland, and the Corine Land Cover (CLC) 2018 database and processed with equations provided by the Global Footprint Network.

The assessment resulted in an Ecological Footprint of $4.24\ gha/cap$. Due to the available Biocapacity of $1.27\ gha/cap$ the assessment concluded an Ecological Deficit of $-2.97\ gha/cap$. The results suggest that the Ecological Footprint of an average Vaasa citizen is more sustainable than the Ecological Footprint of an average Finnish person. Finally, limitations of the methodology are identified, and improvements are suggested with more consistent data sources for future application in UEF calculations in Finland.

Language: English

Keywords: Urban Ecological Footprint, Ecological Footprint, Vaasa, Sustainability Assessment

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Glossary

EF	Ecological Footprint
UEF	Urban Ecological Footprint
BC	Biocapacity
YF	Yield Factor
EQF	Equivalence Factor
EB	Ecological Balance

1 Introduction

Anthropogenic-forced climate change and the developing environmental crisis of land degradation and loss of biodiversity are some of the greatest challenges current and future generations have to face. Moreover, most of these negative anthropogenic impacts can be traced back to humanity's overexploitation of the earth's available natural resources. Estimating this overconsumption, the Global Footprint Network (2021) suggests that the natural resources humanity currently requires are exceeding the earth's capacity by the factor of 1.6. Further projections by Loh and Goldfinger (2006) even indicate that it will exceed a demand of 2 earths by 2050.

This environmental scarcity indicates, that earth's bioproductivity cannot keep up with humanity's demand for natural resources and that therefore the present human lifestyle is unsustainable. The Food and Agriculture Organization of the United Nations (2020) states that 38% of the global land surface is utilised for agriculture, while a study published by Plumptre *et al.* (2021) considers only 2.8% of the global land surface as ecologically fully intact. Moreover, the UN Interagency Framework Team for Preventive Action (2012) reports that 40% of all civil wars fought over the last 60 years are related to natural resources, due to their scarcity in many places of the world.

Most indicators suggest that environmental scarcity will increase. The United Nations Department of Economic and Social Affairs (2019) projects the world's population at 10.9 billion in 2100, leading to a much higher demand for biocapacity. Additionally, Bennich and Belyazid (2017) suggest that the recent shift to a more biobased economy can increase the world's demand for natural resources even more.

It is becoming increasingly evident that earth has biophysical limitations, and that its population and economy cannot grow infinitely. To preserve the earth's resources for future generations, humanity must transit into a more sustainable economy. Hence, it is vital to track the availability and demand for natural resources. Knowledge about the earth's boundaries can help to manage its resources sustainably and to develop successful mitigation against an environmental crisis.

One methodology to estimate the availability and demand of natural capital is to calculate the Ecological Footprint (EF). It can give a reference point for the current situation and future development. While easily accessible results on global and national levels exist, the EF is rarely broken down to a city or sub-regional level. Only a few cities worldwide have conducted Urban

Ecological Footprint assessments, which promote local government legislations and incentives for sustainability development.

1.1 Aim and Objectives

The aim of this thesis is to assess the Urban Ecological Footprint (UEF) of the city of Vaasa. The assessment is expected to result in a value, representing the city's use of natural resources as accurately as possible. The methodology should be easily repeatable so that one can compare, benchmark, and improve the UEF of different cities in Finland.

To meet this aim, the following objectives have been developed:

- Determine the assessment methodology and the assessment area
- Conduct an Input-Output Analysis to gain the necessary data
- Calculate the Urban Ecological Footprint of the city of Vaasa

1.2 Project Purpose

The thesis was commissioned by Kendall Rutledge, who is working at Novia University of Applied Sciences and the University of Vaasa. The results of this thesis are intended to be utilised for his research on Urban Metabolism. This thesis will provide an initial UEF sustainability assessment of the city of Vaasa. The findings should be applicable and enable the project team of Kendal Rutledge and other researchers to assess the UEF of other Finnish cities, as these evaluations are essential for the task of developing sustainable cities.

1.3 Thesis structure

The first section (Section 2) will be the literature review and give further background information about the development and the standards of the UEF method. Section 3 will outline the methodology of the thesis with input-output analysis and the calculation of the Urban Ecological Footprint. The results will be delivered in Section 4 and further discussed in Section 5. A conclusion is given in Section 6.

2 Literature Review

This section will explain the development, concepts, and standards behind UEF assessments. It starts with defining the concept of EF in Section 2.1, as it was developed by Wackernagel (1994), to determine the sustainability of a certain population. An overview of previous EF assessments is given in Section 2.2, whereas Section 2.3 presents the study area. The important categorisation of land-use types is outlined in Section 2.4, and Equivalence Factors are introduced in Section 2.5. Section 2.6 explains important limitations of EF assessments and the calculation standards are outlined in Section 2.7.

2.1 Definition of Ecological Footprint

The idea of Ecological Footprints (EF) was first mentioned by Rees (1992), who argued that modern economics has abandoned its connection to ecology and are thus ignoring real environmental issues. In this context, he arrives at the observations that humanity relies on earth's natural capital and defines the necessary land to sustain a certain region or population as the Ecological Footprint.

Wackernagel (1994) then further developed this theory to create a tool for calculating the EF. In his opinion, due to globalisation the EF of a certain society or person is not limited to its local surroundings but can also occupy land beyond its physical or political borders. Thus, identifying these Ecological Footprints can allow for assessing a person's or society's sustainability and for possible mitigation. The hypothesis for his calculation methodology is that every major consumption or human activity requires bioproductive land or water (Wackernagel *et al.*, 1999). For most human activities the impacts on earth's biocapacity can be measured, and by adding up all bioproductive land required for human living, one will arrive at the Ecological Footprint.

Wackernagel (1994) explains the Ecological Footprint as the area of bioproductive land necessary to sustainably supply human activities. Conversely, the amount of available bioproductive land in a certain study area is called Biocapacity (BC). Both values can be assessed in global hectares [gha] or global hectares per capita [gha/cap], which enables the comparison between different groups of populations. The term Urban Ecological Footprint (UEF) only specifies the EF assessment to an urban area.

2.2 Previous EF assessments

Wackernagel (1994) mentioned that EF assessments could be applied on a wide scale, from a single person up to the whole globe. Nevertheless, they are mostly used on a country level since for sub-national levels more detailed models, data, and estimations would be necessary. In his doctoral thesis, Wackernagel (1994) conducted the first EF assessment on the EF of Canada. Since then, the methods for EF assessments have been further refined and consolidated. Presently, the Global Footprint Network (GFN) (footprintnetwork.org), which is founded by Wackernagel, is the leading research institution in EF assessments and provides international standards. The GFN regularly calculates and updates the EF for most of the world's countries (see Figure 1).

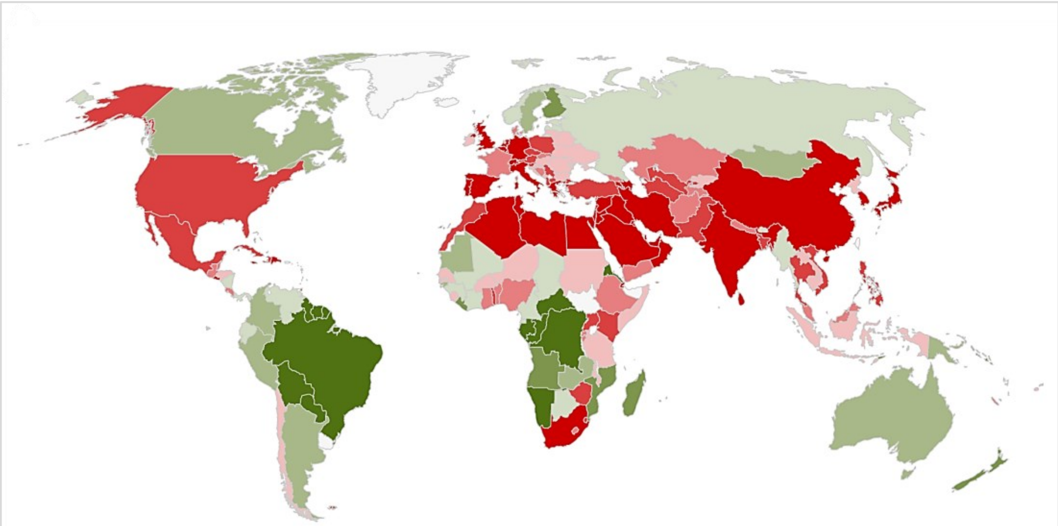

Figure 1. World map distinguishing between countries with "Ecological Deficit" (red) and "Ecological Reserve" (green). – Adapted from footprintnetwork.org.

This world map shows the countries assessed by the Global Footprint Network. Unsustainable countries with an EF higher than their biocapacity (BC), are coloured in different shades of red. Sustainable countries, which have a reserve of biocapacity, are coloured in different shades of green. As part of their research, the GFN also established the number of demanded earths and the Earth Overshoot Day, on which all the natural resources allowed for that particular year are consumed. For 2021 the Earth Overshoot Day was calculated to be the July 29th. More information on the Earth Overshoot Day can be found at overshootday.org.

On sub-national levels, the UEF was assessed only for a few cities worldwide. Figure 2 is a map taken from a 2020 UEF assessment of the city of Wroclaw and locates the cities with a calculated UEF.

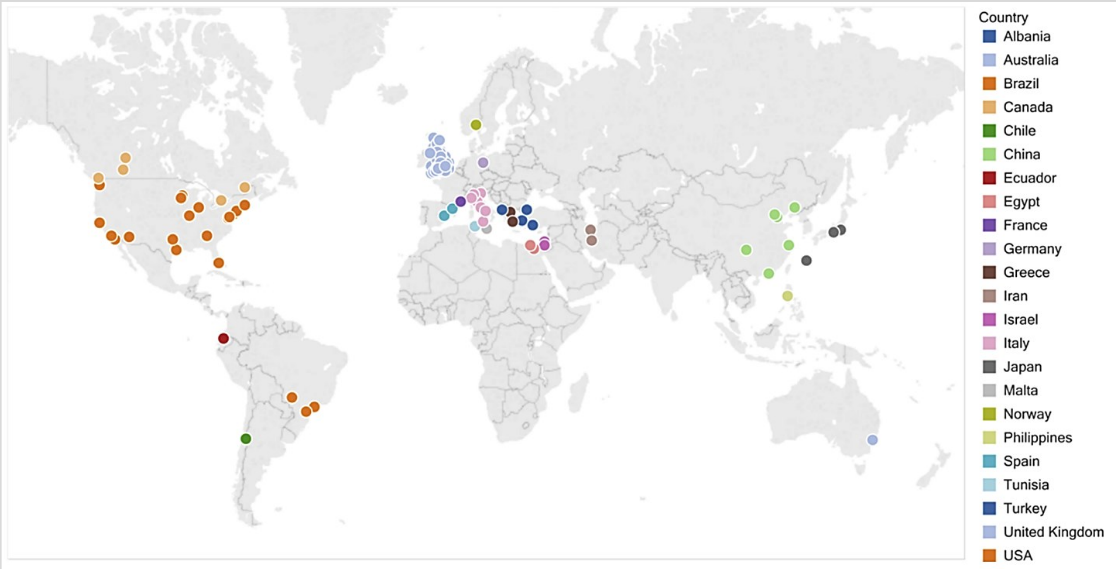

Figure 2. Location of cities where the UEF was assessed between 1998 - 2017 (Świąder et al., 2020).

This map highlights the UEF assessments conducted during 1998 and 2017 (Świąder *et al.*, 2020). One can see that only a few assessments were done, mostly in Europe, the US and China. Especially noticeable is, that in the UK the density of UEF assessment seems to be highest because Calcott and Bull (2007) assessed 60 cities within the UK to rank them according to their EF. In Finland, there has been little work on the topic of UEF. The work, undertaken by Hakanen (no date), on "The Ecological Footprint of a Helsinki Resident" is very limited in scope and methodology, as well as outdated. Calculations seem to be very simplified and have been done only for 1995.

2.3 Study Area

The study area of this assessment will be the city of Vaasa. Vaasa is a coastal city in western Finland, an archipelago region with many islands, lakes, and forested areas. The population of Vaasa was counted for 67,551 residents in December 2020 of which 93% lives in urban areas. This data is updated frequently by Statistics Finland and can be found at pxnet2.stat.fi.

According to the City of Vaasa (2021), it has 13,000 students every year, offering a big workforce for the local industry. Vaasa is known for its industry in the energy sector, with Wärtsilä, ABB Finland, and Westenergy creating local income but also demanding local resources. In 2021, the average salary of a Vaasa citizen is 3,670 Euros (salaryexplorer.com) and therefore only slightly higher than the Finnish average.

According to Beck *et al.* (2018), Vaasa lies within the Dfc Köpper-Geiger climate zone, which is defined by cold climate with cold summers and without dry seasons. Figure 3 illustrates the average precipitation and mean daily temperatures of Vaasa.

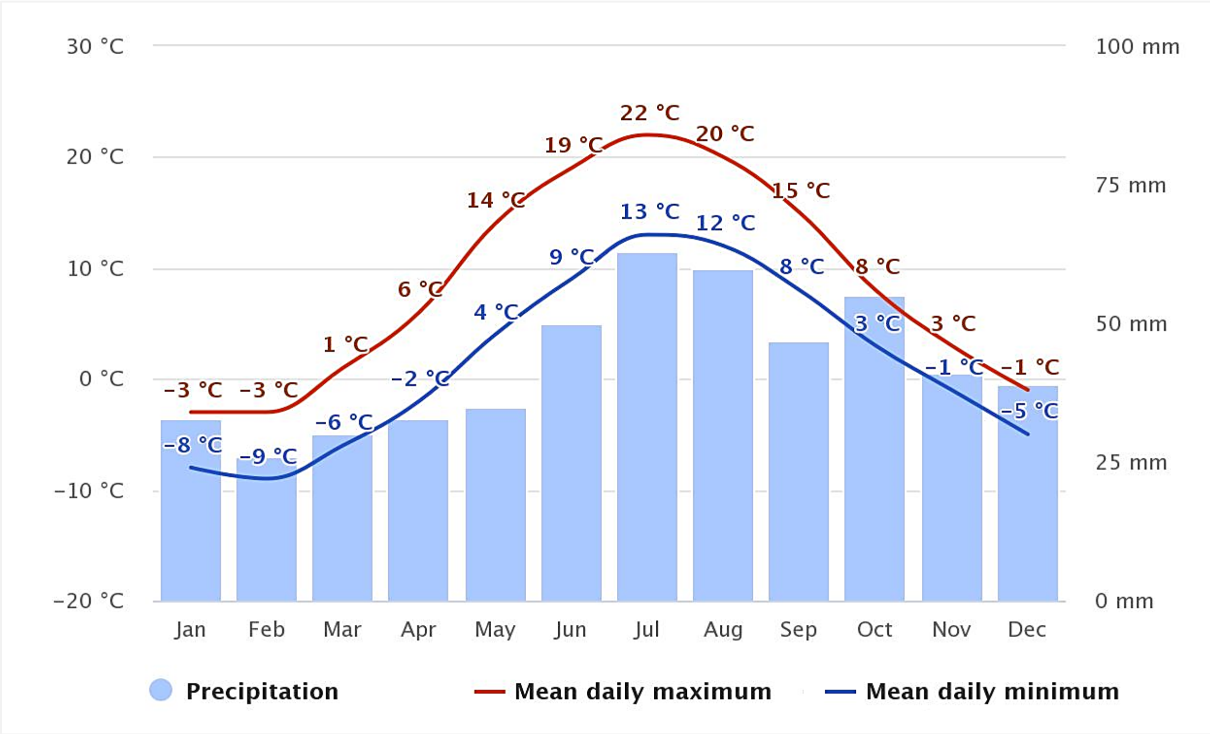

Figure 3. Precipitation [mm] and mean daily maximum and minimum temperature [°C] of Vaasa (Meteoblue, 2021).

Temperatures are typically below 0°C all day from December to February and all night for half of the year, from November to April. Summer days from June to August arrive at 20°C, whereas nights are quite cold. Precipitation is stable throughout the year, as it is lowest in February with 26 mm, and highest in July with 63 mm. Due to its high latitude of 63° north, Vaasa has high daylight change between summer and winter.

This assessment identified a total area of about 518 km² of which 207 km² are water bodies. The spatial properties of the study area are shown in Figure 4, which depicts the region of Ostrobothnia and its municipalities.

Figure 4. Sub-regions and municipalities of Ostrobothnia (Virkkala *et al.*, 2014).

The map illustrates the sub-regions and municipalities of the Ostrobothnia region. The study area is identified by the Vaasa municipality (dark green), which lies within the Vaasa sub-region (green). The study is defined by the administrative area of the city, as several studies, like the ones conducted by Świąder *et al.* (2020) or Geng *et al.* (2014), suggest. This gives a clear division within Finland and enables to address a governing institution, which could react to the study's findings.

In an EF assessment of the Hexi Corridor in China by (Chang and Xiong, 2005), urban and rural residents were differently assessed, due to the difference in consumption habits between the urban and rural areas of China. For the case of Vaasa, there are several reasons to treat both residents equal in the UEF assessment. For one, the very high urbanisation of Vaasa does not make a separation necessary, and secondly, the variation between urban and rural lifestyles is not expected to be as high.

2.4 Land-use Types

EF calculations utilise the concept of land-use types since the EF occupies different types of land in different countries all over the world. Different lands have different bioproductivity, as one can imagine when comparing one hectare of forest with one hectare of desert. Therefore, these areas are categorised and assigned with specific Equivalence Factors (EQF) and Yield Factors (YF) (defined in Section 2.5). This assessment uses the same six land-use types as Lin *et al.* (2019). Every bioproductive land, as well as consumption or human activity, is assigned to one of these categories.

2.4.1 Cropland

Cropland is defined as the area appropriated for growing all crop products, whether it is for food, feed, or industrial purpose. In detail, it includes cereals, fruits, citrus fruits, fibre crops, oil crops, pulses, roots and tubers, sugar crops, tree nuts, and vegetables. Cropland is the most bioproductive land-use type and has therefore the highest EQF. The European Environment Agency (2017) identifies 5% of Finland's area as arable land for permanent crop cultivation.

2.4.2 Grazing Land

Grazing land includes all grassland farmed for feed in addition to feed crops. This includes cultivated grassland, as well as wild pastures. Deriving from the suitability index used for the EQF calculation (Section 2.5), grazing land has compared to cropland a much lower bioproductive value.

2.4.3 Forest Land

Forest land is one of the easiest categories, as it can be mainly classified by land populated with trees. Products deriving from forest land are wood and paper products, as well as firewood. According to the European Environment Agency (2017), Finnish land cover consists of 72% forested land.

2.4.4 Fishing Grounds

Fishing grounds are the only land-use type that is not land. It can be further categorised by marine and inland fishing grounds. It only includes all of the study area's fishing waters and excludes therefore international waters and EEZ areas. According to the European Environment Agency (2017), 9% of Finland's area are water bodies.

2.4.5 Carbon Uptake Land

Carbon Uptake Land is its own category within the EF, but not within the BC calculations. As explained by Borucke *et al.* (2013), carbon uptake land is assumed to be forest land. This is because most of the CO_2 is absorbed by the forest biosphere, and because counting cropland for CO_2 uptake could lead to double counting and overestimations. The effect of ocean CO_2 uptake is considered but apart from that only unoccupied forest land biocapacity is assumed to absorb CO_2.

2.4.6 Built-Up Land

Built-up land is the land directly used by the urban population. It is land covered by human infrastructure, which means its bioproductivity is reduced to zero. Therefore, built-up land is not part of the BC. For built-up land, the EQF of cropland is used as it is assumed that cities are mainly built in fertile areas and therefore occupy highly productive cropland.

2.5 Equivalence Factors

To compare and add up the value of different land-use types, Wackernagel *et al.* (1999) introduced Equivalence Factors (EQF) and Yield Factors (YF). Equivalence Factors and Yield Factors convert the physical area $[ha]$ into the value of global hectares $[gha]$. Without these factors, the BC would only represent the actual land cover and the EF the actual land use. EQFs and YFs are published regularly by the GFN and adopted for most EF assessments. This UEF assessment is using the latest factors published by the GFN at footprintnetwork.org/licenses/.

2.5.1 Yield Factors

YFs consider that yield, and therefore bioproductivity varies from country to country (Lin *et al.*, 2019). For example, farming crops within very cold or dry countries is probably less productive than in countries with a more suitable climate. The YFs are calculated as in Equation 2.1.

$$YF_j = \frac{Y_{L,j}}{Y_{WA,j}} \qquad \left[\frac{wha}{ha}\right] \tag{2.1}$$

Adapted from Lin *et al.* (2019)

YFs describes the relation between national average yield $Y_{L,j}$ and world average yield $Y_{WA,j}$ within a land-use type. This enables to compare EFs and BCs unrelated to a country's individual productivity. Yield factors have the unit $\left[\frac{wha}{ha}\right]$ and transform hectare $[ha]$ into the unit world hectare $[wha]$. Table 1 lists the YFs by land-use type based on 2017.

Table 1. Yield factors for different land-use types.

Land-use type	Yield Factor
Crop Land	0.53
Grazing Land	1.29
Marine Fishing Grounds	4.05
Inland Fishing Grounds	1.00
Forest Land	1.65
Infrastructure	0.53

Adapted from: York University Ecological Footprint Initiative and Global Footprint Network (2021).

These numbers show for example that Finland's croplands have an under-average yield, however, its marine fishing grounds are more than four times as productive as the world average. Yield factors for carbon uptake land do not exist, as carbon uptake land equals forest land. The YF of infrastructure (built-up land) equals the YF of cropland. In terms of fishing grounds, it is distinguished between marine and inland fishing grounds.

2.5.2 Equivalence Factor

Whereas YFs enables the comparison of EFs of different countries, EQFs allow for comparing EFs between different land-use types. Equivalence factors convert world hectare $[wha]$ into global hectare $[gha]$, and consider the different bioproductive values of land-use types. The GFN has calculated EQFs for all land use types with data from 2017 in Table 2.

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Table 2. Yield factors for different land-use types.

Land use type	Equivalence Factor
Cropland	2.49
Forest Land	1.28
Grazing Land	0.46
Fishing Grounds	0.37
Infrastructure	2.49
Carbon uptake	1.28

Adapted from: York University Ecological Footprint Initiative and Global Footprint Network (2021).

The EQF is the relation between the bioproductivity of a land-use type and the global average. For example, cropland is assessed with an EQF of 2.49 and is consequently more valuable than forest land, which has an EQF of 1.28. EQFs are not stable but can change slightly over the years.

The GFN calculates the EQFs with the help of suitability indexes. Lin *et al.* (2019) explain how the Global Agro-Ecological Zones model (GAEZ) divides all global land into five levels of suitability and allocating them to the land-use types. It is assumed that crops are farmed on the most suitable terrestrial land, while the next best suitable land will be forest land and the least suitable land can be only used as grazing land.

2.6 Predefined assessment limitations

Many minor factors of the actual EF are too detailed for being included in the accounting, as it would make the assessment impractical. Wackernagel (1994) described the estimation of an EF as an iterative process that needs to have simplifications. Therefore, certain aspects of human activities will not be considered, which only have a minor effect on the result but are too detailed to be included in the calculation.

This means that, according to Ewing *et al.* (2010), the demand for natural resources (EF) is understated, and the supply (BC) is overstated. In terms of EF, many consumption activities are not recorded or too small to estimate. Freshwater consumption, soil depletion, eutrophication, and other forms of pollution are not considered but affect the BC in the long term. Regarding the BC, land degradation and long-term sustainability are not considered. The limitations on both sides lead to the results depicting a more sustainable EF than the actual exists. Nonetheless, since this model should be a practical estimation, these assumptions and simplifications are necessary and useful, if the limitations are kept in mind during the interpretation. Assumptions and simplifications are outlined in Sections 3.3 and 3.4.

2.7 Calculation standards and sources

As the GFN developed the initial EF assessment and is the leading institution of conducting EF assessments, its methodology is widely accepted as the standard. The following two papers are the latest updates on the calculation methodology for the national EF calculations conducted by the Global Footprint Network and provide a detailed methodology and step by step instructions for National EF calculations.

- Accounting for demand and supply of the Biosphere's regenerative capacity: the National Footprint Accounts' underlying methodology and framework - Borucke *et al.* (2013)
- Working Guidebook to the National Footprint and Biocapacity Accounts - Lin *et al.* (2019)

The GFN also provides an exemplary EF calculation in form of a spreadsheet, from which formulas and methods are adapted. The spreadsheet can be found in an open access workbook learning licence at footprintnetwork.org/licenses.

Methodology specifically for UEF assessments is inspired by assessments of the city of York by Barrett *et al.* (2002), the cities of Shenyang and Kawasaki by Geng *et al.* (2014), the city of Mashhad by Haghparast and Dawoudian (2018), and the city of Wroclaw by Świąder *et al.* (2020). Calcott and Bull (2007) assessed 60 cities within the UK and Galli *et al.* (2020) six cities in Portugal.

3 Methodology

This section outlines the calculations and definitions of the assessment. Section 3.1 addresses the data collection by input-output analysis, while Section 3.2 and 3.3 give details on defined classifications. Section 3.4 outlines the calculation procedure and describes the utilized data sources for every land-use type. Section 3.5 and 3.6 outline the calculations for the Biocapacity and the Ecological Balance, respectively. All calculations were executed in Microsoft Excel (see Figure 5), GIS data was processed in Google Earth Engine (code.earthengine.google.com) (see Section 3.5).

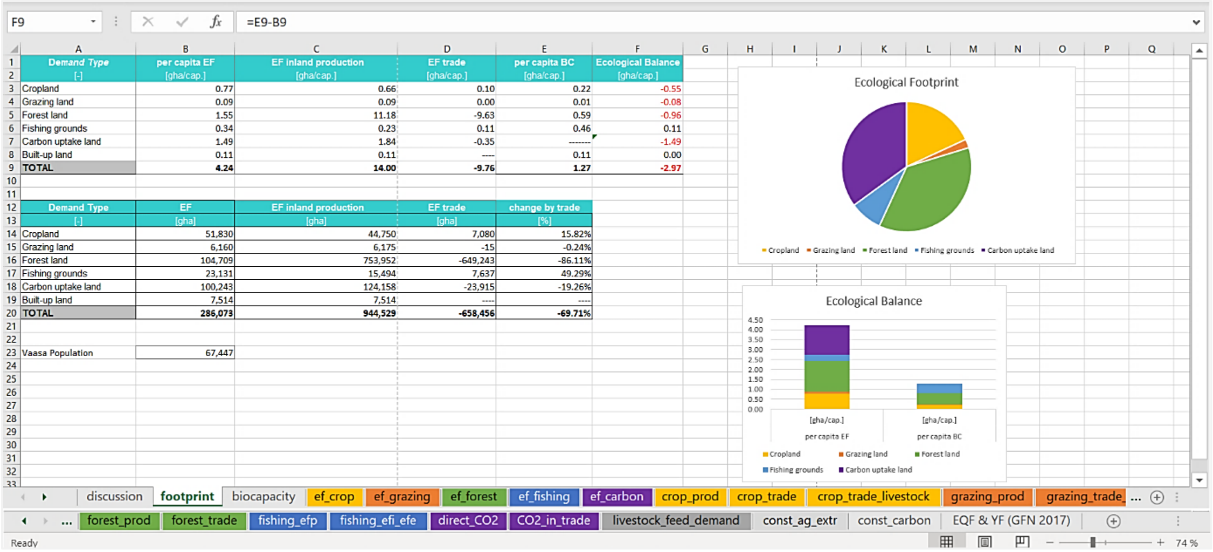

Figure 5. Overview of the calculations conducted in Microsoft Excel.

Calculations have been executed by land-use type. The calculation tabs for cropland, grazing land, forest land, fishing grounds, and carbon uptake land are each coloured differently. In total, the workbook consists of 23 Excel sheets and has a size of 1.30 MB. The Excel file is available at yhnovia-my.sharepoint.com, and detailed metadata and exemplary tables can be found in Appendix III.

3.1 Input-Output Analysis

The input-output analysis is conducted to identify the impacts on the UEF and to decide for which data to use in the assessment. This section discusses the approach of identifying the UEF by the study area's consumption (Section 3.1.1) and compares the two methods of data collection (Section 3.1.2).

3.1.1 Consumption approach

The input-output analysis is conducted to arrive at all consumption within the city. In general, the assessment is consumption-focused since it appropriates the direct and indirect impacts of human existence and activities. Therefore, direct and indirect demands of biocapacity have to be determined as visualised in Figure 6.

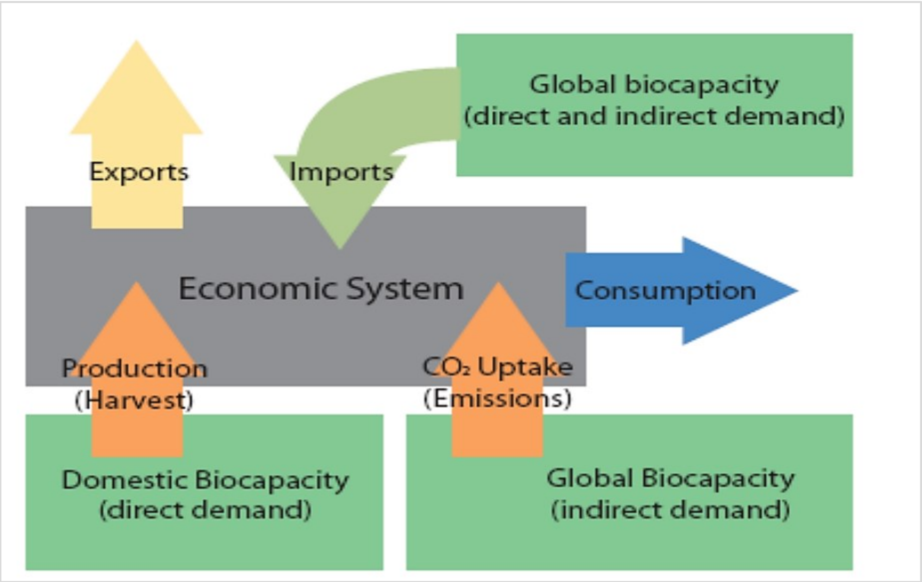

Figure 6. Schematic for direct and indirect demand of biocapacity (Ewing *et al.*, 2010).

Since the goal of this assessment is to identify the impacts caused by the study area's everyday activities, the consumption is assessed. The general source for consumption within the study area is inland production, which directly demands domestic biocapacity but also indirectly demands global biocapacity. However, due to global trade, imports and exports must be considered. The final consumption is calculated by accumulating the EFs of single commodities, as defined in Equation 3.1.

$$EF_C = EF_P + EF_I - EF_E \tag{3.1}$$

Adapted from Lin *et al.* (2019).

Where EF_C is the total EF of consumption, EF_P the EF of domestic production, EF_I the EF of imports, EF_E the EF of exports. Depending on if the commodity is inland production, import, or export its EF is added or subtracted. The accumulation or use of stocks is not included. For this consumption approach, it is important to avoid double counting of specific sources, therefore, for example, the energy consumption of industry is not counted, as the embodied energy within traded products is calculated separately.

3.1.2 Component and Compound Method

There are two basic methods of collecting and processing data UEF assessments, the compound method (top-down) and the component method (bottom-up). The compound method takes national footprint data, breaks it down to a per capita Ecological Footprint and calculates the UEF according to the study area's population (Świąder *et al.*, 2020). This method is by far easier to implement and assures comparability between different UEFs. However, it gives less insight into the city's development, as the per capita EF of every Finnish city would be the same.

Therefore, one must include the component method, which is using local data to arrive at the consumption and waste values of the local study area (Geng *et al.*, 2014). All accessible data regarding local consumption is collected and combined to calculate the UEF, and thus the result represents the city more individually, however, most times also more inaccurately.

Ideally, the UEF would be assessed by the component method with accurate data. However, due to the lack of local data, this assessment uses a combination of the compound and the component method, as done by Świąder *et al.* (2020). Depending on the consumption category and the attributes of its data, the compound, or the component method is used. The land-use types of cropland, grazing land, forest land, and fishing grounds are calculated by compound method, as they rely on national data. Carbon uptake land and built-up land are calculated by the component method, as municipal data exists on these categories. This is further outlined in Section 3.3.

3.2 Consumption types

To better identify the necessary data, this section establishes five consumption categories, that should cover the whole impact of human consumption (and activity) on bioproductive land. This thesis, uses the same consumption types as they have been introduced by Wackernagel (1994): food, consumer goods, housing, transport and service. The input-output analysis adapts the works by Wackernagel and the input-output analysis conducted by Barrett *et al.* (2002). Appendix I shows the results of the input-output analysis, which are all the city's impacts categorised by consumption category. Table 3 shows the consumption matrix for the city of Vaasa. It includes all consumption types and assigns them to the land-use types.

Table 3. Consumption matrix for UEF of the city of Vaasa.

	Cropland	**Grazing Land**	**Forest Land**	**Fishing Grounds**	**Carbon Uptake Land**	**Built-Up Land**
food	plant-based food, animal-based food	animal-based food		fish and seafood	embodied energy (also traded product)	factory land
consumer goods	crop derived products	animal-derived products	wood and paper products		embodied energy (also traded product), fuels	factory land mines
housing			building wood		electricity and heating, construction energy	housing land
transport					fuels, processing energy	road infrastructure
services					energy for public buildings, energy for public services	public buildings

The consumption matrix tries to appropriately reflect the actual UEF of Vaasa. Food consumption affects all land use types except for forest land. Plant-based, animal-based, and seafood are extracted from cropland, grazing land, and fishing grounds. Carbon uptake land is affected by the embodied energy within food products. Built-up land is affected by all consumption categories, as it needs land for factories, housing, or infrastructure.

Consumption goods have the same effect as food products but include forest land instead of fishing grounds. Consumption goods can be derived from plants, animals, or wood. The use of fossil resources and metals can only be seen in the emission of carbon dioxide, as the EF only assesses bioproductive resources.

Houses are assumed to be built from wood or bricks and therefore include only forest land, carbon uptake land, and built-up land. As for the transport and service consumption types, it only affects carbon uptake land and built-up land.

3.3 Calculation groups and assumptions

To arrive at the UEF based on the consumption matrix, one must calculate the single impacts according to the available data. To simplify these calculations, the cells of the consumption matrix are organized by calculation groups, depending on required datasets and calculation methods. Table 4 shows which consumption cells are assigned to which calculation group.

Table 4. Calculation groups within the consumption matrix.

<table>
<tr><th></th><th>Cropland (1)</th><th>Grazing Land (2)</th><th>Forest Land (3)</th><th>Fishing Grounds (4)</th><th>Carbon Uptake Land (5)</th><th>Built-Up Land (6)</th></tr>
<tr><td>food</td><td rowspan="2">• Production
• Trade</td><td rowspan="2">• Production
• Trade</td><td></td><td>• Production
• Trade</td><td rowspan="5">Vaasa municipality CO_2 emissions</td><td rowspan="5">Built-up land from remote sensing</td></tr>
<tr><td>consumer goods</td><td rowspan="2">• Production
• Trade</td><td></td></tr>
<tr><td>housing</td><td></td><td></td><td></td></tr>
<tr><td>transport</td><td></td><td></td><td></td><td></td></tr>
<tr><td>services</td><td></td><td></td><td></td><td></td></tr>
</table>

Every calculation group resembles each one land-use type and is coloured differently. As carbon uptake land (land-use types 5) and built-up land (land-use types 6) deal with indirect consumption, their EF is calculated differently from other land-use types.

Due to the lack of local data and the assumption that the average per capita consumption of food and consumer goods does not vary much between Vaasa and Finland as a whole, the EFs for land use type 1 to 4 are calculated on a national level and scaled-down by capita. This assumption excludes regional consumption differences within Finland and domestic trade between different municipalities. The EFs of land-use types 1 to 4 are calculated in two sub-groups, which are domestic production and trade. Therefore, datasets from the Food and Agriculture Organisation of the United Nations (FAO) (fao.org/faostat) and the Natural Resource Institute Finland (LUKE) (statdb.luke.fi) are utilised. For all calculations, only commodities with at least 100 tonnes of production, import or export per year are considered. If not further specified, data refer to 2019.

The EF of carbon uptake land is calculated from the municipality's CO_2 emissions, as published by the Finnish Environmental Institute SYKE (paastot.hiilineutraalisuomi.fi), and the embodied energy within traded products. The EF of built-up land is calculated by GIS data (together with the BC) from the Corine Land Cover (CLC) 2018 database (land.copernicus.eu).

3.4 Ecological Footprint calculation

As defined in Section 2.1, the Ecological Footprint (EF) resembles all bioproductive areas, necessary to supply the study area's demand of natural resources (Borucke *et al.*, 2013). The total EF of the study area is put together as the sum of the EFs of the six land-use types (see Equation 3.2).

$$EF = \sum_{i=1}^{6} EF_i \tag{3.2}$$

Where the indexes i refer to the six land-use types (or calculation groups), as defined in Chapter 3.3. The equations for calculating the EF of each land-use type are outlined in this section. In these equations, a plus-minus symbol emphasises that imports are added, and exports subtracted. For land-use types 1 to 4 (cropland, grazing land, forest land, and fishing grounds), the Ecological Footprint is accumulated from the EFs of all commodities within the land-use type. The EF of every commodity is calculated by Equation 3.3.

$$EF_j = \frac{\mathrm{P_j}}{Y_{W_j}} \cdot EQ\mathrm{F_i} \tag{3.3}$$

Adapted from Lin *et al.* (2019).

Where P_j is the total amount of a product j (domestic production, import, or export) and $Y_{W,j}$ is the world average yield for product j. The EQF depends on the land-use type i. If the world average yield is not available, it can be approximated by the yield factor (see Section 2.5.1).

In other words, by dividing the total production/import/export of a good $[t]$ by the world average yield $[wha/t]$, one arrives at a value of world hectare $[wha]$, which expresses the area (of this land-use type) needed to produce that good, unrelated to any country of origin. By applying the EQF $[gha/wha]$, the different bioproductive values of different land-use types are considered. This result is given in global hectare $[gha]$.

The yields of traded (derived) commodities are adjusted with extraction factors, as outlined in Appendix II since derived products cannot be associated by the yield of the source crop (or animal). The detailed calculations within every land-use type are further outlined in this section.

3.4.1 Cropland

The EF of cropland is impacted by three sources, which are domestic crop production, crop trade, and crops embodied within livestock trade. The EFs of cropland commodities are calculated as in Equation 3.3 and accumulated as in Equation 3.4.

$$EF_1 = \sum EF_{IP} \pm \sum EF_{TC} \pm \sum EF_{TL} \tag{3.4}$$

EF_{IP} are the EFs of inland production commodities, EF_{TC} the EFs of traded crop commodities, EF_{TL} the EFs of traded livestock commodities. The EFs of livestock commodities are shared with the land-use type grazing land, as animals are feed from crops as well as grass. Therefore, the EF is allocated for cropland and grazing land according to typical feed mixes (details see Appendix II).

All data for calculating the EF of cropland is taken from the FAO database. Production quantity and yields are taken from the crop statistics dataset (http://www.fao.org/faostat/en/#data/QC), trade quantities are taken from the food and agricultural trade dataset (http://www.fao.org/faostat/en/#data/TP). The FAO database does not include crops privately grown and consumed. Wild berries and tree nuts are not allocated for forest land but cropland. However, the FAO database does not include data on the production of tree nuts. As for berries, privately picked berries are not included. Detailed metadata can be found on the web pages of the datasets.

3.4.2 Grazing land

The EF of grazing land is calculated from inland grass production and grass embodied within traded livestock products (Equation 3.5).

$$EF_2 = A_C \cdot YF_2 \cdot EQF_2 \pm \sum EF_{TL} \tag{3.5}$$

Where A_C is the cultivated area and YF_2 and EQF_2 are Yield and Equivalence Factors of grazing land. EF_{TL} are the EFs of traded livestock commodities. Data is adapted from the LUKE dataset on the utilized agricultural area (statdb.luke.fi) within Finland. The calculations include fodder grassland, pasture, and hay.

Domestic grazing land is not calculated by production quantity but by utilized agricultural area, since there are no records on the production quantity of pasture. The EFs of traded livestock commodities are shared with cropland, as explained in Section 3.4.1 and Appendix II. The data on traded livestock can be found in the food and agricultural trade dataset (fao.org/faostat/en/#data/TP). The yield of embodied grass is assumed to be equal to the yield of Finnish green fodder. Reindeer farming which is typical to Finland is not included.

3.4.3 Forest land

For this assessment, the total forest drain is utilised since it includes left and unused deadwood connected to wood felling. The numbers on total forest drain are published by LUKE at statdb.luke.fi. Equation 3.6 shows the calculation for the EF of forest land.

$$EF_3 = \frac{FD_I}{NAI} \cdot EQF_3 \pm \sum EF_T \tag{3.6}$$

FD_I is the total inland forest drain and NAI the Net Annual Increment ($1.82 \frac{m^3}{ha \cdot yr}$), which serves as yield for both produced and traded wood. It is adapted from the GFN spreadsheet mentioned in Section 2.7. EQF_3 is the Equivalence Factor of forest land and EF_T are the EFs of traded forest commodities.

Data on total forest drain can be found in the LUKE database (statdb.luke.fi). The wood drain caused by traded wood is calculated with data from LUKE (statdb.luke.fi) and according to Equation 3.3. The yields for forest commodities are calculated as outlined in Appendix II.

3.4.4 Fishing grounds

Data on marine and inland catches, as well as traded fish products, is provided by the FAO FishStatJ software (fao.org/fishery/statistics/software/fishstatj). EFs of commodities are calculated as in Equation 3.3 and accumulated as in Equation 3.7.

$$EF_4 = \sum EF_P \pm \sum EF_T \tag{3.7}$$

Where EF_P are the EFs of domestically fish catches and EF_T the EFs of traded fish commodities. Yields and extraction factors are used, which were calculated by the GFN spreadsheet (see Section 2.7) based on the concept of Primary Production Requirement established by Pauly and Christensen (1995). Extraction factors are adopted from the GFN spreadsheet, as they do not vary by country.

3.4.5 Carbon uptake land

The data on CO_2 emissions are calculated by SYKE and do not include emissions from industrial processes, icebreakers, foreign shipping, and activities within the land use, land-use change and forestry (LULUCF) category. Emissions from air traffic are calculated separately as a national per capita average, as it is not included in the SYKE data. This additional data is from the Statistics Finland database (stat.fi) and refers not as most other data to 2019 but 2018. The agriculture emissions calculated by SYKE are excluded, as it would lead to double counting. The EF of carbon uptake land is calculated as in Equation 3.8.

$$EF_5 = (E_P - E_A + E_{AT}) \cdot FI \cdot EQF_5 + \sum_j P_j \cdot CI_j \cdot FI \cdot EQF_5 \tag{3.8}$$

The parameters are as follows:

E_P : Primary CO_2 emissions as provided by SYKE

E_A : CO_2 emissions of agriculture as provided by SYKE

E_{AT}: CO_2 emissions of air traffic as provided by Statistics Finland

CI_j: Carbon Intensity of commodity $\left[\frac{t(CO_2)}{kg}\right]$

FI: Footprint Intensity of CO_2 $\left[\frac{wha}{t(CO_2)}\right]$

P_j: Weight of traded commodity j

EQF_5: Equivalence Factor of carbon uptake land

CO_2 emissions from biofuels as firewood and biogas are not included in this calculation as it is assumed that the emitted CO_2 was previously absorbed by the burned biomass. Similarly, animal CO_2 emissions are not included, as it would lead to double counting. It is assumed that the CO_2, which animals (or humans) emit from their bodies gets absorbed by the crops they consume. For the same reason, CO_2 absorption from croplands is not considered.

The CO_2 emissions embodied within traded goods are calculated separately. Again, only goods with at least 100 tonnes of either import or export are included. The Carbon Intensity of commodities CI_j is calculated as in Appendix II. The calculation for the footprint intensity of CO_2 can be found within the constants on carbon uptake in Appendix VI.

3.4.6 Built-up land

As the demand for built-up land is the actual physical paved land, EF and BC are the same for this land-use type. It is calculated in Equation 3.9.

$$EF_6 = \mathrm{BC}_6 = A_6 \cdot YF_1 \cdot EQF_1 \quad (3.9)$$

A_6 is the actual built-up and YF_1 and EQF_1 are the Yield and Equivalence Factor of cropland since built-up land is assumed to be built on cropland (explained in Section 2.4.6).

With GIS data, the paved land within the municipality of Vaasa is determined. Therefore, the EF includes direct built-up land within the study area and not indirect built-up land, which is embodied in traded products. The built-up land is determined as part of the Biocapacity calculation (see Section 3.5).

3.5 Biocapacity (BC)

The biocapacity, as it is defined in Section 2.1, describes the available resource of bioproductive land. Therefore, the total biocapacity of the study area is calculated as the sum of the BC of the four land-use types (since carbon uptake land equals forest land and built-up land is excluded).

The Biocapacity is calculated from open-access GIS remote sensing data from the 2018 CORINE Land Cover (CLC) inventory of the Copernicus programme (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018). The CLC categorises the earth's surface by 44 land cover types, which are assigned to the six land-use types as outlined in Appendix IV. Detailed information on the classification of the land cover types can be found in the "Updated CLC illustrated nomenclature guidelines" (Kosztra *et al.*, 2017).

The data is processed in Google Earth Engine with the help of Kendall Rutledge and Antti Kinnunen. The spatial boundaries are determined by a shapefile provided from the city of Vaasa (paikkatieto-vaasa.hub.arcgis.com/datasets). The developed code can be found in Appendix V and copied into Google Earth Engine to view the results. The spatial allocation of the land-use types can also be found in Figure 9 (Section 4.2). The recorded bioproductive areas are converted into the assessment unit of global hectare by Equation 3.10.

$$BC = \sum_{n=j}^{5} A_j \cdot YF_j \cdot EQF_j \tag{3.10}$$

Adapted from Lin *et al.* (2019).

Where A_j is the recorded area and YF_j and EQF_j are the Yield and Equivalence Factors of the land-use type. The index j represents the five land-use types cropland, grazing land, forest land, fishing grounds, and built-up land. It is important to mention that the biocapacity classification, according to the Global Footprint Network (2021a) FAQ, does not include deserts, glaciers, open oceans, or unproductive land.

3.6 Ecological Balance (EB)

The term EF in general refers to the mentioned value of EF, as well as the overall EF assessment. The EF assessment consists of calculating the Ecological Footprint value itself, and the Biocapacity (BC) separately. From there, an "Ecological Balance" can be done by subtracting the EF from the BC, concluding to whether it exists an "Ecological Reserve" or an "Ecological Deficit" (Geng *et al.*, 2014). The Ecological Balance is outlined in Equation 3.11.

$$EB = BC - EF \tag{3.11}$$

EB resembles the Ecological Balance, *BC* the Biocapacity, and *EF* the Ecological Footprint. The EF and BC are measured in Global Hectares [*gha*]. In the case of an Ecological Reserve, the BC is larger than the EF and the value of the UEF is positive. The assessed urban settlement is sustainable. Conversely, an Ecological Deficit exists if the EF exceeds the BC. The UEF is negative, and the assessed area relies on "imported" bioproductive land or is unsustainable.

4 Results

This thesis assessed the Urban Ecological Footprint of the municipality of Vaasa for the year 2019. The results are presented in the following sections. Section 4.1 gives the total Urban Ecological Footprint and Section 4.2 the total Biocapacity. Section 4.3 shows the EF and BC per capita, as well as the Ecological Balance, which demonstrates the Ecological Deficit of the study area. Section 4.4 compares the results to the EF of Finland. Important to mention is that, while built-up land is included in some tables and figures, it is not included in the calculations for total EF or BC.

4.1 Total Urban Ecological Footprint

The total Urban Ecological Footprint of the municipality of Vaasa has been calculated at $287{,}153\ gha$, with cropland, grazing land, forest land, fishing grounds, and carbon uptake land each contributing to the EF. The numbers, as well as the share of each land-use type, is visualised in Figure 7.

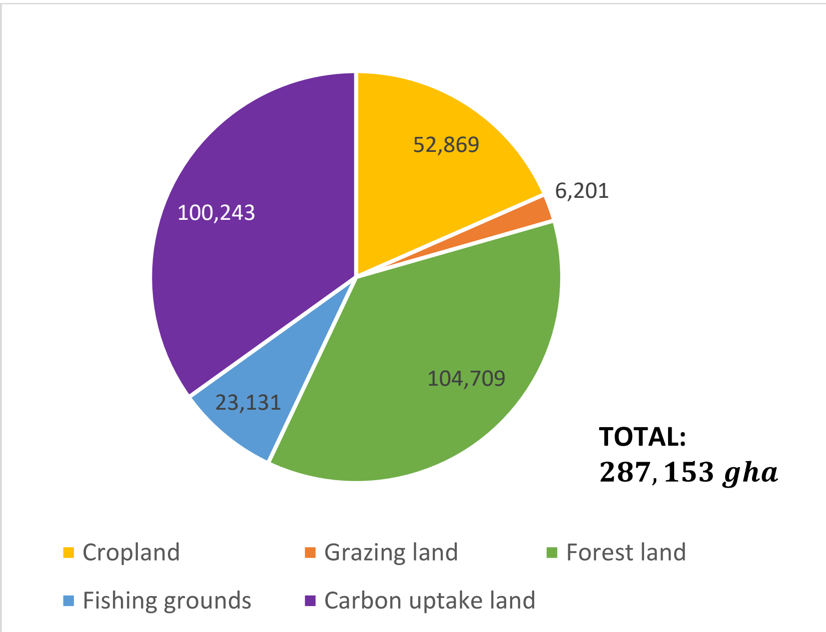

Figure 7. Contribution of each land-use category to the Urban Ecological Footprint of the municipality of Vaasa. Values are given in global hectare [gha].

The EF of forest land and carbon uptake land have the highest contribution between the land-use types. The high share of 36% ($104{,}709\ gha$) for forest land seems appropriate, as Finland is known for its forest industry. The similarly high EF of carbon uptake land with 35%

(100,243 gha) indicates a high impact of energy consumption and fossil fuels. The EF of cropland contributes for 18% (52,869 gha), fishing grounds for 8% (23,131 gha), and grazing land for 2% (6,201 gha).

There are also big variations of whether the EF consists mainly of domestic production or trade, as it indicates if the study area occupies biocapacity inside or outside its spatial boundaries. Figure 8 illustrates the EF of every land-use type divided into domestic production and trade.

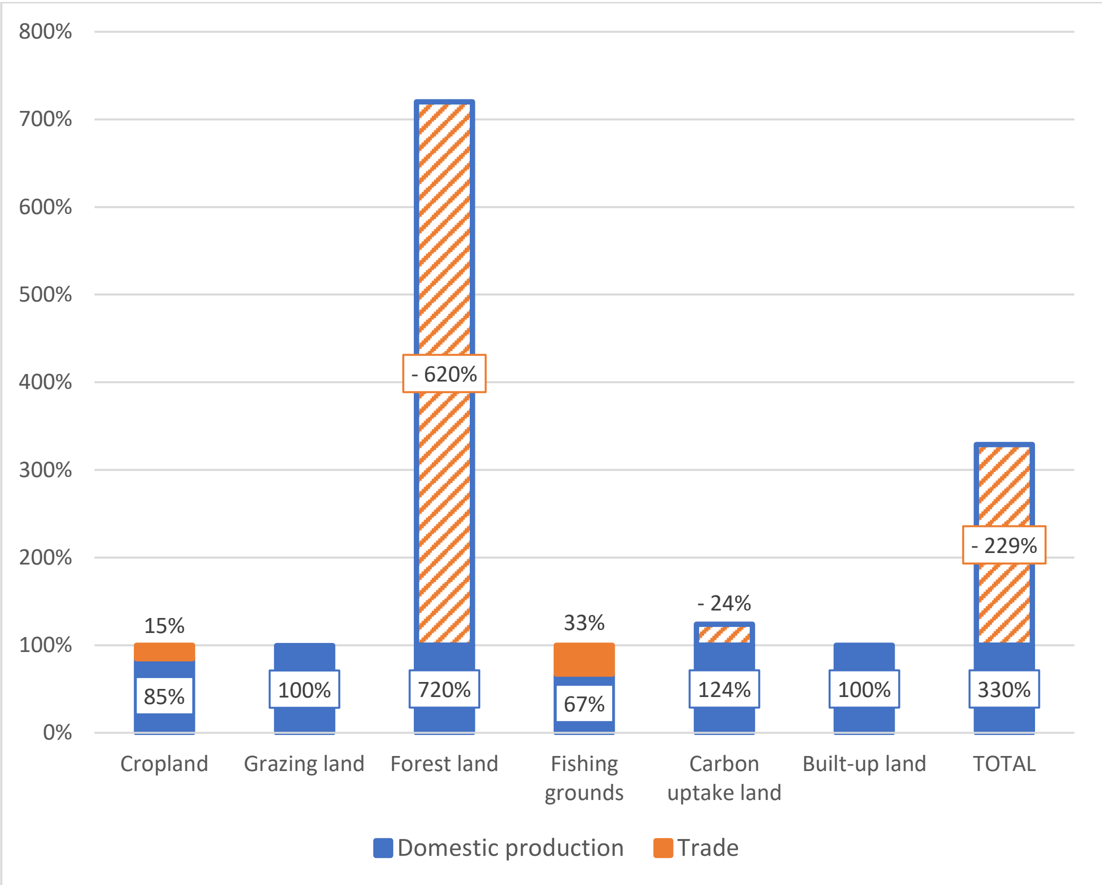

Figure 8. Contribution of domestic production and trade to the total UEF by land-use type.

All numbers in this chart are in relation to the total EF of the land-use type, which is defined as 100%. Consequently, one can see that the EF of inland production (944,529 gha) is much higher than the actual resulting EF since Vaasa is in total exporting EF ($-657{,}375$ gha). Forest land as its largest impact has not only a very high production (753,952 gha) but also similarly high exports ($-649{,}243$ gha). Also, worth mention is, that by trade the EF of forest land and carbon uptake land decreases, whereas the EF of cropland and fishing grounds increase. The EF of grazing land stays the same as imports and exports are almost equal. This means that according to this calculation Vaasa is occupying cropland and fishing grounds outside its borders while supplying forest land and carbon uptake land for communities outside its borders. The EF of built-up land is not affected, as it is only defined for inland EF.

4.2 Total Biocapacity

The total Biocapacity is calculated at 85,785 gha and is therefore 201,368 gha smaller than the Ecological Footprint. Figure 9 illustrated where the assessed land is located.

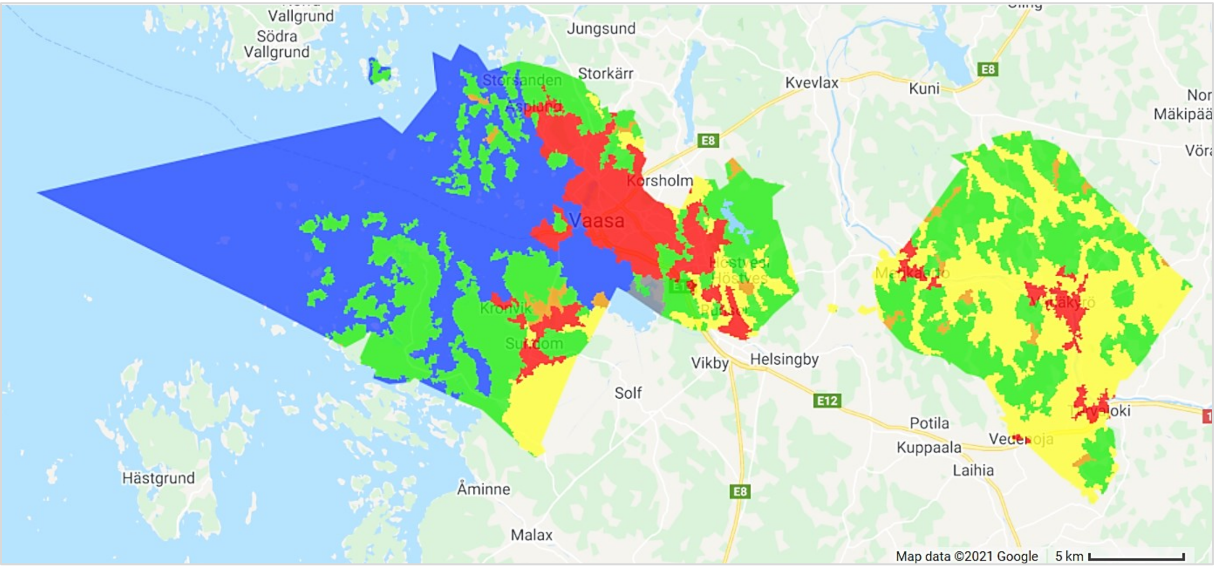

Figure 9. Spatial allocation of the land-use types within the municipality computed in Google Earth Engine. The map shows cropland (yellow), grazing land (orange), forest land (green), fishing grounds (blue), built-up land (red).

The municipality of Vaasa consists of two separate areas of which one is centred around Vaasa itself and the other around Vähäkyrö. Most lands around these two urban areas are forest land or cropland. To the east Vaasa has access to the Bothnian Sea. The total area and contribution of each land-use type to the BC is illustrated in Figure 10. It consists of cropland, grazing land, forest land, and fishing grounds, as carbon uptake land and built-up land are not part of the BC (explained in Section 2.4).

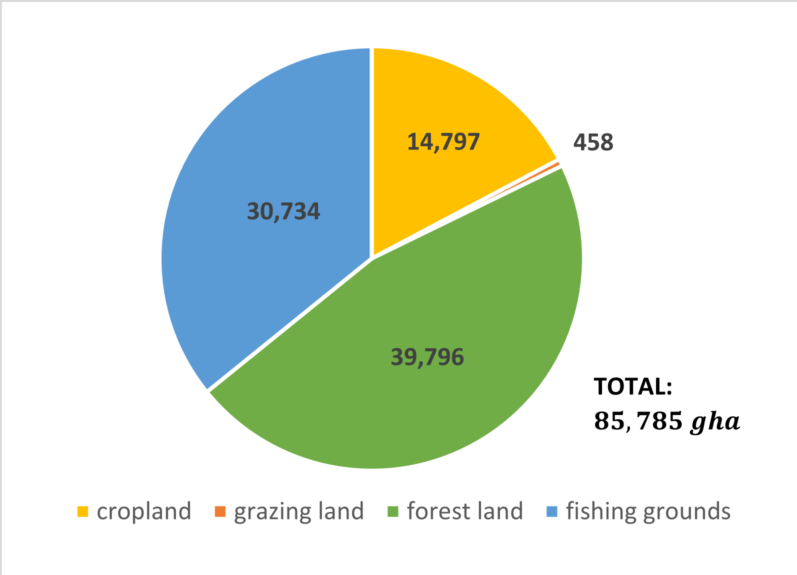

Figure 10. Contribution of each land-use type to the Biocapacity of the municipality of Vaasa. The values are given in global hectare [gha].

The BC consists of large parts of cropland, forest land, and fishing grounds. Cropland contributes for 17% (14,797 gha) of the total BC, forest land for 46% (39,796 gha), and fishing grounds for 36% (30,694 gha). However, fishing grounds are almost entirely marine fishing grounds, as inland fishing grounds are only 40 gha. Grazing land makes up only for less than 1% with 458 gha. The BC/EF of built-up land would be 7,514 gha. The built-up land reduces the original BC of the area by 8%.

4.3 Per Capita EF and BC and Ecological Balance

The per capita UEF is interesting, as it can be compared between different study areas. Also, it enables the Ecological Balance for deciding whether is exists an Ecological Reserve or Ecological Deficit. Expressing the UEF per capita makes it easy to assess the level of sustainability. Table 5 lists the per capita EF and BC of every land-use type and the total municipality. The fourth column shows the Ecological Balance.

Table 5. Ecological Balance with Urban Ecological Footprint and Biocapacity per capita in [gha/cap].

Demand Type	per capita EF	per capita BC	Ecological Balance
[-]	[gha/cap.]	[gha/cap.]	[gha/cap.]
Cropland	0.77	0.22	-0.55
Grazing land	0.09	0.01	-0.08
Forest land	1.55	0.59	-0.96
Fishing grounds	0.34	0.46	0.11
Carbon uptake land	1.49	-------	-1.49
Built-up land	0.11	0.11	0.00
TOTAL	**4.24**	**1.27**	**-2.97**

The total per capita UEF is calculated at $4.24\ gha/cap$ and the total per capita BC at $1.27\ gha/cap$. This leads to an Ecological Deficit of $-2.97\ gha/cap$, as the EF exceeds the BC by times three. Four of the six land-use types have an Ecological Deficit, while it is important to keep in mind that carbon uptake land is additional stress on forest land. The EB of built-up land arrives at zero, due to its definition (see Section 3.4.6). The only land-use type with an Ecological Reserve is fishing grounds since Vaasa has access to the Bothnian Sea. To better visualise these dimensions, Figure 11 symbolises the UEF of Vaasa with a circle drawn around Vaasa.

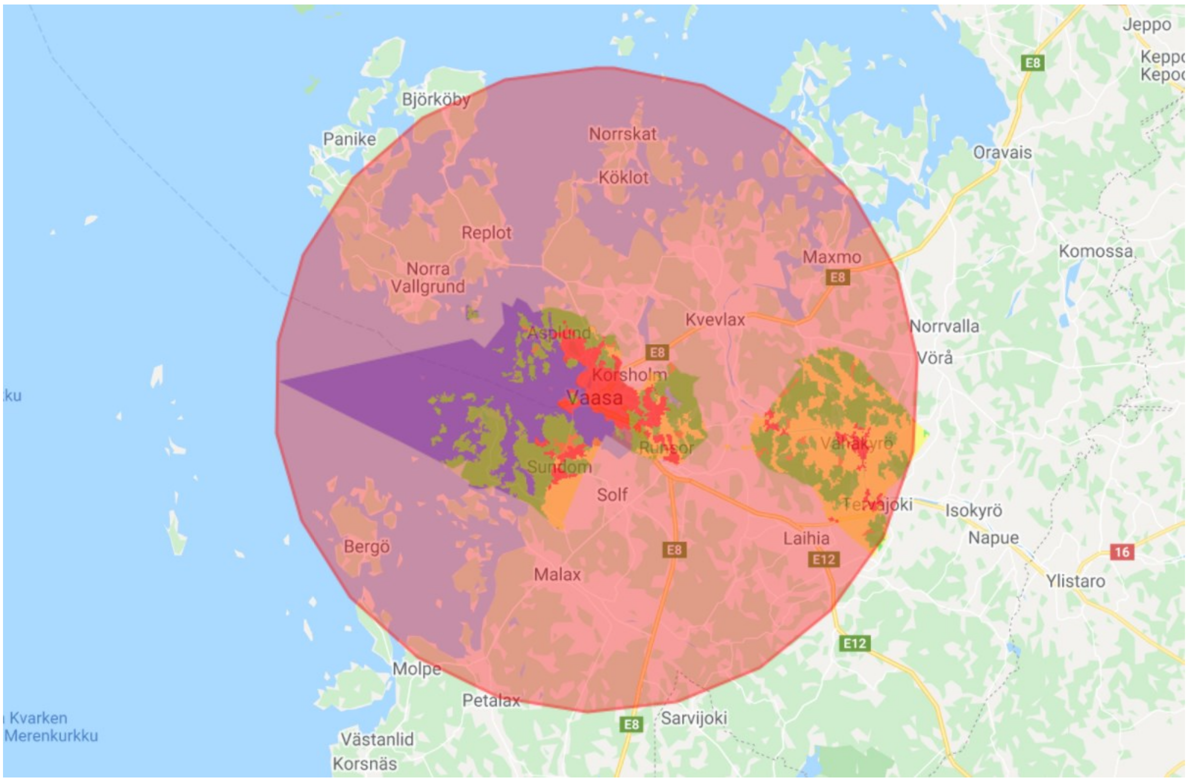

Figure 11. Urban Ecological Footprint of Vaasa symbolised by a circle around Vaasa.

The area of this circle equals the UEF of Vaasa, covering much more area than the actual city boundaries. It is important to mention that the symbolised UEF is measured in global hectares, while the boundaries of Vaasa are measured in hectares. Therefore, the boundaries resemble the real area of Vaasa (51,800 ha) not the Biocapacity of Vaasa (85,785 gha).

4.4 Comparing the results to the EF of Finland

As Vaasa is a city within western Finland, there is interest in comparing the results of this assessment to the EF of Finland and the Global average, as calculated by the GFN. Table 6 lists the per capita EF, BC and Ecological Balance of Vaasa, Finland, and the Global average.

Table 6. Per capita Ecological Footprint, Biocapacity, and Ecological Balance of Vaasa, Finland, and the Global average in [gha/cap].

study area	EF	BC	EB
[-]	[gha/cap]	[gha/cap]	[gha/cap]
Vaasa (2019)	4.24	1.27	-2.97
Finland (2017)	5.9	12.5	6.6
Global average (2017)	2.8	1.6	-1.2

Data on Finland and Global average adapted from GFN (data.footprintnetwork.org).

Here the Ecological Footprints of an average Vaasa citizen and an average Finish citizen are compared. The EF of Finland was calculated by the GFN at 5.9 gha/cap, which is 1.66 gha/cap higher than the EF is calculated for Vaasa in this assessment. This seems appropriate, as Vaasa is a highly urbanised municipality (as stated in Section 2.3), which is often associated with higher energy efficiency and a lower EF (Florida, 2012). Still, the EF of Vaasa is, like the EF of Finland, relatively high compared to the world average.

The per capita BC available within the municipality of Vaasa is almost ten times lower than the per capita BC within Finland. This is due to the definition of the study area. Finland has vast rural areas which bring up for the high per capita BC of 12.5 gha, whereas Vaasa is an urban municipality. These are big differences and can only be compared conditionally. Therefore, the Ecological Balance of Vaasa concludes with an Ecological Deficit while Finland has an ecological reserve.

Comparing the EF between an average person in Vaasa and Finland by land-use type, one can see major similarities and differences. To get a better idea of the results, Figure 12 compares the EF of Vaasa, Finland, and the Global average by land-use type.

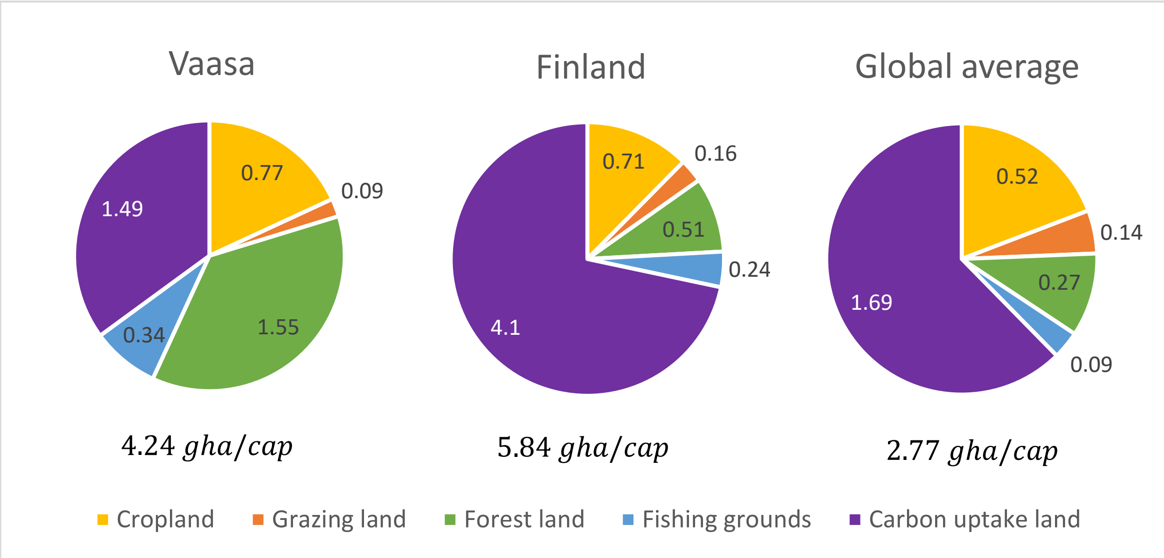

Figure 12. Ecological Footprint of Vaasa, Finland, and the global Average – Data on Finland and Global average adapted from GFN (data.footprintnetwork.org).

The EF of Vaasa seems to be quite different to the EF of Finland and the Global average. The major differences are in forest land and Carbon uptake land, while cropland, grazing land, and fishing grounds seem to be more similar. Vaasa's cropland EF varies from Finland only by $0.06\ gha/cap$. Grazing land varies by $0.07\ gha/cap$ and fishing grounds by $0.1\ gha/cap$. For the Global average, carbon uptake land makes up for more than a half of the EF, for Finland even more than two-third. However, for Vaasa, it is only about one-third. For forest land, it is the other way around, with Vaasa having a three times higher forest EF than Finland.

5 Discussion

Section 5.1 discusses the assessment procedure, Section 5.2 evaluates inconsistencies within the assessment's results. Section 5.3 discusses the assessment's limitations and Section 5.4 suggests improvements for further UEF assessments.

The project aimed to find a value representing the UEF of the city of Vaasa. The assessment calculated the UEF of Vaasa for $4.24\ gha/cap$ and identified forest land and carbon uptake land as the highest demands. With a BC of $1.27\ gha/cap$, the Ecological Balance arrives at $-2.97\ gha/cap$. This means that according to the results the municipality of Vaasa holds a lower per capita EF than Finland. However, due to its much lower BC, the Ecological Balance of Vaasa is negative, concluding with an Ecological Deficit. To validate these results, it is important to assess whether the results can represent the actual EF of the study area.

5.1 Evaluation of assessment procedure

With respect to the initial aim and objectives, the initial goal of calculation the EF of Vaasa was achieved. The first objective was to determine the assessment methodology. After extensive research, the works published by the GFN have been identified as the main source. The study area was defined, calculation factors identified, and the methodology developed and outlined.

Objective two turned out to be the most extensive step in the assessment. FAOstat, LUKE, SYKE, Statistics Finland, and the Corine Land Cover (CLC) 2018 database were identified as the main data sources. The correct datasets had to be chosen and the data had to be properly processed and organised.

To fulfil objective three, the data accumulated in step two had to be combined with the methodology outlined in step one. Even though it required much work, no major difficulties had been come up. However, due to its extensive calculation work, it had to be taken care not to conduct mistakes.

5.2 Evaluation of inconsistencies within the assessment's results

With respect to the results of the assessment few inconsistencies have been found. For one, the project aims to identify the EF of the municipality of Vaasa, however, the EFs of cropland, grazing land, forest land, and fishing grounds are calculated as a national average. Even though reasons for doing so were outlined in this thesis it compromises the results of the assessment.

Secondly, the EF of cropland, grazing land, fishing grounds, and forest land were not expected to differ much from the EF of Finland, as they were calculated on a national level. While cropland, grazing land, and fishing grounds follow these expectations, Vaasa's forest EF is three times higher than compared to Finland. This can only be explained by differences in the calculation methodology or the data sources. The forest EF is calculated very differently in both assessments, which leaves many possible reasons for the different results. The GFN is using a much more complex and, in the opinion of this author, a more inaccurate way of calculating the EF of domestic production (Lin *et al.*, 2019). For the EF of traded products, a similar methodology but different conversion factors were used. Combined with high sensitivity, this could lead to inaccuracies. As illustrated in Figure 9, the calculated EF of trade and domestic production are more than six times higher than the resulting EF. This means already small deviations can to big changes in the results.

Another noticeable difference between Vaasa and Finland is within carbon uptake land. The low share of carbon uptake land indicates that Vaasa may be more energy-efficient or uses a higher share of renewable energies. Regarding the methodology of carbon uptake land, the EF embodied in traded products is calculated by the same methodology for both Vaasa and Finland. For the direct CO_2 emissions, pre-processed data from SYKE is used. This leaves very few insecurities in the methodology of this assessment and supports its accuracy.

5.3 Limitations of the assessment

By its own definition, the assessment gives only a limited depiction of the real Urban Ecological Footprint. As outlined in Section 2.6, the assessment generally understates the EF and overstates the BC. The additional assumptions made throughout the methodology add to this issue. Therefore, the EF depicts not the exact sustainability of the study area.

The effect on earth biodiversity is considered neither, moreover, utilising all of earth's area, biodiversity will be reduced. Wackernagel *et al.* (1999) suggest subtracting 12% of earth biocapacity to preserve biodiversity. However, Mogelgaard (2006) argues that area-based protection is not enough to preserve biodiversity, as it does not consider the uniqueness of specific habitats. Also, she states that, in 2006, still biodiversity is declining, even though more than 11% of the earth's surface are protected. Apart from these issues, Geng *et al.* (2014) for example follow Wackernagel's suggestion, whereas the GFN working guidebook by (Lin *et al.*, 2019) only mentions the concept of biodiversity buffer but does not seems to apply it in its calculations.

Another limitation is the definition of the study area. With 217 inhabitants per km², the municipality of Vaasa has a much higher population density than Finland (18 per km²), which largely reduces the biocapacity per capita. Both values rely more on the administrative division than then on the bioproductivity of the area. Geng *et al.* (2014) discussed this issue and mentioned that different countries have different administration systems. This means the result of the study is largely impacted by the administrative allocation.

Similarly, as the BC relies on the chosen study area, the EF relies on the chosen datasets. As different datasets with deviating data and definitions are available, the subjective choices of the assessment implementer compromise the objectivity of the assessment.

5.4 Suggestions for assessment improvements

UEF assessments rely on the availability of data. Even though open access data is available, data is still incomplete. Detailed documentation of every produced, traded, and especially consumed commodity would improve the overall accuracy of UEF assessments. Data on local consumption or improved models for local allocation would enable calculations more specific to the study area. Also due to the variety of available datasets and allocation factors, extensive research should determine the best sources. As suggested by Świąder *et al.* (2020), future assessments should test different datasets and assess their influence on the results.

Assessing the biocapacity per capita on a sub-national level brings fewer insights than expected. However, to compare the BC between different areas, an assessment per area could be more useful and should be tested in future assessments.

With the methodology outlined in this thesis future assessments could calculate and compare the EF of different Finnish cities. For this kind of assessment, Geng *et al.* (2014) provide good supporting literature as they use different indicators to compare the development level of different cities.

6 Conclusion

Sustainability is an issue gaining more and more spotlight in recent years as it benefits the environment, economy and population (C40 Cities Leadership Group, 2015). To enable improvement and to determine the best possible solutions, accurate assessment methods like the UEF are necessary. UEF assessments give urban planners, governments, and decision-makers a useful estimate on the appropriation of bioproductive land. However, UEF assessments have limitations and a careful interpretation in combination with other assessment methods is recommended.

This research aimed to find a calculation procedure to accurately express the Ecological Footprint of an urban area. This goal was achieved, as an Urban Ecological Footprint of $4.24\ gha/cap$ was identified. The results suggest that Vaasa is more sustainable than overall Finland ($5.84\ gha/cap$). However, due to Vaasa's low Biocapacity of $1.27\ gha/cap$ it results in an Ecological Deficit of $-2.97\ gha/cap$. A repeatable methodology was laid out and improvements were suggested, as the calculations show high sensitivity. For this reason, more accurate data is necessary and further assessments should improve the consistency in data collection and identify local data sources.

The project purpose of enabling future UEF assessments in Finland is accomplished, moreover calculating and comparing the EFs of other Finnish cities is suggested. The findings of this project can be utilised by Kendall Rutledge for his research on Urban Metabolism, as similar challenges can be expected. The suggestions outlined in this thesis should be utilised.

This thesis is one of the first UEF assessments within Finland and laid out a detailed calculation methodology for UEF assessments, closely tied to the standards established by the extensive research conducted by the Global Footprint Network. Therefore, this thesis gives extensive and useful insights for future UEF assessments.

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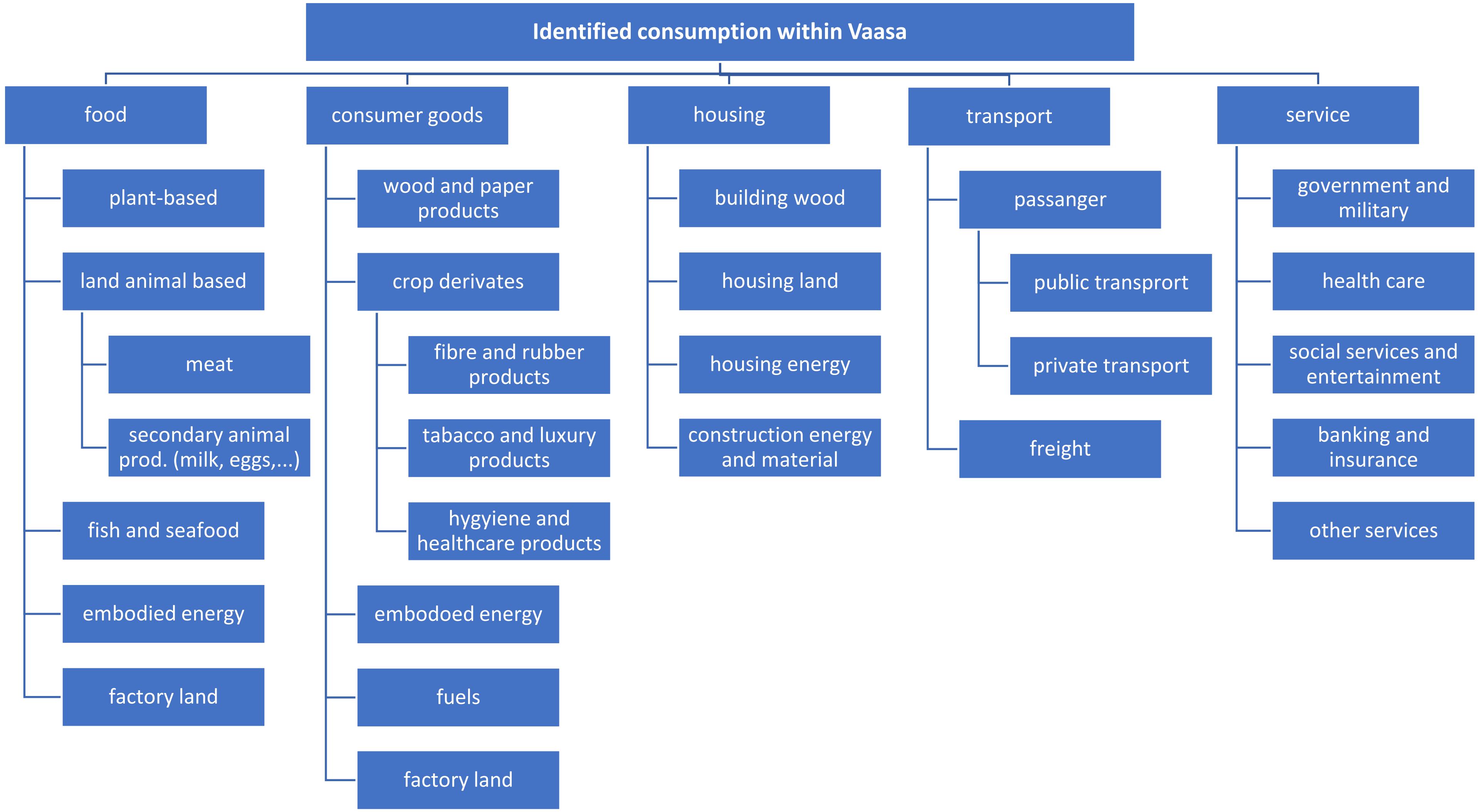
Appendix I: Consumption identified by input-output analysis



Appendix II: Further Equations

Calculation of yields for derived crop commodities with extraction factors

The yields of products deriving from crops are calculated by multiplying the yield of the source product with an extraction factor (Equation II.1).

$$\mathrm{Y_{DC}} = \mathrm{Y_S} \cdot EXTR \tag{II.1}$$

Where:

Y_{DC} : Yield of derived crop product $[\frac{t}{ha \cdot yr}]$

Y_S : Yield of source product (world average) $[\frac{t}{ha \cdot yr}]$

$EXTR$: Extraction factor $[-]$

Adapted from Lin *et al.* (2019).

Calculation of yields for derived livestock commodities with extraction factors

The yields of livestock commodities are calculated as in Equation II.2.

$$\mathrm{Y_{DL}} = \frac{EXTR}{FCR} \cdot \mathrm{Y_{SP}} \tag{II.2}$$

Where:

Y_{DL} : Yield of derived livestock product $\left[\frac{t}{ha \cdot yr}\right]$

Y_{SP} : Yield of source product (world average) $\left[\frac{t}{ha \cdot yr}\right]$

$EXTR$: Extraction factor (mass ratio product to live animal) $[-]$

FCR : Feed conversion ratio (mass ratio of feed to live animal) $[-]$

Adapted from Lin *et al.* (2019)

Source plants (crop or grass) are defined by typical feed mixes adopted from a spreadsheet published by the GFN (footprintnetwork.org/licenses) Feed conversion ratios are taken from Alexander *et al.* (2016).

Calculation of yields for traded forest commodities

The consumption of forest products is expressed by the total forest drain. Therefore, the yields of traded forest commodities, are calculated as in Equation II.3.

$$Y_{DF} = \frac{CF \cdot RWEF}{NAI} \tag{II.3}$$

Where:

Y_{DF} : Yield of derived forest product $\left[\frac{t}{ha \cdot yr}\right]$

CF: Conversion Factor of forest commodity $\left[\frac{m^3}{t}\right]$

$RWEF$: Roundwood Extraction Factor $[-]$

NAI: world average Net Annual Increment $[1.82 \frac{m^3}{ha \cdot yr}]$

Conversion factors are published by the FAO, ITTO and United Nations (2020). The Roundwood Extraction Factor is calculated as the ratio of total forest drain to roundwood removals in 2019 (Equation II.4).

$$RWEF = \frac{FD_I}{RWE} = \frac{87{,}988{,}000\ m^3}{72{,}927{,}000\ m^3} = 1.21 \tag{II.4}$$

Calculation of commodity Carbon Intensity (CI)

for imports

$$CI_j = EAF_j \cdot CI_W \tag{II.5}$$

for exports

$$CI_j = EAF_j \cdot CI_N \tag{II.6}$$

Where:

CI_j : Carbon Intensity of commodity [ ]

EAF: Energy Allocation Factor of commodity $\left[\frac{MJ}{kg}\right]$

CI_W: World average Carbon Intensity of primary energy $\left[\frac{t(CO_2)}{MJ}\right]$

CI_N: National Carbon Intensity of primary energy $\left[\frac{t(CO_2)}{MJ}\right]$

Energy allocation factors EAF_j and the world primary energy carbon intensity CI_W are adopted from the GFN (spreadsheet at footprintnetwork.org/licenses). The national primary energy carbon intensity is calculated by national total primary energy supply and national total CO_2 emissions, both registered by the IEA (iea.org/countries/finland). The calculation for the footprint intensity of CO_2 (FI) can be found in the spreadsheet at footprintnetwork.org/licenses.

Calculation of Extraction Factors

The extraction factors themselves are the ratio of the product's Technical Conversion Factor (TCF) and the Footprint Allocation Factor (FAF) (Equation II.7).

$$EXTR = \frac{TCF}{FAF} \tag{II.7}$$

Where:

TCF: Technical Conversion Factor $[-]$

FAF: Footprint Allocation Factor $[-]$

Adapted from (Borucke *et al.*, 2013)

The FAF is the ratio of the derived product's TCF-weighted price to the source product's price. The source product's price is the sum of TCF-weighted prices of all products deriving from the source product (Equation II.8).

$$FAF = \frac{TCF_D \cdot V_D}{V_s} = \frac{TCF_D \cdot V_D}{\sum TCF_i \cdot V_i} \quad \text{(II.8)}$$

Where:

V_D : Price of derived product $\left[\frac{t}{ha \cdot yr}\right]$

V_S : Price of source product $\left[\frac{t}{ha \cdot yr}\right]$

V_i : Price of all products derived from source product $\left[\frac{t}{ha \cdot yr}\right]$

As explained by Borucke *et al.* (2013), the TCF shows the mass ratio of how much of the source product is needed for the production of the derivate. As most times multiple products are derived from a source product simultaneously, the FAF allocates the footprint according to the TFC-weighted price. It is assumed that a product with a higher TCF-weighted price has a higher production priority and therefore takes a higher share of the EF.

The TCFs are taken from the FAO (2000) and the product prices from FAOstat (fao.org/faostat/en/#data/TP).

Appendix III: Detailed spreadsheet metadata

The Excel workbook contains 1.30 MB of data and 23 worksheets. All the calculations and most of the assessment's work is undertaken within these spreadsheets. Table III.1 lists the several worksheets with their number of cells, size, and number of calculated commodities/items. The full Excel file can be found at yhnovia-my.sharepoint.com.

Table III.1. List of worksheets within workbook including number of cells, size and number of calculated commodities/items.

Name of worksheet	Number of cells	size [KB]	Number of commodities/items
discussion	75	758	-
footprint	92	757	-
biocapacity	85	754	-
ef_crop	60	749	-
ef_grazing	50	749	-
ef_forest	50	749	-
ef_fishing	62	749	-
ef_carbon	47	749	-
crop_prod	281	756	32
crop_trade	2304	817	175
crop_trade_livestock	141	753	7
grazing_prod	27	751	3
grazing_trade_livestock	64	752	1
forest_prod	19	751	1
forest_trade	261	757	22
fishing_efp	187	752	19
fishing_efi_efe	548	755	59
direct_CO2	92	752	13
CO2_in_trade	2736	794	208
livestock_feed_demand	637	769	42
const_ag_extr	7902	890	393
const_carbon	44	751	-
EQF & YF (GFN 2017)	43	750	-

For better demonstration, the names in the table are coloured by land-use type. Register tabs starting with "ef_" summarise the calculations within each land-use type. These main calculation sheets themselves start with the name of the land-use type. The register tabs "footprint" and "biocapacity" summarise the EF results, or BC results, respectively. The "discussion" tab contains figures generated for the discussion section. The last four worksheets contain constants and extraction factors.

Also, the main tables within the several worksheets are listed and organised. The tables are ordered in sections by land-use type with each first showing the summary table and below the contributing main calculations. The (in some cases simplified) calculation tables outline the utilised formulas, whereas empty cells have direct input. The worksheet names are mentioned in brackets. The last two sections (Section 6 and Section 7) are not calculation EFs but the feed demand and Extraction Factors.

1 Cropland ("ef_crop")

	EF_P	EF_I	EF_E		EF
	[gha/cap.]	[gha/cap.]	[gha/cap.]		[gha/cap.]
crop_prod	0.663				0.663
crop_trade		+ 0.271	- 0.136		0.135
crop_trade_livestock		+ 0.130	- 0.145		-0.014
TOTAL	**0.663**	**+ 0.401**	**- 0.281**		**0.784**

1.1 Cropland – domestic production ("crop_prod")

Commodity	FAO Code	Inland Production	Yield	EQF	EF_P
[-]	[-]	[t]	[t/wha]	[gha/wha]	[gha]
					= Inland Production / Yield * EQF

1.2 Cropland – traded crop commodities ("crop_trade")

Commodity	FAO Code	Imports	Exports	Yield	EQF	EF_I	EF_E
[-]	[-]	[t]	[t]	[t/wha]	[gha/wha]	[gha]	[gha]
				= parent crop yield * Extraction Factor		= Imports / Yield * EQF	= Exports / Yield * EQF

1.3 Cropland – traded livestock commodities ("crop_trade_livestock")

Commodity	Crops for Cattle, Milk, Sheep/Goat, Pig, Poultry, Horse, and Egg	Yield	EQF	EF
[-]	[t]	[t/wha]	[gha/wha]	[gha]
IMPORTS	= Feed demand (import) * Feed mix			= Imports / Yield * EQF
EXPORTS	= Feed demand (export) * Feed mix			= Exports / Yield * EQF

2 Grazing land ("ef_grazing")

	EF_P	EF_I	EF_E		EF
	[gha/cap.]	[gha/cap.]	[gha/cap.]		[gha/cap.]
grazing_prod	0.092				0.092
grazing_trade_livestock		+ 0.017	- 0.017		0.000
TOTAL	**0.092**	**+ 0.017**	**- 0.017**		**0.092**

2.1 Grazing land – domestic commodities ("grazing_prod")

Commodity	Cultivated area	YF	EQF	EF_P
[-]	[ha]	[wha/ha]	[gha/wha]	[gha]
				= Cultivated area * YF * EQF

2.2 Grazing land – traded livestock commodities ("grazing_trade_livestock")

Commodity	Grass for Cattle, Milk, Sheep/Goat, Pig, Poultry, Horse, and Egg	Yield	EQF	EF
[-]	[t]	[t/wha]	[gha/wha]	[gha]
IMPORTS	= Feed demand (import) * Feed mix			= Imports / Yield * EQF
EXPORTS	= Feed demand (export) * Feed mix			= Exports / Yield * EQF

3 Forest land ("ef_forest")

	EF_P	EF_I	EF_E		EF
	[gha/cap.]	[gha/cap.]	[gha/cap.]		[gha]
forest_prod	11.178				11.178
forest_trade		+ 2.190	- 11.816		-9.626
TOTAL	**11.178**	**+ 2.190**	**- 11.816**		**1.552**

3.1 Forest land – domestic commodities ("forest_prod")

Commodity	Total wood drain	NAI	EQF	EF_P
[-]	[m³]	[m³/ha]	[gha/wha]	[gha]
				= Total wood drain / NAI * EQF

3.1 Forest land – traded commodities ("forest_trade")

Commodity	Exports	Imports	Yield	EQF	EF export	EF import
[-]	[m³] or [t]	[m³] or [t]	[wha/m³] or [wha/t]	[gha/wha]	[gha]	[gha]
			= NAI / REF / CF		= Imports / Yield * EQF	= Exports / Yield * EQF

* REF = Roundwood Extraction Factor (1.21 m³/m³)

* CF = Conversion Factor

4 Fishing Grounds ("ef_fishing")

	EF_P	EF_I	EF_E		EF
	[gha/cap.]	[gha/cap.]	[gha/cap.]		[gha/cap.]
Marine Capture	0.137				0.137
Inland Capture	0.093				0.093
Trade		+ 0.173	- 0.059		0.113
TOTAL	**0.230**	**+ 0.173**	**- 0.059**		**0.343**

4.1 Fishing grounds – domestic commodities ("fishing_efp")

Commodity	Marine Prod.	Inland Prod.	Yield	EQF	Marine EF_P	Inland EF_P
[-]	[t]	[t]	[t/wha]	[gha/wha]	[gha]	[gha]
					=Marine Production / Yield * EQF	= Inland Production / Yield * EQF

4.2 Fishing grounds – traded commodities ("fishing_efi_efe")

Commodity	Import (2018)	Exports (2018)	Extr	Parent fish yield	EQF	EF_I	EF_E
[-]	[t]	[t]	[-]	[t/wha]	[gha/wha]	[gha]	[gha]
						= Imports / parent yield / Extr.* EQF	= Imports / parent yield / Extr.* EQF

5 Carbon Uptake land ("ef_carbon")

	EF_P	EF_I	EF_E		EF
	[gha/cap.]	[gha/cap.]	[gha/cap.]		[gha/cap.]
direct_CO2	1.841				1.841
CO2_in_trade		0.667	- 1.022		- 0.355
TOTAL	1.841	0.667	- 1.022		1.486

5.1 Carbon uptake land – domestic commodities ("direct_CO2")

Emission category (2019)	Emissions	Footprint Intensity of Carbon	EQF	EF_P
[-]	[t CO2e]	[t (CO2)/wha]	[gha/wha]	[gha]
				= Emissions * Footprint Intensity * EQF

5.2 Carbon uptake land – trade commodities ("CO2_in_trade")

Commodity	SITC-1 Code	Imports/ Exports	EAF	CO_2 Emissions	EF
[-]	[-]	[kg]	[MJ/kg]	[t CO_2]	[gha]
IMPORTS				= Imports * EAF * World average carbon intensity	=Imports CO_2 * EQF * Footprint Intensity
EXPORTS				= Exports * EFA * National carbon intensity	= Exports CO_2 * EQF * Footprint Intensity

6 Livestock feed demand ("livestock_feed_demand")

to determine crops/grass within traded livestock

Commodity	FAO Code	Imports/ Exports	Parent Product	Parent Code	Extr	Livestock weight
[-]	[-]	[t]	[-]	[-]	[tp/td]	[t]
IMPORTS						= Imports* EXTR
EXPORTS						=Imports* EXTR

Commodities are accumulated by parent product

livestock by parent product	Livestock weight	Feed Conversion Ratio	feed demand
[-]	[t]	[t/t]	[t]
IMPORTS			= Livestock import weight * FCR
EXPORTS			= Livestock export weight * FCR

7 Agricultural extraction factors ("const_ag_extr")

Commodity	Parent Key	TCF	Quantity	Value	Price	Price × TCF	EXTR
[-]	[-]	[td/tp]	[td]	[$1000]	[$1000/td]	[$1000/tp]	[tp/td]
					= Value /Quantity		= TCF / SUM(Price x TCF)$_{parent\_key}$ *EXTR$_{parent}$

- all the calculations are explained in more detail in the Methodology (Section 3) -

Appendix IV: Corine Land Cover legend

Level 1	Level 2	Level 3	Grid_Code	RGB
1. ARTIFICIAL SURFACES	1.1Urban fabric	1.1.1 Continuous urban fabric	1	230-000-077
		1.1.2 Discontinuous urban fabric	2	255-000-000
	1.2 Industrial, commercial and transport units	1.2.1 Industrial or commercial units	3	204-077-242
		1.2.2 Road and rail networks and associated land	4	204-000-000
		1.2.3 Port areas	5	230-204-204
		1.2.4 Airports	6	230-204-230
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites	7	166-000-204
		1.3.2 Dump sites	8	166-077-000
		1.3.3 Construction sites	9	255-077-255
	1.4 Artificial, non-agricultural vegetated areas	1.4.1 Green urban areas	10	255-166-255
		1.4.2 Sport and leisure facilities	11	255-230-255
2. AGRICULTURAL AREAS	2.1 Arable land	2.1.1 Non-irrigated arable land	12	255-255-168
		2.1.2 Permanently irrigated land	13	255-255-000
		2.1.3 Rice fields	14	230-230-000
	2.2 Permanent crops	2.2.1 Vineyards	15	230-128-000
		2.2.2 Fruit trees and berry plantations	16	242-166-077
		2.2.3 Olive groves	17	230-166-000
	2.3 Pastures	2.3.1 Pastures	18	230-230-077
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops	19	255-230-166
		2.4.2 Complex cultivation patterns	20	255-230-077
		2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation	21	230-204-077
		2.4.4 Agro-forestry areas	22	242-204-166
3. FOREST AND SEMI NATURAL AREAS	3.1Forests	3.1.1 Broad-leaved forest	23	128-255-000
		3.1.2 Coniferous forest	24	000-166-000
		3.1.3 Mixed forest	25	077-255-000
	3.2 Scrub and/or herbaceous vegetation associations	3.2.1 Natural grasslands	26	204-242-077
		3.2.2 Moors and heathland	27	166-255-128
		3.2.3 Sclerophyllous vegetation	28	166-230-077
		3.2.4 Transitional woodland-shrub	29	166-242-000
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, sands	30	230-230-230
		3.3.2 Bare rocks	31	204-204-204
		3.3.3 Sparsely vegetated areas	32	204-255-204
		3.3.4 Burnt areas	33	000-000-000
		3.3.5 Glaciers and perpetual snow	34	166-230-204
4. WETLANDS	4.1 Inland wetlands	4.1.1 Inland marshes	35	166-166-255
		4.1.2 Peat bogs	36	077-077-255
	4.2 Maritime wetlands	4.2.1 Salt marshes	37	204-204-255
		4.2.2 Salines	38	230-230-255
		4.2.3 Intertidal flats	39	166-166-230
5. WATER BODIES	5.1 Inland waters	5.1.1 Water courses	40	000-204-242
		5.1.2 Water bodies	41	128-242-230
	5.2 Marine waters	5.2.1 Coastal lagoons	42	000-255-166
		5.2.2 Estuaries	43	166-255-230
		5.2.3 Sea and ocean	44	230-242-255
No Data	No Data		48	
	No Data		49	
	No Data		50	230-242-255

Cropland

Grazing land

Forest land

Fishing grounds

Built-up land

Unproductive land

Adopted from http://clc.gios.gov.pl/doc/clc/CLC_Legend_EN.pdf. Only the categories of Cropland, Grazing land, Forest land, Fishing grounds, and Built-up land are used in the assessment. The category of Unproductive land is irrelevant.

Appendix V: Google Earth Engine Code

Below the generated code is listed, of which the expression "DIRECTORY_SHAPEFILE" has to be changed to the imported shapefile's directory.

```
var imageCollection = ee.ImageCollection("COPERNICUS/CORINE/V20/100m"),
    table = ee.FeatureCollection("DIRECTORY_SHAPEFILE");
```

```
//change this to your area, if you add geographical bounds

var target_area = ee.FeatureCollection('DIRECTORY_SHAPEFILE')
.filterMetadata('namn', 'equals', 'Vasa');

var imageCollection = ee.ImageCollection("COPERNICUS/CORINE/V20/100m")

var codes = [
  [111, 112, 121, 122, 123, 124, 133, 141, 142],     // Red codes
  [211, 212, 213, 241, 242, 243],                    // Yellow codes
  [311, 312, 313],                                   // Green codes
  [231, 321, 322, 323, 324],                         // Orange codes
  [511, 512],                                        // Light Blue codes
  [521, 522, 523]];                                  // Dark Blue codes
var palette = [
  "7B797E",
  "FF1010",
  "FFFF33",
  "2CEE18",
  "EE8811",
  "8BC4F9",
  "3349FF"]
var classes = ["Unproductive Land (Grey)","Built-up Land (Red)", "Cropland
(Yellow)", "Forest Land (Green)", "Grazing Land (Purple)", "Inland Fishihg
Grounds (Light Blue)", "Marine Fishing Grounds (Dark Blue)"];

var replacementArray = [];
var combinedArray = [];

for(var i=0; i < 6; i++)
{
```

```
  for(var j=0; j < codes[i].length;j++)
  {
    replacementArray.push((i+2));
    combinedArray.push(codes[i][j]);
  }
}

var corine2018 =
imageCollection.filterMetadata("system:index","equals","2018").map(function
(image){return image.clip(target_area)}) ;

Map.centerObject(target_area, 12);
var viscorine = corine2018.first().visualize();

var corineImage = corine2018.first()
var corineremap = corineImage.remap(combinedArray, replacementArray, 1);

Map.addLayer(viscorine);
Map.addLayer(corineremap, {palette: palette});

var chart =
    ui.Chart.image.histogram({image: corineremap, region: target_area ,
scale: 100})
        .setOptions({
          title: "Remapped Class counts",
          hAxis: {
            title: "Classes",
            titleTextStyle: {italic: false, bold: true},
            viewWindow: {min: 0.5, max: 7.5},
            ticks: [1, 2, 3, 4, 5, 6, 7],
            colors:
["7B797E","FF5733","FFFF33","4CFF33","B533FF","8BC4F9","3349FF"]
          },
          vAxis:
              {title: "Count", titleTextStyle: {italic: false, bold: true}}

        });
print(chart)

for(var i=0; i< 7; i++)
{
  var mask = corineremap.expression(
```

```
    "orig == class?1:0", {
    "orig" : corineremap.select("remapped"),
    "class": (i+1)});

  var number = corineremap.updateMask(mask);
  var tempImage = number.add(ee.Image.pixelArea());
  var area = tempImage.reduceRegion({
    reducer: ee.Reducer.sum(),
    geometry: target_area,
    scale: 100,
    maxPixels: 1e13
  })

  var Sqkm = ee.Number(area.get("remapped")).divide(1e6);
  print("Class (number/color)", (i+1),classes[i], "Estimated area in km^2",
Sqkm);

}
```

Appendix VI: Constants on Carbon uptake

Name	Unit	Value	source
Carbon Uptake EQF	[-]	1.28	GFN
C to CO_2 Ratio	$\left[\frac{t\,(C)}{t\,(CO_2)}\right]$	0.27	
Carbon Sequestration Factor	$\left[\frac{t\,(C)}{wha \cdot yr}\right]$	0.73	GFN
Carbon Uptake per [ha]	$\left[\frac{t\,(CO_2)}{wha \cdot yr}\right]$	2.68	
Ocean Uptake Fraction	[-]	0.297	GFN
Footprint Intensity of Carbon	$\left[\frac{wha \cdot yr}{t\,(CO_2)}\right]$	0.263	GFN
World average Carbon Intensity Primary Energy	$\left[\frac{t\,(CO_2)}{MJ}\right]$	5.68E-05	GFN
National Total Primary Energy Supply	$[PJ]$	1423.093	IEA
National Total CO2 emissions	$\left[\frac{Mt\,(CO_2)}{yr}\right]$	43.8	IEA
National Carbon Intensity	$\left[\frac{t\,(CO_2)}{MJ}\right]$	3.08E-05	

IEA is from 2018 and can be found at iea.org/countries/finland.

GFN data can be found in the spreadsheet published at footprintnetwork.org/licenses.