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EVALUATION OF ENVIRONMENTAL FOOTPRINT INDICATORS FOR THE CALCULATION OF PERSONAL OVERSHOOT DAY

Supervisor:
Prof. Isabella Bianco
Co-Supervisor:
Mr. Danilo Piton

Candidate:
Syed Saad Ahsan
s290117

ABSTRACT

Human activities are exerting immense pressure on the planet, and we are fast approaching a critical transition at a planetary scale. To detect early warning signs and predict the ecological consequences of these pressures on ecosystems, tools must be developed. It is crucial to manage human interaction with the biosphere carefully to guarantee sustainable prosperity in the future. Systemic accounting tools are necessary to monitor the cumulative effects of the various pressures that humans are imposing on the planet.

One such metric is the Ecological Footprint analysis, which quantifies the extent of human resource consumption (Ecological Footprint) and the biosphere's capacity to provide (biocapacity) ecosystem goods and services. This measurement is expressed in terms of the bio-productive land and sea areas (ecological assets) required to sustainably deliver these goods and services.

The research aims to quantify the impacts on bio-productive land and sea due to the main activities and habits of the average inhabitant. The results of the research will be used to support the development of the Human srl web app. This web app will use the information obtained from a series of questions posed to the user to calculate the user's ecological footprint in Gha, overshoot day and no. of earths required and provide hints and suggestions to reduce it.

Research initiates by establishing a comprehensive understanding of the concept of ecological footprint. A detailed examination of the ecological factors and resources that contribute to the footprint, such as carbon emissions, land use, biodiversity loss, and the utilization of various materials is executed which is a critical part of this research. To facilitate user engagement and comprehension, a user-friendly calculator has been developed, Users are prompted to input data pertaining to their daily activities and consumption patterns and according to their daily life activities and habits they will get their ecological footprint and personal overshoot day. Additionally, users can also analyze their CLUM (consumption land-use matrix) for more detailed analysis of impacts of their daily life activities.

This research also encompasses an exhaustive and rigorous approach to the calculation methodology associated with the Ecological Footprint and its constituent indicators. Within this methodological framework, critical elements such as conversion factors, yield factors, and equivalence factors are considered critically. These factors are essential for the precise quantification of the ecological footprint and its diverse indicators, which encompass carbon, cropland, grazing land, forest, built-up land, and fisheries.

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My gratitude extends to my family and friends, especially my parents who have been a constant source of support, understanding, and encouragement. Your belief in my abilities and your unwavering encouragement have been my pillars of strength.

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1 INTRODUCTION

1.1 A CHALLENGE

Economic prosperity and societal well-being are closely linked to the planet's capacity to provide natural resources and ecosystem services. However, it is also true that our planet has finite resources, and therefore, it is essential to operate within the limits set by nature to ensure sustainable development.(Costanza et al., 1997; COSTANZA & DALY, 1992; Daly, 1990; Daly & Farley, 2011; DeFries et al., 2004; Max-Neef, 1995)

The concept of planetary boundaries (Rockström et al., 2009b), identifies nine critical Earth system processes that are essential for maintaining the planet's stability and sustainability. These processes include climate change, biodiversity loss, land-use change, freshwater use, ocean acidification, ozone depletion, atmospheric aerosol loading, chemical pollution, and phosphorus and nitrogen cycles.

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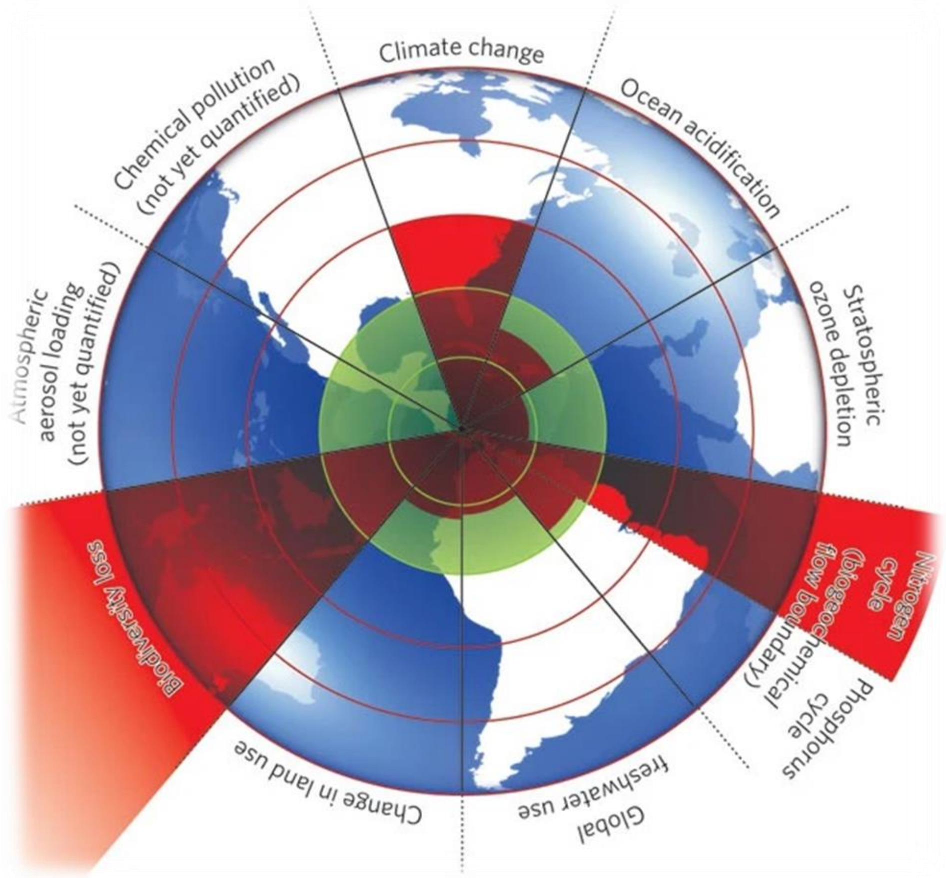

Figure 1: Nine planetary boundaries for safe operating space for humanity (Rockström et al., 2009a)

In figure 1, the green shading inside represents the suggested safe boundaries for nine planetary systems. The current position of each variable is indicated by the red wedges.

However, the boundaries have already been surpassed in three systems: the rate of biodiversity loss, climate change, and human intervention in the nitrogen cycle.

The boundary formerly known as "chemical pollution" has been renamed to "novel entities" by (Steffen et al., 2015). This new term encompasses not only new substances and modified forms of existing substances but also engineered materials, organisms, and naturally occurring elements like heavy metals that are mobilized by human activities but were previously unknown to the Earth's system. (Steffen et al., 2015) highlight plastic pollution as a particular aspect of high concern. In January 2022 assessment was done by (Persson et al., 2022) to quantify the planetary boundary of novel entities and (Persson et al., 2022) concluded that human activities have surpassed a planetary limit regarding environmental pollutants and other "novel entities," which includes plastics. A recent evaluation of the planetary boundary for freshwater, conducted in April 2022 by (Wang-Erlandsson et al., 2022) reveals that it has been surpassed. This determination results from the inclusion of "green water" for the first time in the boundary assessment, which refers to the water accessible to plants.

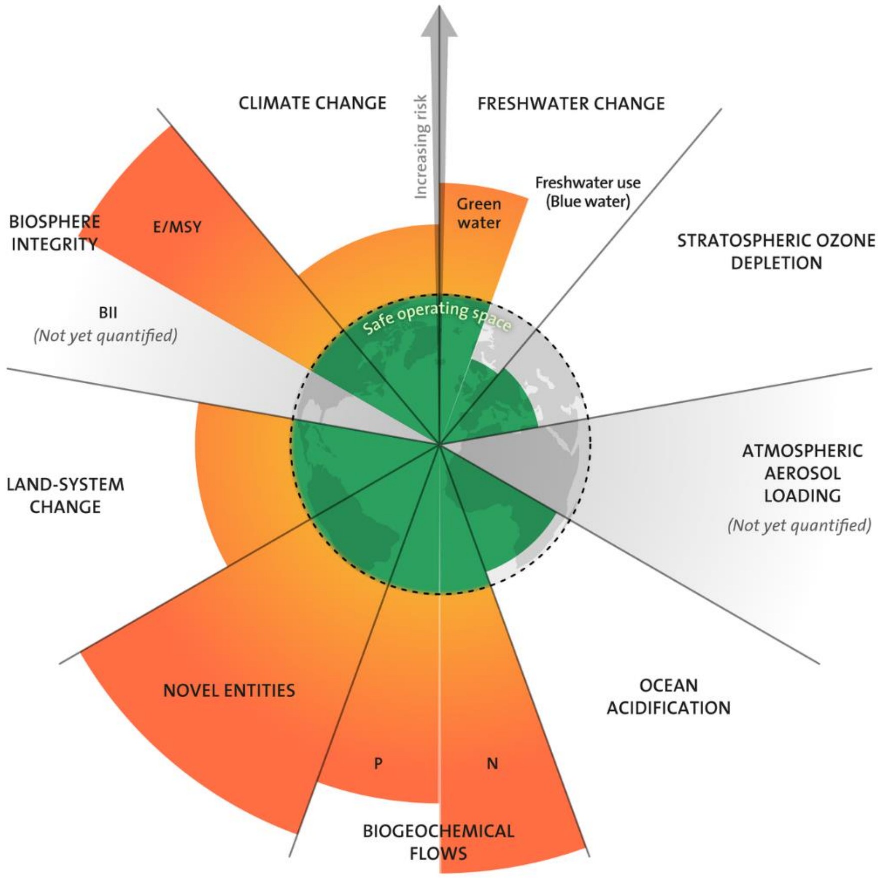

Figure 2: Planetary boundaries as of 2022

In figure 2, it can be clearly seen that according to the latest researches the new boundaries which have surpassed are novel entities, human intervention in the phosphorus cycle, green water and land use change. (Persson et al., 2022; Steffen et al., 2015; Wang-Erlandsson et al., 2022) with biodiversity loss, climate change, and human intervention in the nitrogen cycle.

Policy decisions that do not consider these planetary boundaries can have severe consequences, including ecological collapse, social unrest, and economic instability. Therefore, policymakers must consider the long-term consequences of their decisions and strive to operate within the planet's limits to ensure a sustainable future for all.

The depletion of natural resources, such as deforestation, declining fish populations, and the buildup of carbon dioxide in the atmosphere, suggests that human consumption is surpassing the biosphere's ability to renew and absorb these resources. As the global economy continues to grow and people strive for higher living standards, the demands placed on natural systems are increasing rapidly. Many studies indicate that we are crossing several of the Earth's ecological thresholds, putting the biosphere's future ability to sustain humanity at risk.(Goudie, 1981; Haberl, 2006; Moore et al., 2012; Nelson et al., 2006; Rockström et al., 2009a; Scheffer et al., 2001; Schlesinger, 2009; C. D. Thomas et al., 2004)

With a population of around eight billion and continuing to grow (*Current World Population*, n.d.), the human species is gradually exhausting the most valuable gift from nature (natural resources), that it relies on, to sustain life. It is an undeniable fact that environmental issues such as global warming, widespread deforestation, desertification, and the loss of biodiversity have disrupted the ecological balance of our planet (Goel et al., 2011). Forests in tropical zones are being deforested at a rate that exceeds their natural regeneration capacity, with 130,000 km^2 of forest lost annually over the past 15 years, Similarly, marine fish stocks are being depleted faster than they can be replenished, with 15% of ocean stocks depleted during the same period (United Nations Environment Programme UNEP, 2019). Over the past four decades, there has been a global increase in per capita consumption of food and services (Turner, 2008), as well as a 45% rise in the extraction of natural resources such as biomass, fossil fuels, and minerals over the past 25 years, (Behrens et al., 2007; Giljum et al., 2009; Krausmann et al., 2009). Water scarcity is becoming a critical issue in arid and semi-arid regions like Central and West Asia and North Africa, where many countries are already approaching or falling below the threshold of 1000 m^3 per capita per year (Falkenmark, 1989). Additionally, the accumulation of greenhouse gas (GHG) emissions in the atmosphere (IPCC, 2007) is causing climate change, and having potential negative impacts on ecosystems' health (Butchart et al., 2010; Haberl, 2006; United Nations Environment Programme UNEP, 2019). The global extraction of natural resources is predicted to increase by more than 50% by 2030 compared to current levels (Lutz Christian & Giljum Stefan, 2009), and the demand for ecological assets measured in terms of Ecological Footprint could be equivalent to two Earths' worth of resources soon after 2030 (Moore et al., 2012). Additionally, up to two-thirds of the world's population may face water scarcity in the next few decades (J. A. Thomas & Rösch, 2000; Vorosmarty et al., 2000), and with around one billion people will be experiencing absolute water scarcity (less than 500 m^3 per capita per year) by 2025 (Rosegrant Mark W. et al., 2002). Overall, these trends highlight the urgent need for sustainable resource management and conservation efforts to address the escalating environmental challenges we face.

Human activities are exerting immense pressure on the planet (Barnosky et al., 2012), and we are fast approaching a critical transition at a planetary scale. To detect early warning signs and predict the ecological consequences of these pressures on ecosystems, tools must be developed. It is crucial to manage human interaction with the biosphere carefully to guarantee sustainable prosperity in the future. Systemic accounting tools are necessary to monitor the cumulative effects of the various pressures that humans are imposing on the planet. (Galli et al., 2012)

1.2 CONSUMPTION-BASED ACCOUNTING (CBA)

Consumption-based accounting (CBA) has been the subject of debate among researchers for many years and is gaining increasing relevance due to its potential benefits (Bastianoni et al., 2004; Lenzen et al., 2007; Peters, 2008). CBA takes into account all the resources and ecological assets that are used to produce goods and services that are consumed by people, rather than just looking at the impacts within a specific geographic region (Wiedmann, 2009). By including all driving forces for demands on ecological assets associated with consumption activities, CBA can provide complementary information for the formulation of international environmental policy frameworks, this can assist to facilitate international cooperation among developing and developed countries, by improving competitiveness concerns (Wiedmann, 2009). CBA can also be used to monitor decoupling (the separation of economic growth from environmental degradation) and design strategies for sustainable consumption and production policies at the national, regional, and local levels.

Ecological, carbon and water footprints are the indicators which are based on the CBA approach, by combining the views of the producer and the consumer EF, CF and WF are able to combine conventional studies of human demand analysis. These indicators offer a quantifiable and logical starting point for discussions and the development of solutions relating to the effectiveness of production process, the limits of resources consumption, the global distribution of natural resources, and how to address the sustainability of the use of ecological assets (Galli et al., 2012) (Senbel et al., 2003). Although all three indicators have distinct research objectives and convey varying narratives, they were deemed effective in portraying the environmental outcomes of human actions and serving as supplements for evaluating human impact on the Earth from a consumer perspective.

The EF measures the ecological resources demand that results from resource consumption on the planet, acknowledging the presence of limitations of these resources on humanity expansion and attempting to quantify them. The WF focuses on the volume of freshwater required for human consumption. Its primary objective is to highlight the concealed connections between water usage and consumption activities. And the main objective CF is to quantify the overall quantity of GHG emissions that arise from human activities related to resource consumption, which can help us to gain a clearer understanding of populations' role in contributing to these emissions.

All these three indicators have broad geographical coverage and can be used at various scales ranging from individual products to entire nations or even the planet. However, the EF was found to be the most comprehensive with temporal coverage from 1961 to 2012, whereas the CF and WF have data available for the year 2001 and the average period of 1996-2005, respectively (Galli et al., 2012).

1.2.1 CARBON FOOTPRINT

The Carbon Footprint measures the complete amount of greenhouse gas (GHG) emissions that arise directly or indirectly from a particular activity or the entire life cycle of a product (Wiedmann & Minx, 2008). This covers activities of individuals, organizations, companies, populations, government, industrial sectors, and processes. The calculation takes into account all direct and indirect emissions, including on-site and off-site, internal and external, upstream and downstream emissions. The scope of the measurement, including which GHGs to consider and how to avoid double-counting, may vary (Wiedmann & Minx, 2008). The Carbon Footprint at the national level represents the consumption of goods and services by households, governments, and final demands such as capita investment, as well as the GHG emissions related to trade. It adds up all emissions related to a country's consumption, including imports but not exports, thereby complementing the production-based approach used in national greenhouse gas inventories like those under the Kyoto Protocol (Galli et al., 2012). This consumption-based perspective could encourage international cooperation between developed and developing countries and raise consumer awareness of the GHG emissions from their lifestyles and indirect emissions in governments and businesses.

1.2.1.1 UNIT OF MEASURE

The total quantity of greenhouse gases is measured in weight units such as kilograms (kg) or tons (t), and it is not converted to any area unit such as hectares (ha), square meters (m^2), or square kilometers (km^2). If only CO_2 is considered, the unit of measurement is kg CO_2, while if other GHGs are included, the unit of measurement is kg CO_2-e, which expresses the mass of CO_2 equivalents. These equivalents are calculated by multiplying the actual mass of a gas with the global warming potential factor for that particular gas, which makes it possible to compare and add up the global warming effects of different GHGs. The six GHGs identifies in the Kyoto protocol are CO_2, CH_4, N_2O, HFC, PFC, and SF_6 (UNFCCC, 1997).

1.2.2 WATER FOOTPRINT

In 2002, Arjen Hoekstra at UNESCO-IHE Institute for Water Education created the concept of water footprint (WF) as a measure of the total amount of water consumed directly or indirectly by human activities. It considers the water used in the production of goods and services, as well as the water consumed or polluted during their entire life cycle (Water Footprint Network, n.d.). This concept was introduced as a response to the need for an indicator that took into account the appropriation of natural resources, particularly water, for human use (Hoekstra A Y. (Ed.), 2003). This concept is closely connected to the virtual water concept (Allan, 1998), which also considers the amount of water needed to produce goods and services consumed by humans (Hoekstra A Y., 2009).

The calculation of WF involves tracking three important components related to water:

1. Blue water, which indicates the consumption of surface and groundwater. (Hoekstra A Y. et al., 2011)

2. Green water, which refers to the consumption of rainwater stored in soil as soil moisture and, (Hoekstra A Y. et al., 2011)
3. Grey water, which indicates pollution and is defined as the amount of freshwater needed to neutralize the pollutants based on the current water quality standards. (Hoekstra A Y. et al., 2011)

The WF can be determined for a specific product, a well-defined group of consumers or producers, such as an individual, a city, a province, a state, or a nation (Hoekstra A Y. & Chapagain A K., 2008). It is defined as the total amount of freshwater utilized in the production of goods and services consumed by a community or individual or produced by a business or organization (Hoekstra A Y. & Chapagain A K., 2008).

The WF concept is intended to demonstrate the unseen connections between human consumption and water usage, and global trade and water resources management. Its introduction to water management science serves to emphasize the significance of human consumption and global dimensions in effective water governance (Hoekstra A Y., 2009).

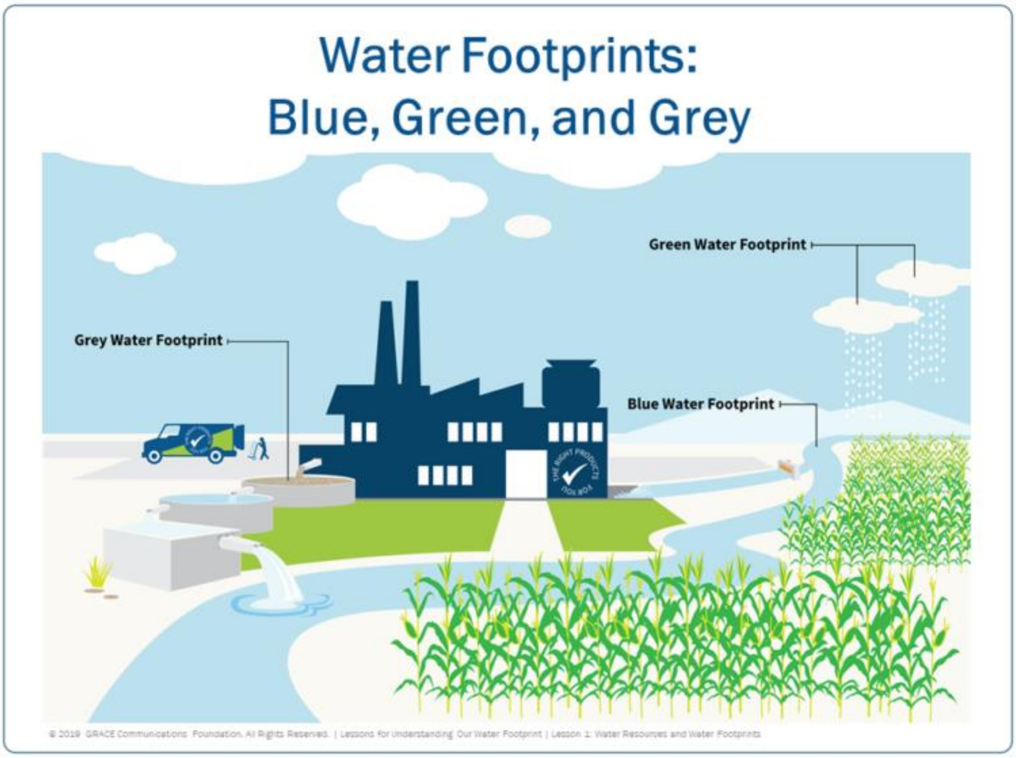

Figure 3: Three different water components of water footprints (Grace Communication Foundation (GCE), 2019)

1.2.2.1 UNITE OF MEASURE

The WF methodology measures the amount of water used by considering the volume of water consumed (such as through evaporation or in the production of goods) and the amount of pollution generated, all measured per unit of time. The level of detail included can vary, with measurements expressed in terms of daily, monthly, or yearly use, depending on the desired level of precision (Hoekstra A Y., 2009).

The scope of this thesis is to explore the methodologies which can be applied to determine an individual's personal overshoot day; therefore, the fundamental focus of this thesis will be on ecological footprint (EF) and biocapacity.

2 ECOLOGICAL FOOTPRINT AND BIOCAPACITY

2.1 HISTORY

The concept of ecological footprint was first introduced in the early 1990s by Canadian ecologist William Rees and Swiss economist Mathis Wackernagel (Rees, 1992) (Wackernagel Mathis, 1991b, 1991a, 1994). The idea behind the ecological footprint is to measure the impact of human activities on the environment in terms of land use and resource consumption. The ecological footprint considers the amount of land needed to produce the resources that people consume and the land required to absorb the waste that they generate.

In 1996, Wackernagel and Rees published the book "Our Ecological Footprint: Reducing Human Impact on the Earth," (Wackernagel & William Rees, 1996) which brought the concept of ecological footprint to a wider audience. The book presented a methodology for calculating the ecological footprint of individuals, communities, and nations.

Since then, the ecological footprint has become a widely recognized measure of environmental sustainability, it is used by governments, businesses, and individuals to understand the impact of their activities on the environment and to develop strategies for reducing their ecological footprint.

The Global Footprint Network, founded by Wackernagel in 2003 (Global Footprint Network, 2003), is an international organization that promotes the use of the ecological footprint as a tool for sustainability. GFN was established with the aim of revolutionizing how the world manages its natural resources and tackles climate change. Over the years, it has collaborated with more than 200 nations to provide scientific insights that have led to influential policy and investment decisions. Its objective is to build a future in which everyone can flourish while staying within the earth's limits. This involves promoting the scientific rigor and practical application of the ecological footprint and elevating it to the same level of importance as the Gross Domestic Product (GDP). For the ecological footprint to gain recognition as a reliable sustainability metric, it must rely on a scientifically sound methodology that is consistently and rigorously applied in all analyses. Additionally, results should be presented in an honest and clear manner to avoid any misunderstandings. To achieve these objectives, GFN and its partners developed the Ecological Footprint Standards in 2009 (Global Footprint Network, 2009). They also established a committee process that relies on consensus-building to improve and advance the Ecological Footprint methodology (Global Footprint Network, n.d.-b). This academic network is set to reinforce and enhance these processes.

2.2 ECOLOGICAL FOOTPRINT

The Ecological Footprint is a widely recognized resource accounting instrument designed to quantify the biologically productive land and water area utilized by an individual, city, country, region, or humanity. It assesses the resources consumed and the waste generated by these entities.

2.3 BIOCAPACITY

Biocapacity refers to the ecosystems' ability to generate valuable biological resources and assimilate waste materials produced by human activities under existing management practices and extraction technologies. The term "useful biological materials" is defined annually based on the resources utilized by the human economy during that specific year. The definition of "useful" is subject to change over time; for instance, the adoption of technologies like using corn stover for cellulosic ethanol production transforms corn stover into a valuable material, consequently enhancing the biocapacity of maize cropland. (Kitzes, Peller, et al., 2007a)

2.4 BIOLOGICALLY PRODUCTIVE AREA

A biologically productive area encompasses both land and water, including marine and inland regions, that sustain substantial photosynthetic activity and biomass collection for human utilization. Excluded from this classification are non-productive zones, such as arid regions, open oceans, the cryosphere, and other surfaces with low productivity. Additionally, areas generating biomass that lack benefit for humans are not considered in this context.

2.5 MAJOR LAND-USE TYPES IN ECOLOGICAL FOOTPRINTS AND BIOCPACITY ACCOUNTING

Ecological Footprint accounting involves monitoring of five biocapacity components and six Footprint components. It is noteworthy that "carbon footprint" is recognized as a distinct Footprint component, and at present, there is not explicitly designated biocapacity for it (Borucke et al., 2013a). The summation of these demand and supply components yields an overall estimate of either Ecological Footprint or biocapacity. In 2022, the area of biologically productive land and water on Earth was approximately 12.2 billion hectares. (Global Footprint Network, n.d.-c)

Figure 4: Major Land-use typed in Ecological Footprint accounting.

2.5.1 CARBON

Carbon dioxide (CO_2) is emitted into the atmosphere through diverse channels, encompassing both anthropogenic factors like the combustion of fossil fuels and specific land management practices, as well as natural occurrences such as forest fires, volcanic activities, and the respiration processes of animals (US Geological Survey , n.d.). Various natural cycles actively eliminate carbon dioxide from the atmosphere. These processes involve the absorption of carbon dioxide by the oceans and the uptake of carbon dioxide by plants during photosynthesis.

Presently, the term "carbon footprint" is commonly employed as a representation of anthropogenic greenhouse gas emissions. However, in the Ecological Footprint methodology, it interprets the quantity of anthropogenic carbon dioxide as the extent of productive land and sea area necessary to sequester these carbon dioxide emissions (Galli et al., 2012).

Carbon is the only land-use type category in ecological footprint accounting for which the biocapacity is not calculated yet because the Global Footprint Network has yet to identify dependable global datasets concerning the extent of legally protected forests dedicated to long-term carbon sequestration. Legally protected forests mean forests area that are legally safeguarded and committed to the prolonged storage of carbon. Human needs for both forest products and the capacity of forests to absorb carbon dioxide are in competition for forested land. However, when a forest is utilized for products, carbon dioxide is reintroduced into the atmosphere that is why only legally protected forest can genuinely be recognized as carbon uptake areas.

2.5.2 CROPLAND

Cropland, characterized as the most bioproductive among all land-use types, encompasses areas dedicated to the cultivation of food and fiber for human consumption, livestock feed, oil crops, and rubber. The FAO estimates that there are roughly 1.6 billion hectares of cropland worldwide as of 2019 which is one-third of the total agricultural land area which is 4.8 billion hectares (FAOSTAT Analytical Brief 28, 2019). Cropland biocapacity reflects the collective productivity of all land allocated for crop cultivation, setting a limit that the cropland Footprint cannot surpass. As an actively managed land-use type, cropland is characterized by harvest yields equivalent to growth yields. Consequently, it is inherently impossible for the production Footprint of this land-use type to exceed its biocapacity within any specified area (Kitzes et al., 2009). The calculations for cropland footprint do not account for activities that diminish the long-term productivity of cropland, such as soil degradation, erosion, or salination. Although these processes will eventually result in reductions in biocapacity in the future, the current allocation does not attribute these decreases to the activities causing degradation at present. (Kitzes, Peller, et al., 2007b)

2.5.3 GRAZING LAND

The grazing land Footprint quantifies the area of grassland utilized, in addition to crop feeds, to sustain livestock. The grazing land Footprint is determined by assessing the disparity between the quantity of livestock feed accessible in a country and the aggregate feed demand for all livestock during that year. Any unfilled feed demand is then presumed to be fulfilled by grazing land. According to FAO in 2019 worldwide, there are approximately 3.2 billion hectares of permanent meadows and pasture which is the remaining two-thirds of the 4.8 billion hectares of total agricultural land (FAOSTAT Analytical Brief 28, 2019). Since 1990, the permanent meadows and pastureland decreased by four percent and total agricultural land decreased slightly one percent with a five percent increase in the cropland area.

2.5.4 FOREST LAND

Forest Land category of ecological footprint measures the amount of fuel wood and timber products consumed annually by a country, region or an individual. Forest land is utilized to supply timber for construction and furniture, wood fiber for paper, and fuelwood (Merkel J, 2003). According to Our World in Data total area of world forest land is approximately 4.06 billion hectares in 2020 which decreased by 10% in a decade.

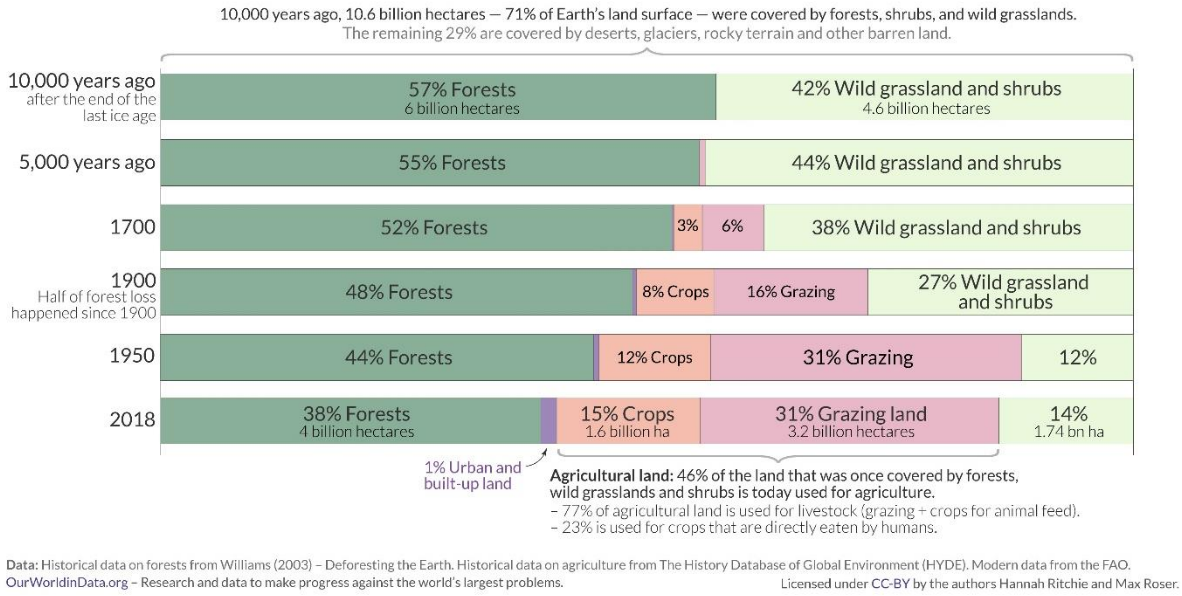

Figure 5: Historical area of forest land (Hannah Ritchie, 2021)

It can be seen in figure 5 that how the forest land area decreases historically. Half of the forest land loss has happened since 1900 when humanity starts expanding agricultural land which includes cropland and grazing land. Agriculture is by far the biggest reason for deforestation. If humanity wants to bring deforestation to an end, they must find ways to produce more food on less land (Hannah Ritchie, 2021).

2.5.5 FISHING GROUNDS

Fish and other marine products harvesting requires productive freshwater and fishing grounds. Over 95 percent of the marine fish catch is situated on continental shelves (Merkel J, 2003), constituting a total of 2.7 billion hectares when excluding inaccessible or unproductive waters (Blue Habitats, n.d.). Continental Shelf is A region adjacent to a continent (or around an island) that extends from the low water line to a depth characterized by a notable increase in slope toward oceanic depths (International Hydrographic Organization (IHO), 2008). The 2.7 billion hectares of total continental shelves is 7% of the total ocean surface (Blue Habitats, n.d.). Marine areas outside continental shelves are currently excluded in ecological footprint accounting (Kitzes, Peller, et al., 2007b). Inland waters which include lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains as well as inland wetlands consist of an additionally 0.4 billion hectares of accessible fishing grounds (Kitzes, Peller, et al., 2007b). National Footprints accounts estimates both fish catch for human use and as well as catch for fish meal.

2.5.6 BUILT-UP LAND

The development of infrastructure for housing, transportation, and industrial structure takes up built-up land. The built-up land footprint calculation is based on the total area occupied by human infrastructure. The area which is covered by reservoirs and hydroelectric dams for power generation are also considered in built-up land. Human settlements mostly settled on the fertile land which were with the potential to support the high yielding of the cropland that is the reason that built-up land mostly occupies what previously were cropland (Imhoff et al.,

1997) (Wackernagel et al., 2002). According to Our World in Data in 2016 the total area of built-up land was around 60 million hectares which increases by 400% in the last decade as shown in figure 6 below (Hannah Ritchie & Max Roser, 2013).

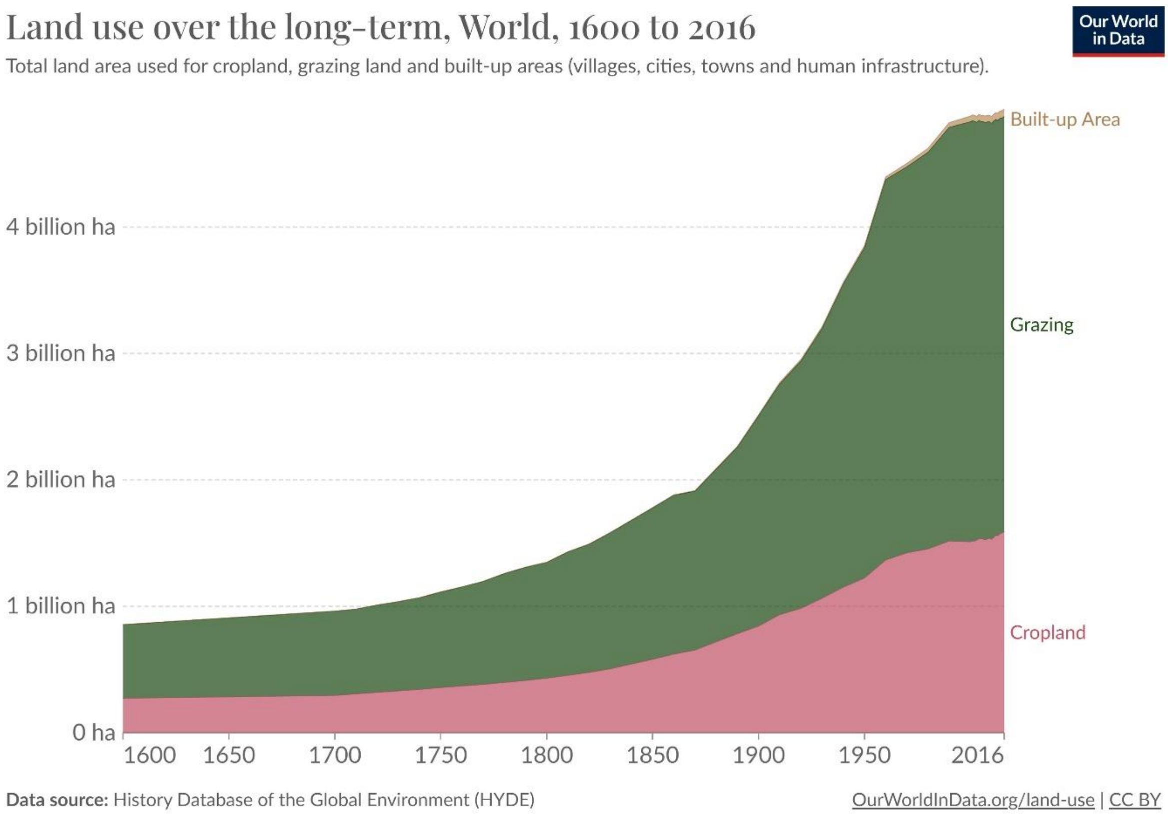

Figure 6: Land-use area from 1600-2016 (Hannah Ritchie & Max Roser, 2013)

2.6 CURRENT WORLD SCENARIOS

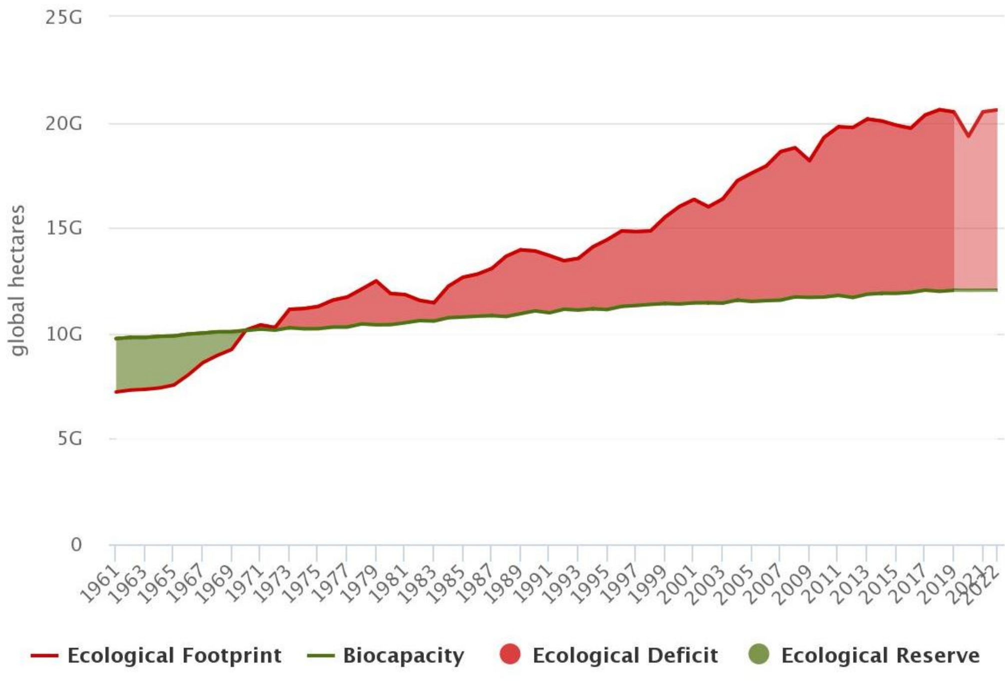

Figure 7: Ecological footprint and Biocapacity of the world

Results of national footprint accounts show that humanity's resource demands and carbon dioxide emissions began to exceed the regenerative capacity of the planet to meet these demands in the 1970s. It can be seen in figure 7 that 1970 was the year when earths biocapacity and ecological footprint are break even after that ecological footprint achieves a steep push which getting steeper year by year. In 2022 earth's ecological footprint was around 20 billion Gha and biocapacity is 12 billion Gha which means we are in a deficit of around 8 billion Gha. According to Global Footprint Network estimates for 2022 humanity exceeds the planet's ability to provide biological resources by over 75 percent.

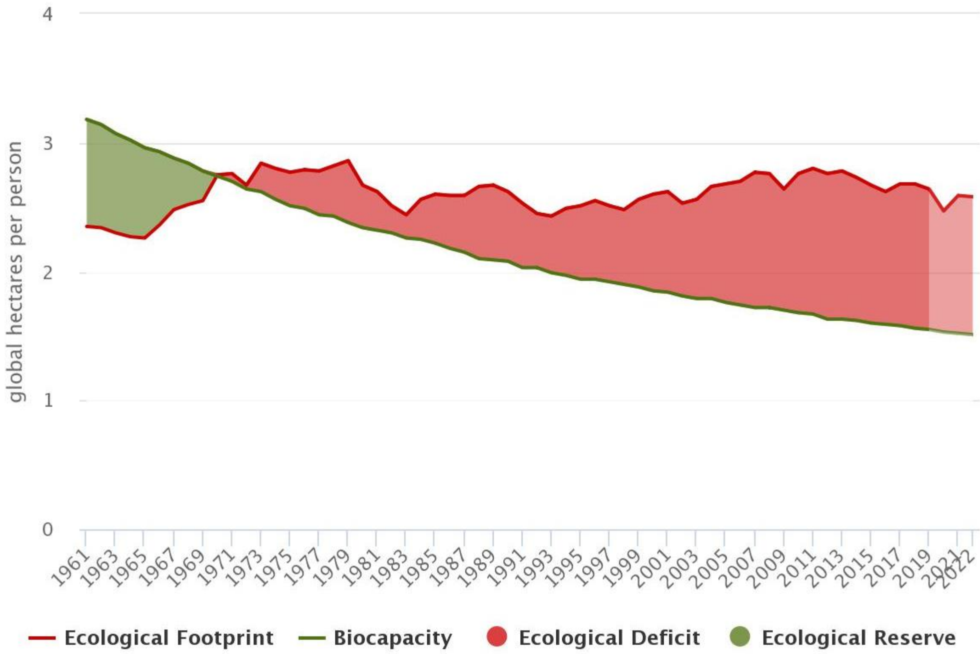

Figure 8: Ecological footprint and Biocapacity of the world in Gha per person

In 2022, the latest year of calculations by Global Footprint Network, the world average biocapacity was 1.51 Gha per person. In contrast, the world average ecological footprint was 2.58 Gha per person. From the 1970s biocapacity drastically decreased due to the uncontrollable population increase.

Wild species also require access to biocapacity to maintain their populations and biodiversity. Without such access, there is an inevitable decline in species abundance and overall biodiversity. (Wackernagel et al., 2018) Deciding how much of Earth's biocapacity should be allocated to the preservation of biodiversity is a political decision but Professor Edward O. Wilson from Harvard University, proposes dedicating half of the planet's biocapacity to remain in a wild state to safeguard up to 85% of the existing biodiversity. (Wilson, 2016)

Ecological footprint and biocapacity vary extensively among countries. For illustration the ecological footprint of Europe is around 3.1 billion Gha and biocapacity 2.2 billion Gha with a deficit of around 1 billion Gha but as compared to other regions European countries are undertaking efforts to decrease their ecological burden on the land as shown in figure 9.

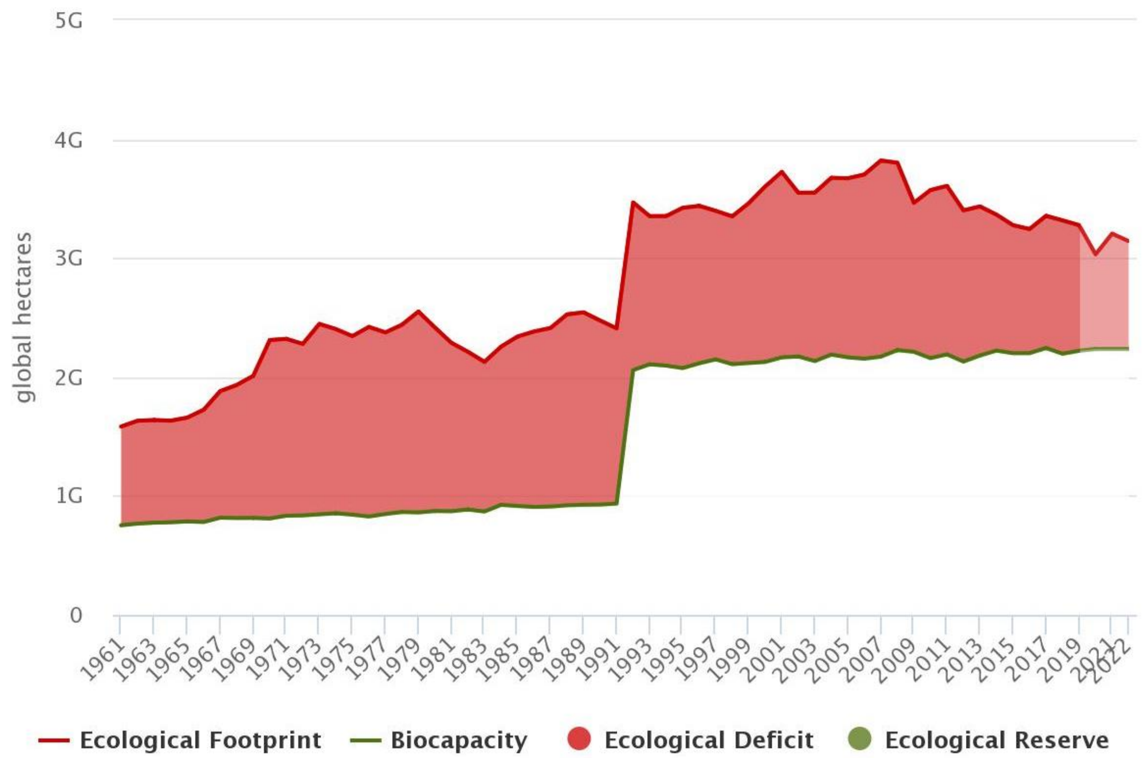

Figure 9: Ecological footprint and Biocapacity of Europe

Through the calculation of our ecological footprint, we can gain insight into the extent of our impact on resources by quantifying the amount of land necessary to support our actions and the products we consume. We can use figure 10 to analyze and think about the different kinds of land and their finite availability.

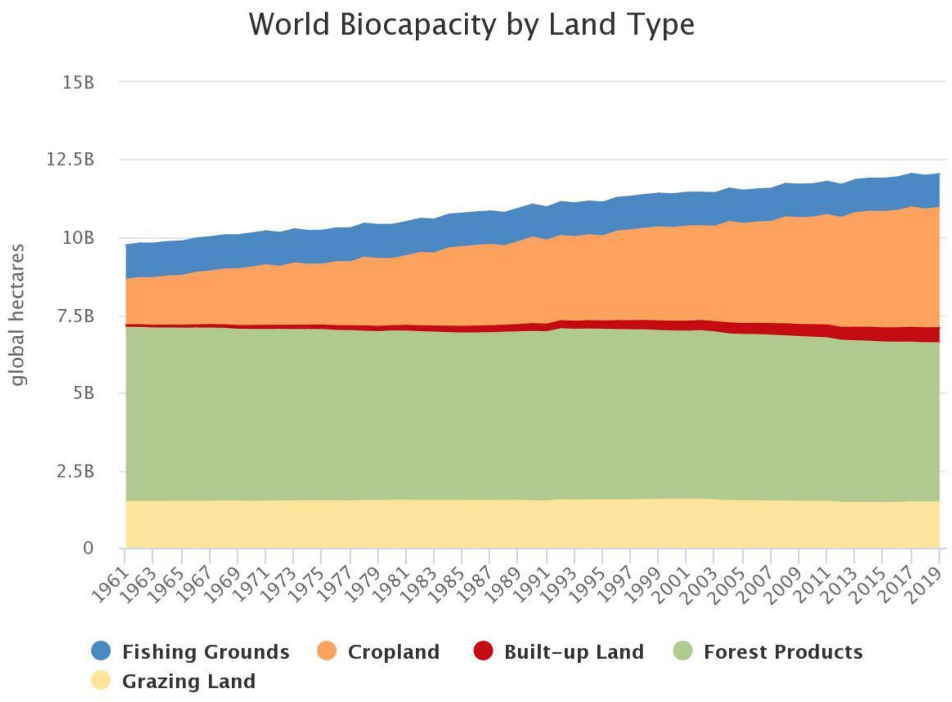

Figure 10: Biocapacity of the world by Land-use type

All the resources we utilize are sourced from the approximately 12 billion hectares of Earth's biocapacity, and a significant portion of our waste and byproducts are returned to these same hectares. In the year 2022, with a global population of 8 billion individuals, this equated to an estimated 1.5 hectares of usable land per person worldwide. If the human population were to fully consume all this available land, there would be no land left to fulfill the needs of other species.

if we talk about ecological footprint of each land-use type it is evident that carbon alone is around 12 billion Gha of the total 20 billion Gha with second highest cropland which has ecological footprint of 3 billion Gha as shown in figure 11.

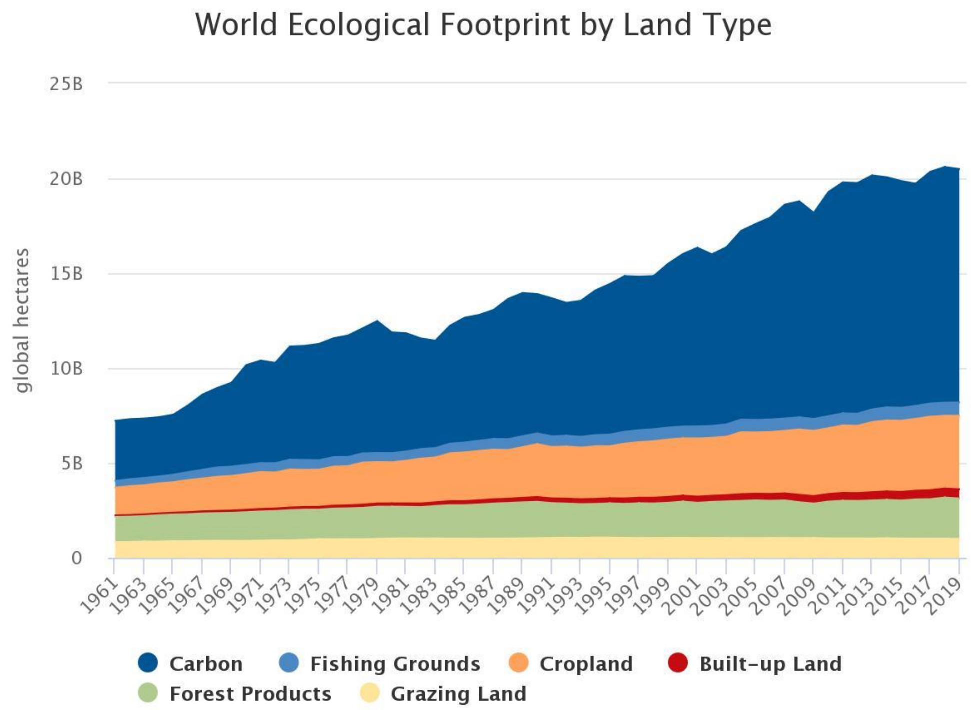

Figure 11: Ecological Footprint of the world by Land-use type

2.7 APPLICATIONS

Several governments and international organizations have employed the ecological footprint. Examples are mentioned in the table below:

1. Scottish Environmental Protection Agency (SEPA) https://www.sepa.org.uk/one-planet-prosperity/ https://www.footprintnetwork.org/one-planet-prosperity/:

Under the banner of "One Planet Prosperity," Scottish Environmental Protection Agency (SEPA) has streamlined its regulatory framework. The SEPA aimed to recognize the achievements of its industry and government partners who have gone above and beyond regulatory compliance in promoting one planet prosperity. They also sought to spread awareness among new audiences about the advantages of participating in initiatives that advance one planet prosperity.

2. Calgary, Canada: https://www.footprintnetwork.org/2015/04/10/calgary/

Calgary, the largest city in Alberta, Canada, was the first city to establish precise ecological footprint reduction objectives. Calgary participated in one of the earliest municipal-level Ecological Footprint studies in collaboration with Global Footprint Network in 2005. The study revealed that Calgary's per capita Footprint exceeded the Canadian average by over 30%, at 9.8 global hectares per person, which would require five Earths if the entire planet consumed resources at the same rate.

To address this issue, imagineCALGARY, the City of Calgary’s 100-year sustainability vision, identified reducing the city's Ecological Footprint as one of its 114 targets. By 2036, Calgary aims to reduce its Footprint to the national average of 7.25 global hectares per person.

Since then, Calgary has applied Ecological Footprint analysis to 14 land-use plans, including a proposed downtown redevelopment plan. The analysis demonstrated that mobility poses the greatest challenge and emphasized the need for a multi-modal transportation system and an improved jobs-to-housing balance to reduce the Ecological Footprint.

3. Switzerland: https://www.footprintnetwork.org/2017/01/10/switzerland/

Switzerland took the initiative in December 2006 to collaborate with the Global Footprint Network in order to analyze and comprehend its Ecological Footprint and biocapacity findings. Following Switzerland's lead, over a dozen other countries have subsequently undertaken similar actions. The Swiss government presented their initial assessment in a report titled "Switzerland’s Ecological Footprint – A Contribution to the Sustainability Debate," which was authored by INFRAS, a preceding Swiss policy research institute. The Federal Office of Spatial Development and the Statistical Office integrated the Ecological Footprint into the Swiss government's "Sustainable Development Report 2012," launched during Rio+20 conference. The Ecological Footprint was formally adopted as an indicator within Switzerland's sustainable development monitoring system, and since 2008, the Swiss Federal Statistical Office has published an annual report on it. They maintain a webpage containing crucial statistics on the Swiss Footprint and acknowledge that "nearly three planet Earths would be necessary if everyone lived like the Swiss population." In a historic event in autumn 2016, Switzerland became the first nation to vote on the inclusion of a green economy in its constitution, aiming to achieve one-planet living by 2050 using Ecological Footprint accounting (Wackernagel et al., 2018).

4. Vancouver, Canada: https://www.footprintnetwork.org/2017/02/20/vancouver-kicks-off-neighborhood-footprint-campaign/

Residents of Vancouver have an Ecological Footprint that is three times larger than the global average per person. In 2011, the city set a target to reduce its Ecological Footprint by 33% below the 2006 levels by the year 2020, with the ultimate goal of achieving one-planet living by 2050. In 2015, Vancouver reaffirmed its commitment by aiming for zero waste and zero carbon emissions by 2020. In July of the previous year, the Vancouver City Council passed the Zero-Emission Building Plan, demonstrating its dedication to sustainability. Additionally, the city has been actively engaging with key players in the private sector such as hotels, retailers, and real-estate developers. (Vancouver Kicks off Neighborhood Footprint Campaign, n.d.)

To involve citizens in sustainability efforts, Vancouver provided grants to Evergreen to establish the Green Bloc Program. Furthermore, in 2017, a grant was allocated to support the Green Bloc Project in three (potentially four) neighborhoods. Meanwhile, Vancouver is taking measures to enhance the accuracy of its Ecological Footprint calculation. The largest contributor to Vancouver's Ecological Footprint is food, followed by buildings and transportation. To address this, the city has announced plans to create more than 2000 garden plots for households by 2020 and is actively promoting local and seasonal foods through farmers' markets. (Vancouver Kicks off Neighborhood Footprint Campaign, n.d.)

5. China: https://www.zujiwangluo.org/

China is actively promoting the concept of Ecological Civilization, which aims to achieve a harmonious relationship between human activities and nature. The notion of Ecological Civilization in China encompasses sustainable development, environmental protection, and the preservation of ecological balance. It emphasizes the need to balance economic growth with environmental conservation, recognizing that a healthy environment is crucial for the well-being and prosperity of both present and future generations.

As part of its commitment to Ecological Civilization, China has established an active academic footprint community. This community consists of scholars, researchers, and experts who are dedicated to studying and addressing ecological issues in the country. These academics contribute to the understanding and development of strategies, policies, and practices that promote sustainable development and environmental protection.

Through research, collaboration, and knowledge sharing, the academic footprint community in China plays a vital role in generating innovative ideas and solutions to environmental challenges. They conduct studies on various aspects of ecology, including biodiversity conservation, ecosystem management, climate change mitigation, and sustainable resource utilization. Their work helps inform policymakers, government agencies, and other stakeholders on effective measures to enhance ecological sustainability.

Furthermore, the academic footprint community in China actively engages in international collaborations and exchanges. They participate in conferences, workshops, and research partnerships with scholars and institutions from around the world. These interactions foster global cooperation and enable the sharing of best practices and experiences in ecological research and conservation.

By promoting Ecological Civilization and nurturing an active academic footprint community, China demonstrates its commitment to advancing sustainable development, protecting the environment, and building a greener future for its citizens and the world at large.

6. Finance for Change “A Project of Global Footprint Network”: https://www.footprintfinance.org/

Incorporating the ecological footprint into financial risk assessment is gaining traction within the financial sector. The Global Footprint Network, in partnership with the UN Environment Programme Finance Initiative and seven prominent financial institutions, has undertaken a collaborative effort to examine methods for integrating ecological footprint and biocapacity trends into global credit ratings for sovereign bonds. This initiative recognizes the significance of ecological factors in evaluating the overall sustainability and long-term viability of financial investments. By incorporating ecological footprint and biocapacity trends into credit ratings, financial institutions aim to gain a comprehensive understanding of the environmental risks associated with sovereign bonds. (Finance for Change "A Project of Global Footprint Network," n.d.)

The collaboration between the Global Footprint Network, the UN Environment Programme Finance Initiative, and these financial institutions signifies a growing recognition of the importance of ecological considerations within the financial sector. It highlights the need to assess the ecological impacts and sustainability implications of investments, beyond traditional financial indicators.

By exploring ways to integrate ecological footprint and biocapacity trends into global credit ratings, the financial sector is taking steps towards incorporating environmental factors into their risk assessment frameworks. This development showcases a broader shift towards more holistic and sustainable approaches to financial decision-making, considering both financial and ecological dimensions.

3 CALCULATION METHODOLOGY BEHIND ECOLOGICAL FOOTPRINT ACCOUNTING

3.1 ASSUMPTIONS FOR ECOLOGICAL FOOTPRINT ACCOUTING

Ecological footprint and biocapacity accounting are based on six fundamental assumptions listed below: (Ewing et al., 2010)

1. Most of the resources that people use and the waste they produce can be monitored and accounted for.

2. Ultimately, all the flows of resources and waste can be quantified in relation to the quantity and type of land required to sustain these flows.

3. Different types of land-use area can be converted into an average unit of productivity i.e., global hectares Gha.

4. As a single global hectare signifies a specific use, and all global hectares within a given year indicate an equal amount of bio productivity, they can be summed together to derive a composite measure of Ecological Footprint or biocapacity.

5. Human demand, as represented by the Ecological Footprint, can be straightforwardly compared to nature's provision, biocapacity, when both are expressed in global hectares.

6. The area demanded can surpass the area supplied when the demand placed on an ecosystem exceeds its regenerative capacity. This phenomenon is referred to as "overshoot."

3.2 BASIC EQUATIONS FOR ECOLOGICAL FOOTPRINT AND BIOCAPCITY ACCOUNTING

3.2.1 ECOLOGICAL FOOTPRINT

The basic equation which can be used for ecological footprint accounting is:

$$EF = \frac{D_{annual}/C_{annual}}{Y_{annual}} \qquad \text{EQ 1}$$

Where D is the annual demand of the product or C is the annual consumption of the product and Y is the annual yield of that same product.

To get the results in a single comparable unit global hectare (Gha) for all land-use types two most important factors equivalence factors (EQF) and yield factors (YF) plays an important role. Therefore, the equation can be written as:

$$EF = \frac{P}{Y_N}\,.YF\,.EQF \qquad \text{EQ 2}$$

Where P is the amount of product that is harvested or consumed; Y_N is the national yield for the same product and YF and EQF are yield factor and equivalence factor respectively.

By doing a little more mathematics the equation 2 becomes:

$$EF = \frac{P}{Y_W}\,.EQF \qquad \text{EQ 3}$$

Where the term Y_w is the world average annual yield.

For the carbon category of ecological footprint, a different equation is used which is:

$$EF_C = \frac{E_C\,.\,(1 - S_{ocean})}{Y_C}\,.EQF \qquad \text{EQ 4}$$

Where, E_C represents the annual anthropogenic carbon emissions, S_{ocean} denotes the part of annual anthropogenic carbon emissions sequester by oceans. The ocean uptake ranges between 25% to 35% in different studies (Gruber et al., 2019; National Oceanic and Atmospheric Administration (NOAA), 2022; Ridge & McKinley, 2021; Watson et al., 2020). The latest ocean uptake range we found on ESSD's article "Global Carbon Budget 2022" is 30% (Friedlingstein et al., 2022). Y_C signifies the annual rate of carbon uptake per hectare of world average forest land (t C/ha/yr). (Borucke et al., 2013a)

3.2.2 BIOCAPACITY

Biocapacity measures the extent of available terrestrial and aquatic area which can be used for ecological services. Ecological services are the benefits humans are deriving from ecosystem. It can be measured by following equation:

$$BC = A \,.\, YF \,.\, EQF \qquad \text{EQ 5}$$

Where A is the bioproductive area and YF and EQF are the yield factor and equivalence factors respectively. Biocapacity is measured to compare it with ecological footprint to get the ecological deficit.

3.3 UNIT OF MEASURE

Ecological footprint uses Global Hectares (Gha) of bio-productive land as its accounting unit. A global hectare represents a hectare of land with the average biological productivity of the world for a specific year. Global hectares are essential because average bio productivity differs between various land use types, as well as between countries for any given land use type. For instance, one global hectare of cropland would cover a smaller physical area compared to much less productive grazing land, as more grazing land would be required to match the biocapacity of one hectare of cropland. Since global biological productivity experiences slight annual variations, the precise value of a global hectare may also fluctuate from year to year. Global hectares are not a measure of area but rather of the ecological production associated with an area. Global hectares offer a more comprehensive perspective than just considering weight, which fails to encompass the full scope of land and sea area utilization, or physical area, which overlooks the ecological production linked to the land. Two crucial coefficients, namely yield factors (YF) and equivalence factors (EQF), enable the presentation of results using a standardized unit of measurement. (Kitzes, Galli, et al., 2007). Utilizing global hectares permits the amalgamation of Ecological Footprint values from diverse land use categories into a singular numerical representation.

3.4 EQUIVALENCE FACTORS

To combine the Ecological Footprint from various land-use categories, equivalence factors are used, these coefficients convert the areas of different land use types, based on their respective world average productivities, into equivalent areas according to the global average bio productivity across all land use types. Equivalence factors are subject to variation based on both land use type and the specific year.

The concept behind the equivalence factors calculation lies in assigning weight to different land areas according to their inherent capacity to generate biologically useful resources for human consumption. The weighting criterion doesn't consider the actual quantity of biomass produced but rather focuses on the inherent potential of each hectare to deliver such resources. To approximate inherent capacity, equivalence factors are presently computed using suitability indexes derived from the Global Agro-Ecological Zones (GAEZ) model, in conjunction with data on the actual areas of cropland, forest land, and grazing land obtained from FAOSTAT (Borucke et al., 2013a). The GAEZ model categorizes all global land into five groups, determined by the potential crop productivity calculated under the assumption of agricultural input. Each land category is assigned a quantitative suitability index from the following options:

- Very Suitable (VS) – 0.9
- Suitable (S) – 0.7
- Moderately Suitable (MS) – 0.5
- Marginally Suitable (mS) – 0.3
- Not Suitable (NS) – 0.

The EQF computation is grounded on the assumption that within each country, the land best suited for cultivation will primarily be designated as cropland, followed by the allocation of the most suitable remaining land for forest use, while the least suitable land is typically reserved for grazing purposes (Wackernagel et al., 2002). On an annual basis, equivalence factors are determined by comparing the world average suitability index for a particular land use type to the average suitability index across all land use types. Figure 12 illustrates a schematic representation of this calculation process.

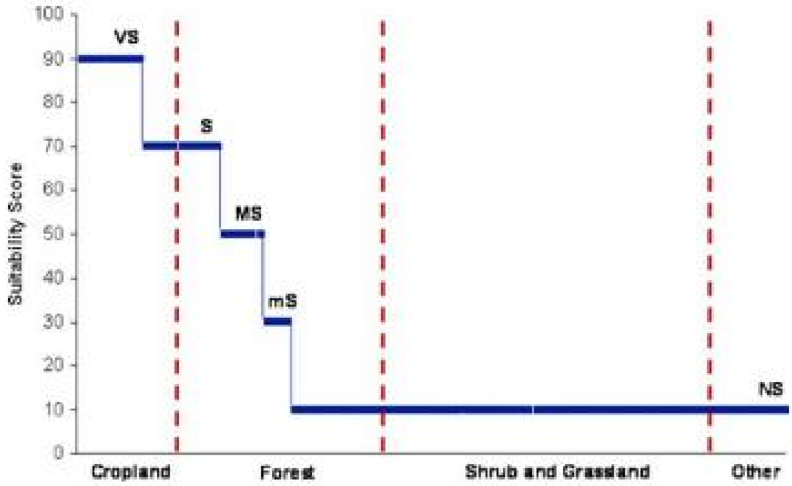

Figure 12: Global Agro-Ecological Zones (GAEZ) model

The total count of bio productive land hectares is depicted along the horizontal axis, with vertical dashed lines demarcating this overall land area into three terrestrial land use categories for which equivalence factors are computed (namely, cropland, forest, and grazing land). Each horizontal bar's length on the graph corresponds to the total land area associated with a specific suitability index. The vertical position of each bar indicates the suitability score assigned to that suitability index, ranging from 10 to 90.

The latest equivalence factors were calculated in 2018 by Global Footprint Network as shown in table 1. For instance, cropland exhibited an equivalence factor of 2.50, signifying that the average productivity of world cropland was more than twice that of the average productivity across all other land types. During the same year, grazing land had an equivalence factor of 0.45, indicating that grazing land, on average, possessed only half the productivity of a world-average bio productive hectare. The equivalence factor for built-up land is set equal to that of cropland based on assumption that most suitable land will devoted to cropland. The equivalence factor for carbon uptake land is established to be equivalent to that of forest land, as it is assumed that the carbon Footprint depends on forest area. The equivalence factor for marine area is computed based on that the calories of salmon produced by one global hectare of marine area are equivalent to the calories of beef produced by one global hectare of pasture. This assumption is grounded in the belief that calories derived from animal protein, whether from land or sea, hold an equal resource value for human consumption. The EQF for inland water is established to be identical to that of marine area.

Table 1: EQFs for all land use types

Land use type	Equivalence Factor
Cropland	2.50
Forest Land	1.26
Grazing Land	0.45
Marine Fishing Grounds	0.36
Infrastructure	2.50
Inland Fishing Grounds	0.36
Carbon	1.26

3.5 YIELD FACTORS (YF)

Yield factors take into consideration variations in productivity for a specific land use type between a country and the global average within that land category. They are country specific and vary year by year, the disparities arise from both natural factors, such as precipitation or soil quality, and anthropogenic differences between countries.

The yield factor is determined as the ratio of a country's average national yield to the global average yield for a particular land use type. It is calculated based on the yearly availability of usable products. For any given land use type denoted as "L," a country's yield factor, represented as yield factor, can be expressed as follows:

$$\mathrm{YF}_L = \frac{Y_{N,i}}{Y_{W,i}} \quad \text{EQ 6}$$

Where:

YF_L= yield factor for a country
$Y_{N,i}$= national yield of that country for specific product
$Y_{W,i}$= world average yield of the same product

Except for cropland, all the land use types incorporated in the NFAs are presumed to offer only a solo human-useful primary product, such as wood from forest land or grass from grazing land.(Wackernagel et al., 2002)

Sample yield factors for Italy as compared to world average yield factors of different land use typed are reported in table 2 and table 3 below respectively:

Table 2: National yield, world yield and yield factors of Italy 2018

Land use type [-]	National Yield [t ha-1]	World Yield [t wha-1]	Yield Factor [wha ha-1]
Crop Land	7.97302	13.2152	0.603324
Grazing Land	11.81	6.19	1.90792
Marine Fishing Grounds	452	503.836	0.897117
Inland Fishing Grounds	0	0	1
Forest Land	3.05307	1.81878	1.67864
Built-up Land	0	0	0.603324
Carbon	0	0	1.67864

Table 3: National yield, world yield and yield factors of world 2018

Land use type [-]	National Yield [t ha-1]	World Yield [t wha-1]	Yield Factor [wha ha-1]
Crop Land	6.25	6.25	1
Grazing Land	6.19	6.19	1
Marine Fishing Grounds	504	504	1
Inland Fishing Grounds	0	0	1
Forest Land	1.82	1.82	1
Built-up Land	0	0	1
Carbon	0	0	1

Based on the idea that urban areas are typically built on productive agricultural lands the yield factor for built-up land is assumed to be the same as that for cropland. Regarding the carbon footprint, the yield factor is assumed to be equivalent to that of forest land due to limited data availability regarding the carbon uptake of other land use types. Furthermore, all inland waters are attributed to a yield factor of 1 because of the lack of a comprehensive global dataset on freshwater ecosystem productivities.

It can be seen in table 2 that Italy has almost double pasture as compared to world average grazing land and cropland and built-up land are half as compared to world average cropland and built-up land these differences can be due to the differences in natural factors such as climatic conditions, soil conditions and geographical differences between every country.

3.6 CONSUMPTION, PRODUCTION AND TRADE APPORACH FOR COUNTRY ANALYSIS

Every manufacturing process relies to a certain extent on utilizing biocapacity for material inputs and waste removal throughout the production chain. Consequently, all products inherently bear an embodied Footprint, and international trade dynamics can be viewed as the movement of embodied demand for biocapacity (a schematic representation can be seen in figure 13). (Borucke et al., 2013b)

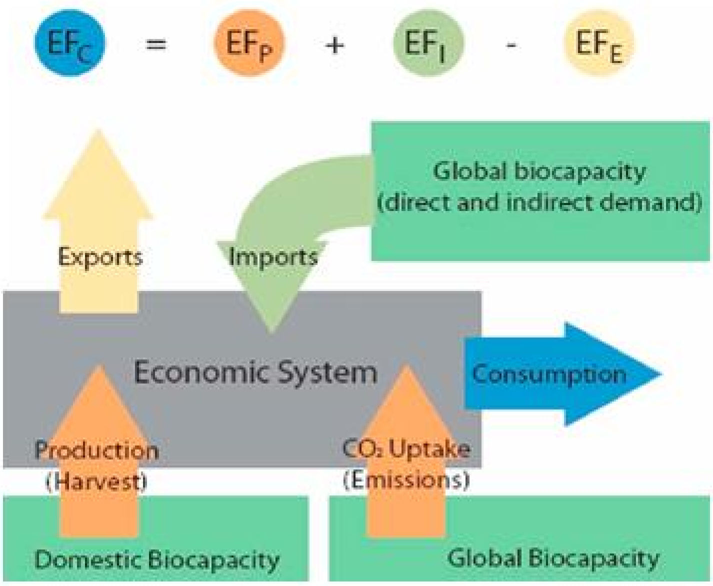

Figure 13: Schematic representation of direct and indirect global biocapacity demand

The Ecological Footprint of a country's primary production is the cumulative measure of Footprints associated with all resources harvested and all waste generated within the geographical confines of the country. This encompasses the total area required within a country to sustain the actual harvesting of primary products (such as cropland, grazing land, forest land, and fishing grounds), the country's infrastructure and hydropower needs (built-up land), and the space necessary to absorb carbon dioxide emissions from fossil fuel sources generated within the country (carbon Footprint). The equation use for country analysis of ecological footprint thus becomes:

$$EF_C = EF_P + EF_I - EF_E \qquad \text{EQ 7}$$

Where, EF_P represents the Ecological Footprint of production, while EF_I and EF_E denote the Footprints embedded in imported and exported commodity flows, respectively. The calculations for EF_I and EF_E for each traded product follow the equation as in equation 3, where production P signifies the quantity of product imported or exported, respectively.

A more detailed description of consumption, production and trade approach for ecological footprint country analysis is shown in figure 14:

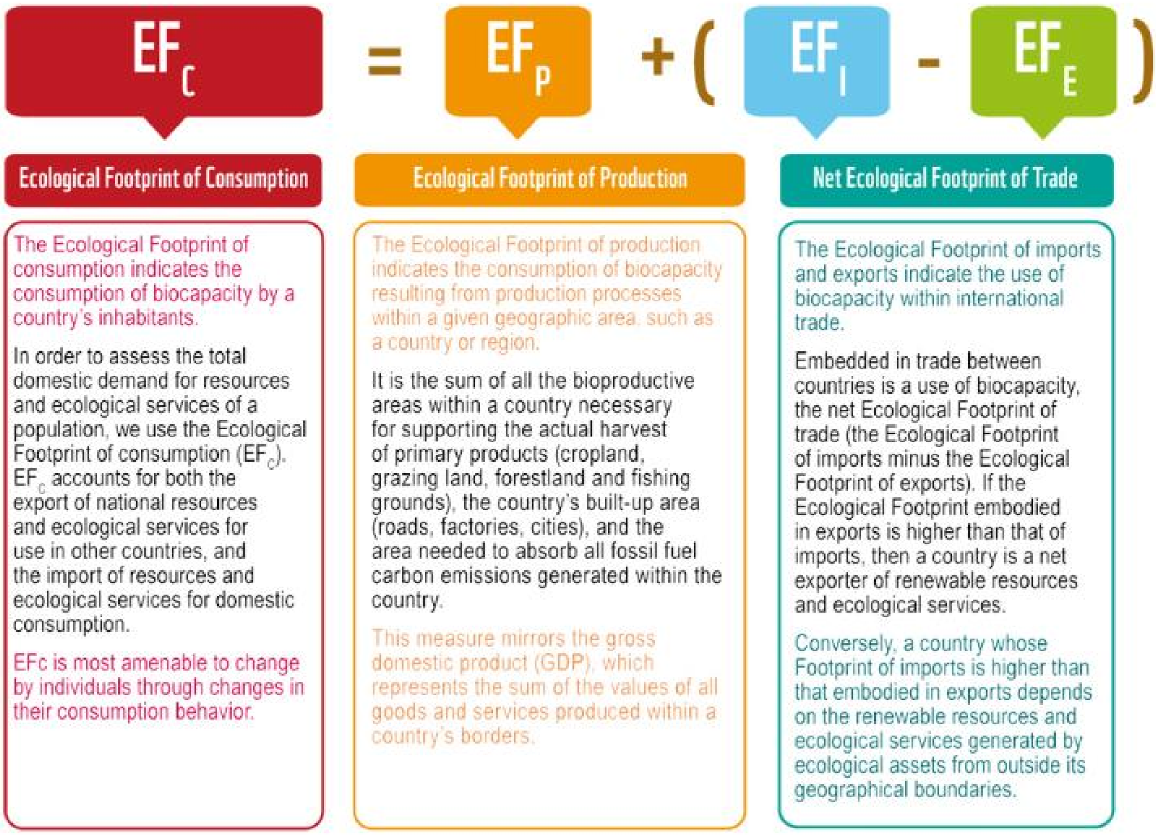

Figure 14: Consumption, Production and Trade Approach (Global Footprint Network, n.d.-a)

4 SCOPE OF THE THESIS

The research aims to thoroughly measure and assess the far-reaching consequences on both terrestrial and aquatic bio-productive land, arising from the main activities and behaviors exhibited by the average habitant.

The pivotal findings gathered from this research are to play an essential role in fortifying the foundations of the forthcoming HUMAN SRL web application. This innovative digital platform is designed to harness the insights derived from a series of inquiries posed to each user. These inquiries are strategically curated to capture the essence of diverse lifestyle aspects, establishing a precise and personalized portrait of an individual's ecological impact. This web app will use the information obtained from a series of questions posed to the user to calculate the user's ecological footprint in Global Hectares (Gha). Users will gain a profound understanding of their ecological footprint, quantified in Global Hectares (Gha), shedding light on the extent of their impact on the delicate equilibrium of our planet's bio-productive capacity.

Furthermore, the app goes beyond numerical representation, offering users a glimpse into the temporal dimension of their ecological influence. Through the concept of "overshoot day," individuals will be made aware of the point in the calendar year when their cumulative demands on Earth's resources exceed its regenerative capacity. This compelling metric serves as a wake-up call, urging users to reflect on the urgency of adopting sustainable practices.

In a visionary step towards environmental awareness, the HUMAN SRL web app doesn't stop at interpreting the scale of impact. It extends its reach to convey a tangible portrayal of the ecological debt accrued by each user, expressed in terms of the number of Earths required to sustain their current lifestyle. This representation serves as a reminder of the finite nature of our planet's resources and the necessity to adopt more sustainable habits.

In order to enhance user interaction and foster a deeper understanding of their ecological impact, a user-friendly calculator has been developed. This digital tool serves as the conduit through which users can actively participate in the assessment of their environmental footprint. Engaging with this calculator is a straightforward process, where users are prompted to input a spectrum of data pertaining to their daily routines, activities, and consumption patterns. By aligning their responses with their unique lifestyle choices, the calculator dynamically generates a comprehensive overview of their ecological footprint. This dynamic feedback mechanism offers users an immediate and tangible connection to the environmental repercussions of their daily choices.

Furthermore, the calculator doesn't merely stop at providing high-level metrics; it extends its functionality to accommodate a more detailed analysis. Users are offered the opportunity to examine deeper into the details of their ecological impact through the examination of their Consumption Land-Use Matrix (CLUM). This matrix serves as a sophisticated analytical tool, allowing users to scrutinize and comprehend the specific land-use implications associated with their daily life activities. By offering this comprehensive level of analysis, the calculator empowers users with a deep understanding of the environmental consequences woven into the fabric of their lifestyle choices. This holistic approach encourages a more informed and mindful approach to daily living, as users gain insights into the specific areas where adjustments can be made to reduce their ecological footprint.

In essence, the user-friendly calculator serves as a gateway to environmental consciousness, transforming complex ecological data into accessible and actionable insights. Through this innovative tool, individuals are not only informed about their impact but are also equipped with the knowledge needed to make informed decisions and contribute to the collective endeavor of fostering a sustainable and balanced coexistence with our planet.

5 WORKING METHODLOGY

A sophisticated ecological footprint calculator, designed on the Excel platform, has been developed for integration into HUMAN's forthcoming web application. This meticulously crafted tool incorporates a comprehensive analysis of six key consumption categories, aligning with the typical daily life activities of an average inhabitant.

5.1 CONSUMPTION CATEGORIES

The six consumption categories considered are:

5.1.1 FOOD

The utilization of natural resources, including land, water, and energy, in farming activities, along with the generation of waste and emissions during the farming process, as well as the transportation of food to supermarkets and households contributes to the ecological footprint of food. The environmental impact of food production is significant. Agriculture necessitates extensive land use, contributing to deforestation and the loss of natural habitats. Additionally, according to FAO approximately 70% of global freshwater is dedicated to agricultural activities. On the other hand, the process of food production generates considerable waste, including carbon dioxide emissions from fertilizer usage and methane emissions from livestock digestion.

5.1.2 HOUSING/SHELTER

Construction activities contribute to the ecological footprint through the utilization of natural resources and the generation of waste. The extensive land requirements for construction can lead to the destruction of natural habitats. The energy utilizing in the household for electricity and heating purposes regardless of its source also contributes to the housing/shelter footprint.

5.1.3 TRANSPORT

The use of energy for commuting contributes to the ecological footprint of transport. Transportation necessitates energy in the form of fossil fuels, resulting in emissions that contribute to environmental pollution. Moreover, it requires expansive areas of land for road infrastructure. Additionally, transportation activities produce noise pollution, posing potential harm to both humans and wildlife. Activities involve the type of transportation the person is using.

5.1.4 WASTE

The generation of waste can occur at multiple stages, and it poses threats to ecosystems and human health. The disposal of waste necessitates land, which can deplete resources and harm ecosystems, with improper disposal leading to pollution. Additionally, waste disposal is a contributor to greenhouse gas emissions.

5.1.5 GOODS

The ecological footprint of goods involves physical products and materials consumed or used by individuals, communities, or societies. Each of these goods has its own ecological footprint, representing the environmental impact associated with its production, use, and disposal.

5.1.6 SERVICES

Services refer to the non-material activities or experiences that contribute to human well-being. While goods involve physical products, services are more intangible and include a diverse range of activities.

Each consumption category is correlated with one or more land-use categories within the ecological footprint framework, reflecting their respective impacts on the natural environment. The correlation can be seen in figures 15 and 16.

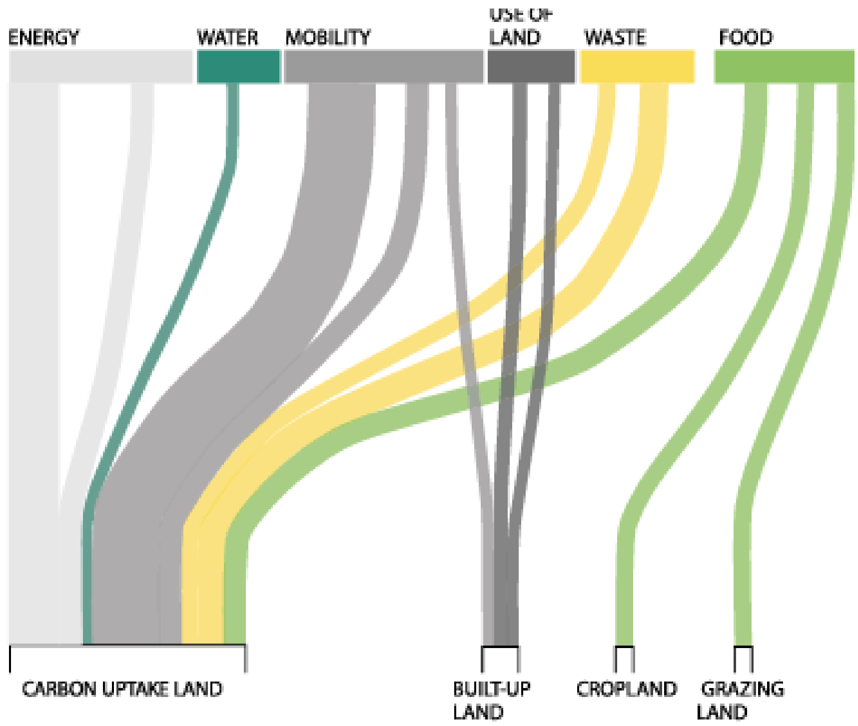

Figure 15: Type of land-use corresponding to different consumption categories.

Figure 16: Land-use corresponding to different consumption category.

5.2 SUPPORTING DATA

The supporting data played a pivotal role in establishing the ecological footprint calculator. Supporting data which were used are footprint factors, constants, and equivalence factors.

5.2.1 FOOTPRINT FACTORS

To assess the influence of our products and activities in relation to the land they require, it is imperative to employ footprint conversion factors. Various conversion factors are essential for translating objects and activities into the corresponding land areas they rely upon. Different objects and activities might have different components that require several different types of conversion factors.

Some examples of possible footprint conversion factors of apples from (National Science Foundation (NSF), 2015):

Some obvious ones: apples/tree, trees/acre, trees/hectare

Gasoline associated with cultivation and harvesting: gallons/acre, liters/m^2.

Gasoline associated with transportation: gallons/mile, miles/apple.

Packing materials (paper, cardboard, wood): pounds/apple, kg/m²

Pesticides, herbicides, fertilizer: pounds/acre

Water: gallons/acre, liters/m²

Fortunately, we are relieved from the exhaustive task of determining precise values for all the conversion factors required to compute the footprints of diverse objects and activities. Environmental scientists play a pivotal role in conducting much of this research, and the National Footprint Accounts (NFA) serve as a valuable resource containing a spectrum of footprint conversion factors for various objects and activities (Global Footprint Network, n.d.-a). The computations within the National Footprint and Biocapacity Accounts rely on data sets from the United Nations (UN) or UN-affiliated sources, which encompass publications from entities such as the Food and Agriculture Organization, United Nations Commodity Trade Statistics Database, and the UN Statistics Division. Additionally, data from the International Energy Agency contribute to these calculations. Complementary information is drawn from studies published in peer-reviewed scientific journals and thematic collections.

The procedure for developing a footprint factor involves a series of steps, outlined below to provide insight into the generation process: (Merkel J, 2003)

1. The harvest yield data is sourced from the Food and Agriculture Organization of the United Nations (FAO). For instance, it involves determining the sustainable quantity of carrots, cotton, or lumber that can be harvested from one acre of land within a given year.
2. If the product incorporates energy in its manufacturing process, augment the first step with the fossil energy component. This encompasses all the energy required to enable the ultimate consumption of the raw material or manufactured product. A structural consumption multiplier is applied to factor in the energy consumed by the government in procuring public goods and services. In our case we consider structural consumption value as 10%.
3. To the outcomes of the preceding steps one and two, a correction factor is introduced to align the overall footprint system with data derived from the more comprehensive national accounting system.
4. This step involves incorporating the productivity of each land-use type in relation to the average productivity of all biologically productive land and sea space on Earth. Upon completion of this step, the aggregated land amounts can be calculated.

Footprint conversion factors we considered in our research are mentioned in table 4 below:

Table 4: Footprint Intensity Conversion Factors

Footprint Intensity	Cropland (gm2/kg)	Grazing Land (gm2/kg)	Forest (gm2/m3 roundwood)
Veggies, potatoes & fruit	1.6		
Bread and bakery products	8.3		
Flour, rice, noodles, cereal products	8.3		
Maize	5.0		

Beans and other dried pulses	24.0		
Milk, cream, yogurt, sour cream	2.3	1.2	
Ice cream, other frozen dairy	11.6	6.2	
Cheese, butter	23.2	12.4	
Eggs	20.8		
Meat			
Pork	27.9		
Chicken, turkey	19.0		
Beef	54.7	32.3	
Goat, Lamb	46.9	31.1	
Fish	121.9		
Sugar	3.4		
Vegetable oil	61.8		
Margarine	61.8		
Coffee & tea	40.1		
Juice & wine	3.8		
Beer	2.0		
Cotton	39.3		
Cigarettes, other tobacco products	13.6		
Timber			6,469

5.2.2 EQUIVALNCE FACTORS

Equivalence factors portray an important role in ecological footprint accounting, it is productivity-based scaling factor that converts a specific land use type such as cropland or pastureland into a universal unit of biologically productive area a global hectare (Gha). A detailed explanation of equivalence factors is provided in section 3.4.

Latest year of calculation of equivalence factors by Global Footprint Network is 2018 (Global Footprint Network, n.d.-a) which employed in our research are mentioned in table 5 below:

Table 5: EQF employed in Ecological Footprint calculator.

Land use type	Equivalence Factor
Cropland	2.50
Forest Land	1.26
Grazing Land	0.45
Marine Fishing Grounds	0.36
Infrastructure	2.50
Inland Fishing Grounds	0.36
Carbon	1.26

5.2.3 ENERGY INTENSITY

Energy intensities of different products are used in calculating the carbon footprint category of ecological footprint. The values are taken from different literatures, Global Footprint Network's NFA and EC Europa EUROSTAT Agri-Food data portal (Maysami & Berg, 2021) (EC EUROPA EUROSTAT, n.d.) (Global Footprint Network, n.d.-a).

The energy intensities of the different products are listed below in tables 6 to 11.

Table 6: Energy intensities of food items

Item	Energy Intensity MJ/Kg
Veggies, potatoes & fruit	10
Bread and bakery products	25
Flour, rice, noodles, cereal products	20
Maize	20
Beans and other dried pulses	10
Milk, cream, yogurt, sour cream	10
Ice cream, other frozen dairy	20
Cheese, butter	65
Eggs [assumed to be 50 g each]	25
Meat	
Pork	100
Chicken, turkey	80
Goat, Lamb	100
Beef	130
Fish	150
Sugar	15
Vegetable oil (seed or olive oil)	30
Margarine	30
Coffee & tea	65
Juice & wine	25
Beer	25
Garden [area used for food]	
Dining out	8

Table 7: Energy intensities of house category

Item	Unit	Energy Intensity
House or apartment	GJ/m^2	6
Electricity from fossil fuels	MJ/kWh	3.6
Natural gas	MJ/kWh	3.6
LPG	MJ/kWh	3.6

Fuel oil	MJ/l	35
Coal	MJ/kg	20

Table 8: Energy Intensities of transport

Item	Unit	Energy Intensity
Bus, transit (around town)	MJ/km	4.7
Bus, intercity (Greyhound)	MJ/km	1.1
Train, transit (tram, light rail)	MJ/km	3
Train, intercity	MJ/km	3
Car (your own)	MJ/l	35
Taxi / rental/ other's car	MJ/l	35
Motorcycle	MJ/l	35
Airplane	MJ/km	3.1

Table 9: Energy intensities of waste items

Item	Energy intensity MJ/kg
paper and paperboard	35
aluminum	250
other metal	60
glass	15
plastic	50

Table 10: Energy Intensities of goods

Item	Energy intensity MJ/kg
Clothes and textiles	
cotton	20
wool	20
synthetic	20
Furniture (wooden)	5
Furniture (plastic/metal)	60
Major appliances	150
Computers and electronic equipment	200
Small appliances	100
Durable paper products (books) and hygienic paper products (toilet/tissue paper)	35
Car parts for repair	100

Metal items, tools	60
Leather	20
Plastic products and photos	50
Porcelain, glass	15
Medicine	200
Hygiene products, cleaning stuff	40
Cigarettes, other tobacco products	125

Table 11: Energy intensities of services

Item	Unit	Energy intensity
Postal services		
international	MJ/kg	50
domestic	MJ/kg	10
Water, sewer, garbage service	MJ/$	12
Dry cleaning or external laundry service	MJ/$	6
Telephone	MJ/$	1
Medical insurance and services	MJ/$	4
Entertainment	MJ/$	6
Education	MJ/$	3

5.3 OTHER CONSTANTS

Other constants which are employed in the calculation methodology are listed in table 12 below:

Table 12: Other constants used in ecological footprint accounting.

Constants	
absorption rate [t C/ha/yr]:	0.73
Ocean uptake %	30%
Carbon intensity [t C/GJ]:	
coal	0.026
oil (avg. fossil fuel)	0.020
natural gas	0.015
Carbon absorption factor [m^2/MJ]:	
coal	0.25
oil (avg. fossil fuel)	0.19
natural gas	0.14
Pre-purchase food loss	1.13
Structural consumption	1.1
Total built area of goods and waste (m2/cap)	244

Total built area of services (m2/cap)	244
Good	1903
Services	1652
Waste	1283

Absorption rate is the annual absorption of carbon in tons per hectare of forest land and is taken as 0.73 t C/ha/yr. (Global Footprint Network, n.d.-d)

Ocean Uptake is taken as 30%. (for detail description see section 2.5.1)

Carbon intensity is the carbon released in tons per unit of energy in GJ. Carbon intensities of the three most common fossil fuels are mentioned in table 12 with natural gas having the lowest carbon intensity amongst others. The values for carbon intensities of three fossil fuels are taken from National Footprint and Biocapacity Accounts (Global Footprint Network, n.d.-d). Carbon absorption factors for all three fossil fuels are then calculated from carbon absorption rate, ocean uptake and carbon intensities.

Pre-purchased food loss is the waste food factor, FAO figures reveal that there is on average a 13 percent food loss after harvesting at the farm, transport, storage, wholesale, and processing levels.

structural consumption multiplier accounts for the energy consumed by government to purchase public goods and services. The structural consumption multiplier is taken as 10%. For more details see section 5.2.1.

6 ECOLOGICAL FOOTPRINT CALCULATOR

A comprehensive calculator on excel is created based on the six consumption categories. The calculation methodology is explained below:

The initial column pertains to the number of people living in a household. To accurately reflect the total consumption, users are required to specify the number of individuals within the household. If users are reporting only their personal consumption, they should indicate '1' to prevent an understated result, as the ecological footprint will otherwise be divided by the number of people, yielding a disproportionately low figure.

6.1 FOOD

Section for food category is shown in table 13 below:

Table 13: Food Category table

CATEGORIES	Units	AMOUNT (per month)	Eqv. Amount (per year)	CARBON	CROPLAND	GRAZING LAND	FOREST	BUILT-UP LAND	FISHERIES
Enter percentage of food purchased that is wasted rather than eaten in your household.									0%
How much of the food that you eat is processed, packaged, and not locally grown? (from more than 200 miles away) In percentage									0%

Veggies, potatoes & fruit	kg		0.0	0.0	0.0				
Bread and bakery products	kg		0.0	0.0	0.0				
Flour, rice, noodles, cereal products	kg		0.0	0.0	0.0				
Maize	kg		0.0	0.0	0.0				
Beans and other dried pulses	kg		0.0	0.0	0.0				
Milk, cream, yogurt, sour cream	liter		0.0	0.0	0.0	0.0			
Ice cream, other frozen dairy	liter		0.0	0.0	0.0	0.0			
Cheese, butter	liter		0.0	0.0	0.0	0.0			
Eggs [assumed to be 50 g each]	#		0.0	0.0	0.0				
Meat			0.0						
Pork	kg		0.0	0.0	0.0				
Chicken, turkey	kg		0.0	0.0	0.0				
Goat, Lamb	kg		0.0	0.0	0.0	0.0			
Beef	kg		0.0	0.0	0.0	0.0			
Fish	kg		0.0	0.0					0.0
Sugar	kg		0.0	0.0	0.0				
Vegetable oil (seed or olive oil)	liter		0.0	0.0	0.0				
Margarine	kg		0.0	0.0	0.0				
Coffee & tea	kg		0.0	0.0	0.0				
Juice & wine	liter		0.0	0.0	0.0				
Beer	liter		0.0	0.0	0.0				
Garden [area used for food]	m²		0.0		0.0				
Dining out	$		0.0	0.0	0.0	0.0			0.0
SUB-TOTAL-1				0.0	0.0	0.0	0.0	0.0	0.0

Users first must mention the percentage of food that is waste and the food which they are buying is processed, packaged, and not locally grown because in ecological footprint accounting the food which is unprocessed, not packaged and locally grown less than 200 miles has no ecological footprint.

This category comprises a listing of the 21 most common food items. Users are instructed to input their monthly consumption in the designated 'Amount' column, utilizing the specified units provided in the corresponding 'Unit' column.

Except for the sub-categories 'Eating Out' and 'Garden Area,' all sub-categories in the Food section should include only food being brought into the household from an outside source (i.e., not homegrown food).

All the land-use categories will be calculated according to the ecological footprint accounting methodology, explained below:

CARBON: Carbon component of the household footprint follows this formula:

(Carbon sequestration ratio) * (Energy intensity) * (Waste factor, if needed) * (Quantity in metric) * (Equivalence Factor: Carbon)

6.2 HOUSING

Housing section is shown below:

Table 14: Housing category table

CATEGORIES	Units	AMOUNT (per month)	Eqv. Amount (per year)	CARBON	CROPLAND	GRAZING LAND	FOREST	BUILT-UP LAND	FISHERIES
Residence									
House or apartment	m^2		0.0	0.0			0.0		
Current age of residence	years		0.0						
Total lot size including building	m^2		0.0					0.0	
Energy									
Electricity total	kwh		0.0						
Enter as fraction (eg 50% = 0.50)									
fossil fuels			0.0	0.0					
nuclear energy			0.0	0.0					
Renewable energy resources									
Large hydroelectric			0.0					0.0	
Small hydroelectric			0.0			0.0			
PV solar			0.0					0.0	
wind			0.0					0.0	
geothermal			0.0						
Natural gas	m^3		0.0	0.0					
Liquid petroleum gas (propane)	liter		0.0	0.0					
Firewood	kg		0.0				0.0		
Fuel oil, kerosene	liter		0.0	0.0					
Coal	kg		0.0	0.0					
SUB-TOTAL-2				0.0	0.0	0.0	0.0	0.0	0.0

In the first of residence the user must mention the area of their house or apartment in its respective unit. The formula for carbon is:

(Area in m^2) * (embodied energy/age of the residence) * (carbon sequestration factor) * (Equivalence Factor: Carbon)

The life-cycle embodied energy of a standard European house is 3-6 GJ/m2. Life expectancy of the house is 50-70 years. We take 6GJ/m2 with a life expectancy of 70 years.

Formula for forest:

(Area in m^2) * (footprint conversion factor for forest) * (23.6*2.2/150/age of the residence)

An average house uses 23.6 m3 of wood and is assumed to last 40 years (Government of Canada, 1991. The State of Canada's Environment. Ministry of Environment, Ottawa). The house is assumed to contain 150 m2 of living space. 2.6/10000 is the roundwood productivity, 2.2 is the ratio of roundwood needed per unit of construction wood. Another estimate from the Canadian Mortgage and Housing Corporation (OPTIMIZE, 1991) shows the use of over 50 m3 roundwood equivalent for a 350 m2 house.

In the energy sub-category user must mention their average monthly electricity consumption in Kwh, and in the next column mention how much percentage of electricity is coming from which source fossil fuel or renewable energy, because every renewable energy resource has different ecological impact on different land-use category.

6.3 TRANSPORTATION

This section contains the daily commuting means of an average habitant. The section is shown below in table 15:

Table 15: Transportation category table

CATEGORIES	Units	AMOUNT (per month)	Eqv. Amount (per year)	CARBON	CROPLAND	GRAZING LAND	FOREST	BUILT-UP LAND	FISHERIES
Bus, transit (around town)	km		0.0	0.0				0.00	
Bus, intercity (Greyhound)	km		0.0	0.0				0.00	
Train, transit (tram, light rail)	km		0.0	0.0				0.00	
Train, intercity	km		0.0	0.0				0.00	
Car (your own)	km		0.0	0.0				0.00	
average fuel efficiency	km/l		0.0						
Taxi / rental/ other's car	km		0.0	0.0				0.00	
average fuel efficiency	km/l		0.0						
Motorcycle	km		0.0	0.0				0.00	
average fuel efficiency	km/l		0.0						
Airplane	hrs		0.0	0.0					
(e)conomy, (b)usiness or (f)irst class									
SUB-TOTAL-3				0.0	0.0	0.0	0.0	0.00	0.0

The transportation means have ecological impacts on two categories carbon and built-up land. The formula for carbon is:

(Carbon sequestration ratio) * (Energy intensity) * (Quantity in metric) * (Equivalence Factor: Carbon)

For cars and motorcycles the sequestration factor will be multiplied by the fuel efficiency.

6.4 WASTE

In this section the household waste is divided into 5 sub-categories. Paper and paperboard, aluminum, glass, plastic, and other metal. The section is shown in table 16 below:

Table 16: Waste category table

CATEGORIES	Units	AMOUNT (per month)	Eqv. Amount (per year)	CARBON	CROPLAND	GRAZING LAND	FOREST	BUILT-UP LAND	FISHERIES	
Household waste:										Enter % recycled in your household:
paper and paperboard	kg		0.0	0.0			0.0	0.0		
aluminum	kg		0.0	0.0				0.0		
other metal	kg		0.0	0.0				0.0		
glass	kg		0.0	0.0				0.0		
plastic	kg		0.0	0.0				0.0		
SUB-TOTAL-4				0.0	0.0	0.0	0.0	0.0	0.0	

All the sub-categories have an impact on carbon and built-up land while paper also has an impact on forest land-use category.

Formula used for carbon is:

(Carbon sequestration ratio) * (Energy intensity) * (Quantity in metric) * (Equivalence Factor: Carbon) * (1-% recycled in the household*% of energy that be saved through recycling of different sub-category)

Formula used for forest only for paper and paperboards is:

(footprint conversion factor for forest/600) * 1.65 * (Quantity in metric) * (1-% recycled in the household*% of energy that can be saved through recycling of different sub-category)

For forest component of paper products 600 kg/m3 is the average wood density and 1.65 is the ratio of roundwood needed per unit of paper.

(1-% recycled in the household*% of energy that can be saved through recycling of different sub-category) in the formula calculates to what extent energy is recuperated. % recycled gives the percentage of recycling in the household. Percentage of energy that can be saved through recycling of different products is 45% (Hershkowitz Allen, 1997).

6.5 GOODS

This section contains 17 most common items that can be bought or used in an average household.

Goods section is shown in table 17 below:

Table 17: Goods category table

CATEGORIES	Units	AMOUNT (per month)	Eqv. Amount (per year)	CARBON	CROPLAND	GRAZING LAND	FOREST	BUILT-UP LAND	FISHERIES
Clothes and textiles									
cotton	kg		0.0	0.0	0.0			0.0	
wool	kg		0.0	0.0	0.0	0.0		0.0	
synthetic	kg		0.0	0.0				0.0	
Furniture (wooden)	kg		0.0	0.0			0.0	0.0	
Furniture (plastic/metal)	kg		0.0	0.0				0.0	
Major appliances	kg		0.0	0.0				0.0	
Computers and electronic equipment	kg		0.0	0.0				0.0	
Small appliances	kg		0.0	0.0				0.0	
Durable paper products (books) and hygenic paper products (toilet/tissue paper)	kg		0.0	0.0			0.0	0.0	
Car parts for repair	kg		0.0	0.0				0.0	
Metal items, tools	kg		0.0	0.0				0.0	
Leather	kg		0.0	0.0	0.0	0.0		0.0	
Plastic products and photos	kg		0.0	0.0				0.0	
Porcelain, glass	kg		0.0	0.0				0.0	
Medicine	kg		0.0	0.0				0.0	
Hygiene products, cleaning stuff	kg		0.0	0.0				0.0	
Cigarettes, other tobacco products	kg		0.0	0.0	0.0			0.0	
SUB-TOTAL-5				0.0	0.0	0.0	0.0	0.0	0.0

All the goods items have ecological impact on carbon and built-up land. Cotton, wool, leather, and tobacco products have impacts also on cropland. Wool and leather have an impact on grazing land as well. And wood products like furniture and durable paper products have an impact on forest too.

Carbon category follows formula:

(Carbon sequestration ratio) * (Energy intensity) * (Quantity in metric) * (Equivalence Factor: Carbon)

Cropland and grazing land follow:

(Quantity in metric) * (footprint conversion factor) * (pre-purchased food loss only for cropland)

6.6 SERVICES

The services section contains 8 common services which an average habitant uses. The table is shown below:

Table 18: Services category table

CATEGORIES	Units	AMOUNT (per month)	Eqv. Amount (per year)	CARBON	CROPLAND	GRAZING LAND	FOREST	BUILT-UP LAND	FISHERIES
Postal services									
international	kg		0.0	0.0				0.0	
domestic	kg		0.0	0.0				0.0	
Water, sewer, garbage service	$		0.0	0.0				0.0	
Dry cleaning or external laundry service	$		0.0	0.0				0.0	
Telephone	$		0.0	0.0				0.0	
Medical insurance and services	$		0.0	0.0				0.0	
Entertainment	$		0.0	0.0				0.0	
Education	$		0.0	0.0				0.0	
SUB-TOTAL-6				0.0	0.0	0.0	0.0	0.0	0.0

All services impact only carbon and built-up land categories. As for postal services, all the sub-categories must be mentioned in the amount spent in dollars $. For carbon formula is:

(Quantity in metric or amount spend in $) * (Carbon sequestration ratio) * (Energy intensity) * (Equivalence Factor: Carbon)

6.7 RESULTS

Upon inputting all requisite data into the designated columns, users will receive their outcomes presented in three distinct formats: ecological footprint measured in global hectares (Gha), personal overshoot day, and the no. of earths required if they persist in their current lifestyle practices. Additionally, users have the option to analyze their Consumption Land Use Matrix (CLUM), which provides a comprehensive breakdown of an individual's consumption footprint into its constituent elements.

7 APPLICATION OF THE TOOL

To illustrate the functionality of the tool and demonstrate how results are presented, I computed my ecological footprints by entering data aligned with my personal lifestyle choices.

The results of my ecological footprint are shown in figure 17 below:

ECOLOGICAL FOOTPRINT RESULTS

Total ecological footprint	40,946	Global square meter (m²)
Your ecological footprint is	4.1	Global hectare (Gha)
Your personal overshoot day is	143	th day of a year
	May 22	
No. of earths required	3	

Figure 17: Results of my ecological footprint

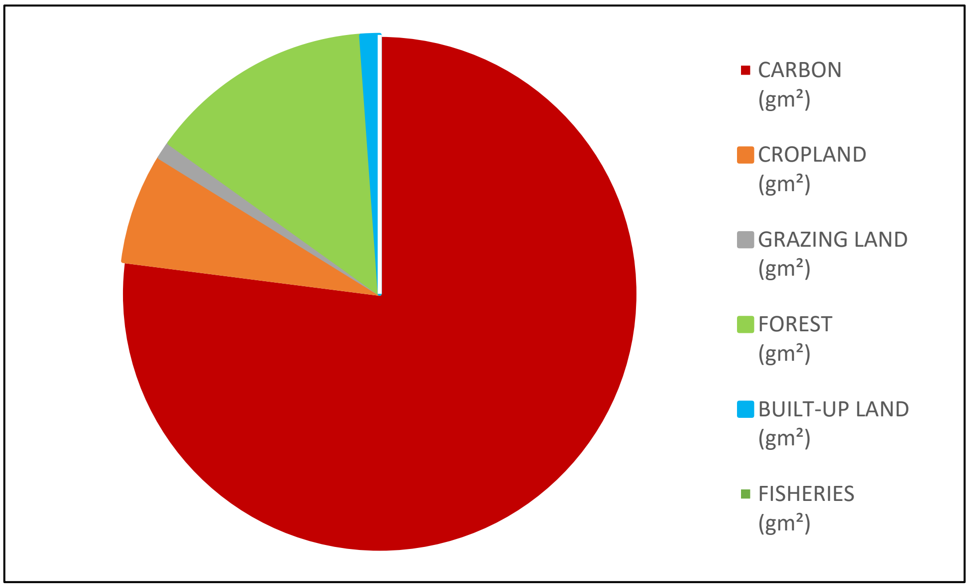

Figure 18: By land-use type

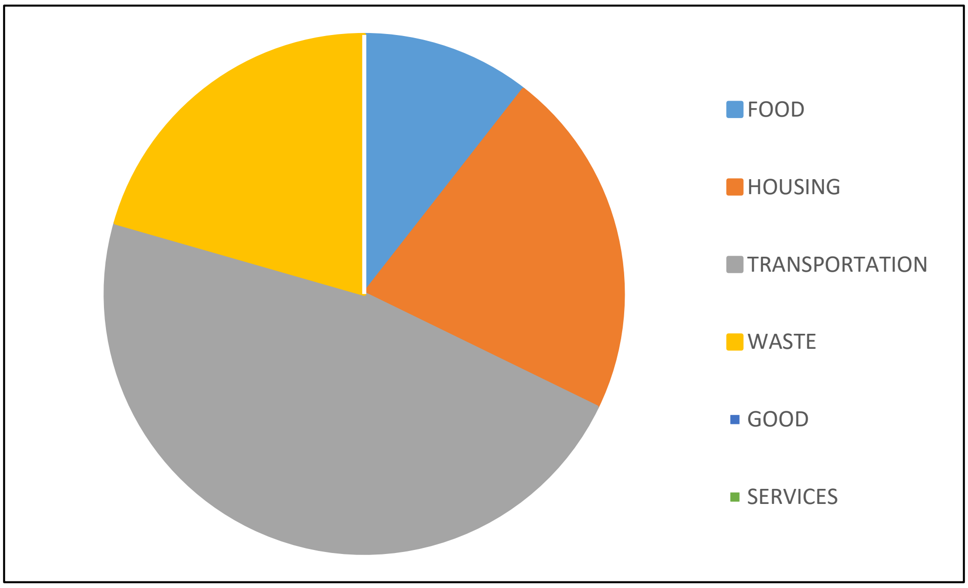

Figure 19: By consumption category

As illustrated in Figure 17, my ecological footprint is calculated to be 4.1 Global Hectares (Gha). Disappointingly, my personal overshoot day precedes the world's global overshoot day by almost three months, falling on the 22nd of May, while the world overshoot day is slated for the 2nd of August in 2023. Maintaining current habits would entail a demand for approximately three Earths. For a detailed breakdown of my ecological footprints based on land-use type and consumption category, please refer to Figures 18 and 19. Beyond doubt I must reconsider my living habits, specifically my transportation choices.

8 CONCLUSION

In a world marked by growing resource limitations, the importance of precise and efficient resource management systems cannot be overstated, especially for individuals, nations and cities aspiring to maintain their well-being.

The study aimed at developing an ecological footprint calculator in collaboration with Human srl which further will develop a web app which aims at increasing users' awareness and commitment towards reducing their environmental impacts.

Research initiates by establishing a comprehensive understanding of the ecological footprint. This indicator is a quantitative consumption-based measure of the ecological resources and services required to support a particular human population or activity. It assesses the demand placed on ecosystems and the Earth's natural resources, considering factors such as energy consumption, food production, transportation, and waste generation. A detailed examination of the ecological factors and resources that contribute to the footprint, such as carbon emissions, land use, biodiversity loss, water consumption, and the utilization of various materials is executed which is a critical part of this research.

An essential component of this research entails the acquisition and systematic analysis of appropriate data. All supporting data, encompassing equivalence factors, yield factors, conversion factors, and related parameters, are sourced from the Global Footprint Network. To facilitate user engagement and comprehension, a user-friendly calculator has been developed. Users are prompted to input data pertaining to their daily activities and consumption patterns. The resulting output is organized into three distinct categories:

1. Ecological Footprint in Global Hectares (Gha)
2. Personal Overshoot Day
3. Number of Earths Required to Sustain Their Daily Resource Consumption

The tool is thoughtfully segmented into six consumption use categories: namely, food, housing, transportation, waste, goods, and services. Corresponding subcategories aligned with these consumption classifications are thoughtfully delineated within their respective columns. Users are instructed to furnish their consumption data on a monthly or yearly basis, adhering to the specified units outlined in an adjacent column. The tool promptly computes and displays the outcomes within the designated ecological footprint indicators column through meticulous calculations. Additionally, users have the option to analyze their Consumption Land Use Matrix (CLUM), which provides a comprehensive breakdown of an individual's consumption footprint into its constituent elements, following the United Nations' COICOP (Classification of Individual Consumption by Purpose) classification.

The carbon indicator within the framework of ecological footprints holds utmost significance, primarily owing to its consistently dominant contribution, often exceeding 50% of the total ecological footprint. The prominence of the carbon indicator underscores the fundamental role of energy-related activities in influencing our ecological impact. It encompasses the greenhouse gas emissions stemming from sources such as the burning of fossil fuels for electricity generation, the operation of vehicles powered by conventional internal combustion engines.

The ecological footprint concept highlights the fact that human life is dependent on, and embedded in, nature and that consumption is indeed limited by nature's reproductive capacity. Realizing the resource limitations raises questions about how humankind is to consume resources in the future. If human consumption continues to exceed nature's capacity to regenerate, future generations will have even less "natural capital" available and will therefore be even more likely to erode the remaining stock as they meet their consumption needs. Therefore, life on earth can only be sustained within the limits of nature's dividends which can be measured by ecological footprint. In other words, ecological footprint demonstrates that excessive consumption today means reduces life-supported services for future generations.

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