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FOOD AND HEALTH.

Comparing environmental impacts for some fresh foods: a composition-related life cycle assessment.

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Table of Contents

List of tables

List of figures

Abbreviations and acronyms

LCA	Life cycle assessment
GHG	Greenhouse gas
GHGEs	Greenhouse gas emissions
MD	Mediterranean diet
CF	Carbon footprint
PCA	Principal Component Analysis
MUFAS	Monounsaturated fatty acids
PUFAS	Polyunsaturated fatty acids
ADP	Abiotic Resource Depletion
SHD	Sustainable Healthy Diet
CIQUAL	Nutritional composition table of foods in France
CVD	Cardiovascular disease

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Abstract

Both human and environmental health are impacted by the food that people eat. The biggest global and regional health burden is caused by imbalanced diets that are heavy in red and processed meat and low in fruits, vegetables, nuts, and whole grains. Food consumption has been shown to have a major impact on an individual's environmental impact, but there is less evidence to support the link between a food's function and its impact. To date, impact reductions have focused on food production processes, however eating patterns, the drivers behind production demand, need to also be understood. This paper aims to shed light on how to contribute to ongoing discussions about the need for dietary change by correlating the nutritional value of various foods with their potential contributions to climate change impact category. To achieve this aim, we examined the relation between nutrient content of 82 foods products and climate change expressed as kg CO_2 equivalents. This allowed us to determine the efficiency of nutrient content sustainability for different food groups, namely fruits group, vegetables group, legumes and cereals group, meat and fish group, and nuts and seeds group. As revealed by PCA analysis for fruit group, pumpkin, avocados, mango fruits, strawberries, kiwis, and pear are all sustainable sources of essential nutrients, including vitamin E, fat, vitamin E, calcium, vitamin C, and fiber respectively. The sustainable sources for vegetable group of vital nutrients like beta-carotene, iron, vitamin C, folate, vitamin D, niacin and include sweet potatoes, beetroot, parsley, carrots, sweet pepper, and garden peas respectively. Grain and legumes products indicated that, french bean, oat, millet, maize grain and sorghum have a balanced sustainable nutrient profile, with high levels of beta-carotene, protein, riboflavin, calcium, and carbohydrates, respectively. A variety of sustainable products is found in meat, poultry, and fish products. Mackerel, tuna, goat milk, cow milk, and sheep milk are high in essential nutrients, such as protein, beta-carotene, calcium, and selenium, respectively. According to PCA's analysis of nuts and seeds, Alfalfa seeds, flaxseeds, almonds, macadamia, sunflower seeds, and walnuts are appropriate for diets high in protein, thiamin, vitamin D, fat, vitamins B, and beta-carotene, respectively. Based on the ranking factor, foods that are high in macronutrients include maize grains, apples, sweet potatoes, almonds, and mackerel, respectively. The vitamins ranking factor yielded the following results: strawberries, sweet pepper, rice, chestnuts, and mackerel, respectively. Finally, foods with high sustainable mineral values were beetroot, strawberries, sorghum, goat milk, and flaxseed, respectively. Food's environmental impact should be considered alongside nutrient value and health concerns. Further research is needed to determine when the higher nutritional value of nutrient-dense foods outweighs their higher carbon footprint.

Keywords: Nutrient value, Sustainable food products, Sustainable healthy diets, global warming.

Chapter 1

1. Introduction.

1.1 Sustainability.

The term "sustainability" has become widely used in recent decades, spreading among countries, industries, and market actors. Similarly, "the term sustainability has become popular in policy-oriented research as an expression of what public policies ought to achieve." (Keeble, 1988). Although there are many definitions available on the topic of sustainability and sustainable development, the origin of the concept dates to 1987 (Cassen, 1987). The World Commission on Environment and Development published the Brundtland report, Our Common Future, which defined the concept of sustainability. The concept of sustainability in this document is based on the conflict between human aspirations for better living conditions and the constant pursuit of growth on the one hand and limited natural resources on the other. Accordingly, sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Cassen, 1987). Therefore, sustainability in its true form simultaneously connects economic aspects, environment, and social well-being (Basiago, 1998; Clune & Zehnder, 2018). These three aspects are called pillars of sustainable development (Gibson, 2009; Hansmann et al., 2012; Purvis et al., 2019). But we can also meet with labelling such as “dimensions” (Bocken et al., 2015; Chiesa et al., 1999;), “components” (Ioana et al., 2016), “aspects “(Azapagic & Perdan, 2000; Peruzzini & Pellicciari, 2018) and other similar terms.

1.2 life cycle assessment

Life cycle assessment is a technique for estimating product-related environmental aspects and impacts (ISO, 2006b). LCA assesses each impact associated with all stages of a process from cradle-to-grave (i.e., from raw materials through materials processing, manufacture, distribution, use, repair, maintenance, and disposal or recycling (ISO,2006b). Life-cycle assessment (LCA) also deals with the environmental impact of product systems (Swarr et al., 2011). It considers the life cycle of a product from resource extraction to waste disposal. LCA starts from a definition of the so-called functional unit of product (Wernet et al., 2016). In the inventory analysis, the releases and resource extractions that occur because of the production of 1 extra functional unit of product are obtained. In a subsequent impact assessment, the additional impact of these emissions and extractions is quantified (Wernet et al., 2016). This step is known as life-cycle impact assessment. Many environmental sustainability measures include the use of land, water, and energy resources, biodiversity, and ecosystem protection (Wernet et al., 2016).

1.3 Impact Characterization (at midpoint).

This section provides details for some impact categories.

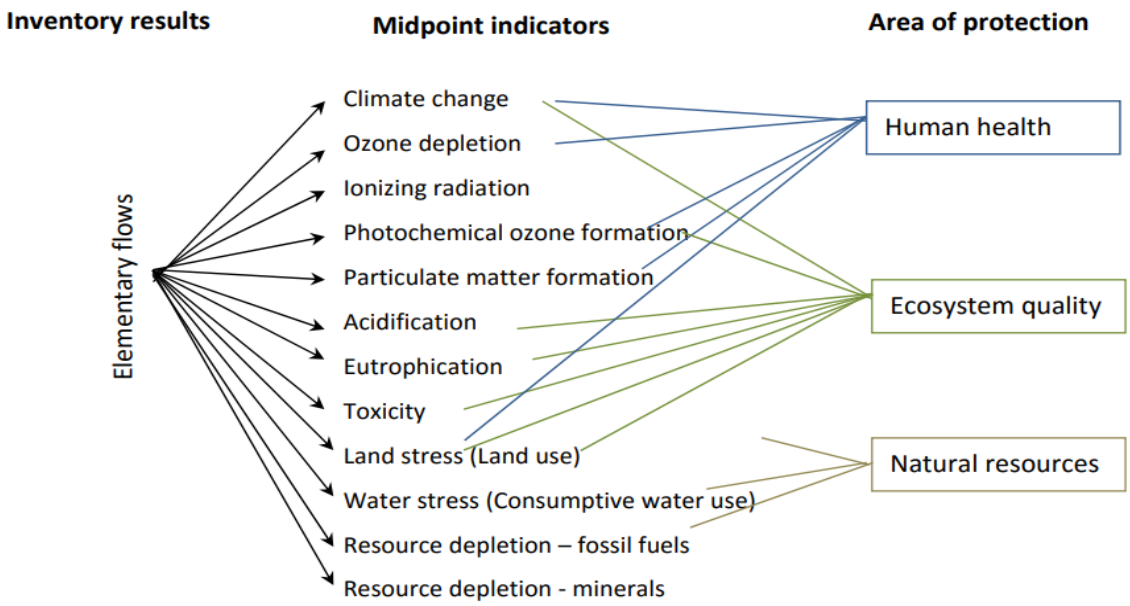

Figure 1. Framework of mid-point and end-point indicators commonly considered in LCA (based on impact pathways described in the LC- Impact method (Huijbregts et al., 2016).

1.3.1 Climate Change

The impact category of 'climate change' (also known as Global Warming) quantifies the effects of human activity on the climate (IPCC, 2013). The primary impact pathway for human-induced (i.e. anthropogenic) climate change is the release of greenhouse gases (GHGs) into the atmosphere (IPCC, 2013). Although climate can also be affected by release of aerosols or black carbon (soot), altering of the surface albedo or changes to cloud cover, LCA studies rarely include climate impacts other than those due to GHG emissions. The GHGs of most importance, and most commonly accounted for, are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (IPCC, 2013). Various hydrocarbon GHGs are also included when data are available. Human activities can impact climate by absorbing carbon dioxide into biomass and soils, countering the global warming effect (IPCC, 2013).

The anthropogenic release of GHGs leads to accumulation of these compounds in the atmosphere, increasing the rate at which energy from the sun is absorbed in the atmosphere and re-emitted as heat. According to the Intergovernmental Panel on Climate Change's (IPCC)

Fifth Assessment Report, the atmospheric concentration of CO_2 has increased by 40%, and the average temperature has increased by approximately 0.85°C between 1880 and 2012 (IPCC, 2013). Rising global temperature generates several flow-on effects, such as melting of glaciers and polar ice, sea level rise due to expansion of water in the oceans, changed rainfall patterns causing droughts and flooding, increased incidence of cyclones and other extreme weather events, disruption to ecosystem functions, heat stress in humans and livestock, and ultimately damage to human health and infrastructure, and damage to ecosystems and loss of biodiversity (figure 2). The areas of protection that climate change relates to are Human Health and Ecosystem Quality (figure 1) (IPCC, 2013).

The primary source of GHG emissions is fossil fuel combustion, which is linked to nearly all human activities. It is especially important for electricity and heat generation, transportation, agriculture, and mining. As a result, climate change has an impact on all sectors. Furthermore, climate change is recognized as a critical issue for society, it is the most assessed impact category in LCAs (IPCC, 2013).

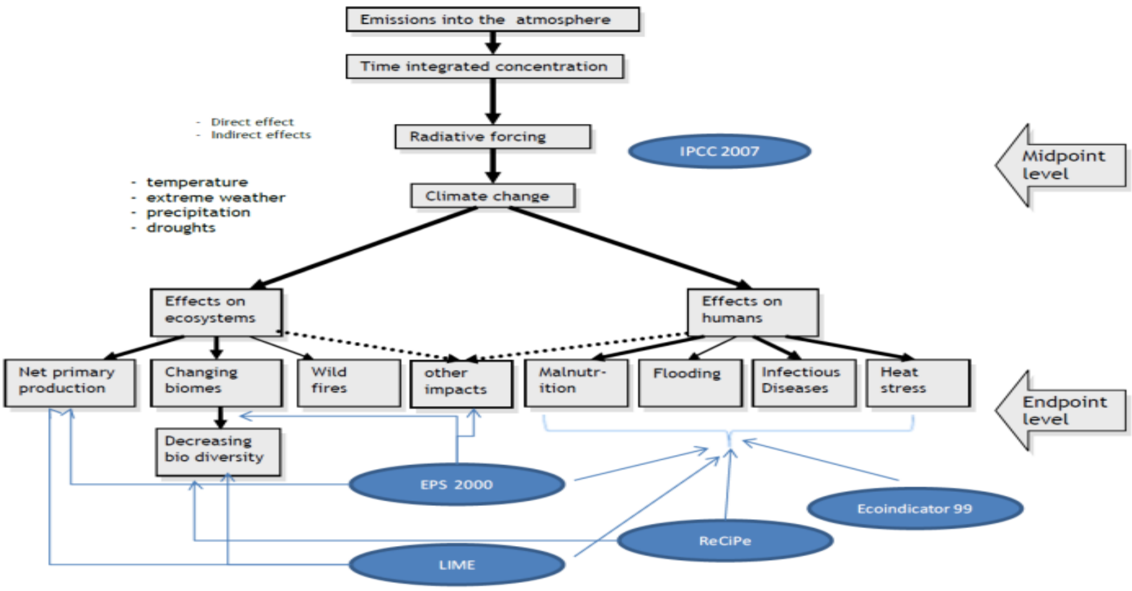

Figure 2. Impact pathways for climate change. Taken from ILCD Handbook (EC-JRC, 2011).

1.3.2 Resource depletion (fossil and mineral).

The impact category of "resource depletion," also known as "abiotic depletion," describes the depletion of natural resources on Earth (EC-JRC, 2011). This is typically divided into biotic and abiotic resources. Biotic resources are not covered here; instead, they are addressed under land use, where biotic resources are produced, or biodiversity, where biotic resources are damaged (EC-JRC, 2011). This leaves abiotic resources, which can be separated into minerals and fuels or minerals and fossil fuels (depending on perspective on nuclear fuels). Therefore, these aspects of resource depletion can be referred to as ‘Abiotic Resource Depletion (ADP)” (Heijungs et al., 1997).

1.3.3 Water scarcity.

Consumptive water use is the abstraction of water that is no longer available for other uses because it has evaporated, transpired, been incorporated into products and crops, or consumed by humans or livestock. The water scarcity that it can cause is a problem of international concern (Uhlenbrook & Connor, 2019). Globally, water use has been increasing at more than twice the rate of population growth (Vorosmarty et al., 2000), and most withdrawals are in watersheds already experiencing water stress (Ridoutt and Pfister, 2010). The problem is so severe that planetary environmental boundaries for freshwater use have been proposed to prevent irreversible environmental change (Rockström et al., 2009). The demand for everyday goods and services that use water in their production creates pressure on global freshwater resources (Ridoutt and Pfister, 2010). The interconnected nature of global economic systems means that water abstraction can occur far from where final consumption occurs. Solutions must be more than improving local water resource management to include sustainable consumption and production (Rockström et al., 2009). A local initiative to reduce water use can shift the burden to another location where production increases to meet demand, resulting in an overall exacerbation of water stress (Huang et al., 2013). The areas of protection that water use relates to are Human Health, Environmental Quality and Natural Resources (figure 1).

1.3.4 Eutrophication.

Eutrophication is an important impact category for processes involving the use or mobilization of nutrients (agricultural cropping and pastures) or the disposal of wastes with a high organic compound content (livestock production, food processing, pulping, urban solid waste and wastewater treatment and disposal (figure 3) (EC-JRC, 2011).

The impact category of ‘eutrophication’ characterizes the atrophying impacts when macro-nutrients are released to air, water, and soil (Yang et al., 2008). The macro-nutrients most accounted for are nitrogen (N), phosphorous (P) and organic compounds (BOD_2) (Andersen et al., 2004). Eutrophication (also known as nutrification) can occur in aquatic and terrestrial environments, but the former is more commonly a problem (Chislock et al., 2013). When macro-nutrients find their way to water (aquatic eutrophication) it can lead to accelerated algae growth, reduced sunlight infiltration and oxygen depletion, which can ultimately lead to changes in species composition (Chislock et al., 2013). Releases to land (terrestrial eutrophication) can increase susceptibility of plants to diseases and pests potentially also leading to changes in species composition, for example encouraging weeds (EC-JRC, 2011). The end-point area of protection that it relates to is Ecosystem Quality. However, fuel combustion (for electricity and transport) and other processes that release nitrogen compounds into the air (e.g., nitrogen oxides from fuel combustion, volatilization of ammonia from fertilizer and manure, etc.), also contribute to eutrophication. So, it is relevant to most production systems. The end-point area of protection that it relates to is the Ecosystem Quality (figure 1) (EC-JRC, 2011).

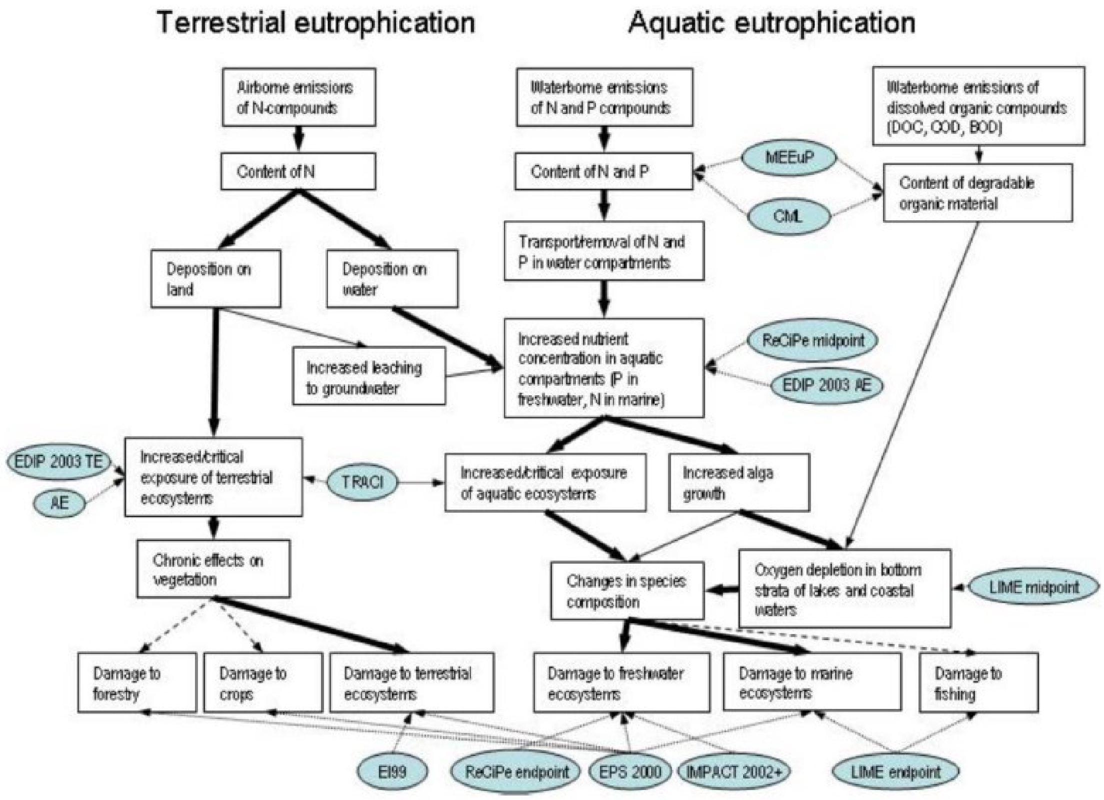

Figure 3. Impact pathways for eutrophication. Taken from ILCD Handbook (EC-JRC, 2011).

1.3.5 Acidification.

The impact category of 'acidification' quantifies the acidifying impacts when acid precursor compounds are released to air and subsequently deposited on land or water. The substances most accounted for are nitrogen oxides (NOx), sulphur oxides (SOx), sulphuric acid and ammonia (Bouwman et al., 2002). When these are emitted to air, they react with moisture in the atmosphere to form acidic compounds (such as nitric acid, sulphuric acid, etc.), and subsequently deposit in terrestrial and aquatic environments (figure 4). When acidic compounds deposit on land (terrestrial acidification) it can reduce soil pH (making it acidic) which leads to a decline in richness of vascular plants (Huijbregts et al., 2014).

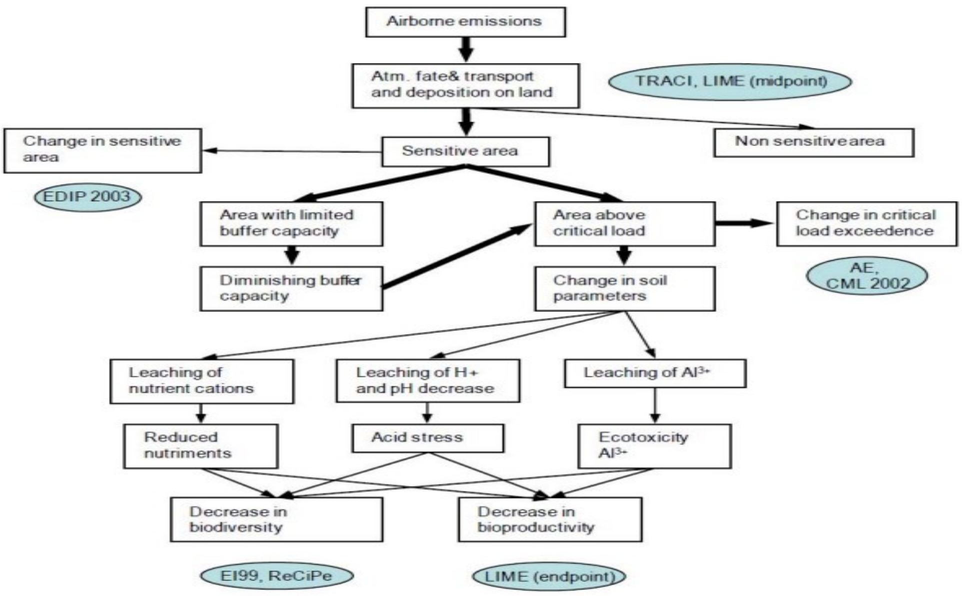

Figure 4. Impact pathways for acidification. Taken from ILCD Handbook (EC-JRC, 2011).

1.4 Sustainable Development Goals (SDGs).

The SDGs were established in 2015 by the United Nations General Assembly as part of the Post-2015 Development Agenda (Biermann et al., 2017b). This agenda sought to design a new global development framework, replacing the Millennium Development Goals, which were completed that very year (Biermann et al., 2017b). These goals were formally articulated and adopted in a UNGA resolution known as the 2030 Agenda, often informally referred to as Agenda 2030.

The Sustainable Development Goals (SDGs), or Global Goals, are a collection of seventeen interconnected objectives designed to serve as a "shared blueprint for peace and prosperity for people and the planet, now and in the future" (Salvia et al., 2019c). The short titles of the 17 SDGs are: No poverty, Zero hunger, Good health and well-being, Quality education, Gender equality, Clean water and sanitation, Affordable and clean energy, Decent work and economic growth, Industry, innovation and infrastructure, Reduced inequalities, Sustainable cities and communities, Responsible consumption and production, Climate action, Life below water, Life on land, Peace, justice, and strong institutions, and Partnerships for the goals (figure 5) (United Nations, 2017).

Figure 5. Sustainable development goals (United Nations, 2017).

1.5 Sustainability of healthy diets.

Discourse on the relationship between food production, healthy eating and sustainability has become increasingly prominent and controversial in recent years (Davies et al., 2023). Many research groups report on sustainable diets without considering cultural acceptability, nutritional requirements, and long-term dietary change efficiency (Aleksandrowicz et al., 2016; British Dietetic Association, 2021; Davies et al., 2023).

1.5.1 Sustainable healthy diets definition.

Sustainable healthy diets, according to Harrison et al. (2022) are dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; and what is culturally acceptable, accessible, or affordable will vary for people around the world (figure 6). Sustainable healthy diets aim to achieve optimal growth and development of all individuals; support functioning and physical, mental, and social wellbeing at all life stages for present and future generations; contribute to preventing all forms of malnutrition; (i.e. undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet related NCDs; and support the preservation of biodiversity and planetary health. Sustainable healthy diets must combine all the dimensions of sustainability to avoid unintended consequences (Harrison et al., 2022).

Figure 6. Guiding principles for sustainable healthy diets (FAO & WHO, 2019).

1.5.2 Illustration of a sustainable diet.

For quantifying a food's green gashouse (GHG), Life cycle assessments (LCA) are used to estimate the environmental impact of different food products (ISO, 2006b). The environmental impact of every stage of food production is assessed and summed up to estimate all associated emissions generated throughout all stages of the food system (ISO, 2006b; Röös et al., 2017). GHGE varies greatly between foods depending on their type and method of production. Furthermore, it is generally agreed that certain foods have greater environmental impacts than others, regardless of variations in GHGE within foods and food groups (Lune et al., 2017; Poore & Nemecek, 2019). For instance, enteric fermentation, a unique food digestion process used by ruminant animals like cattle and sheep, causes the animals to release methane into the atmosphere and raises the GHG of beef and mutton (Itjen & Beckett, 1996). Dairy products (milk, cheese, and yogurt) are by-products of ruminants, but because production can continue for longer periods of time without experiencing the same high turnover, their GHG emissions are moderate (Lune et al., 2017; Poore & Nemecek, 2019). Smaller, monogastric animals—like fish, pork, or poultry—produce significantly less greenhouse gas emissions but have a higher to moderate environmental impact than ruminant animals (Lune et al., 2017; Poore & Nemecek, 2019). On the other hand, low to moderate GHGE is produced by plant-based foods like fruits, vegetables, legumes, and whole grains (Lune et al., 2017; Poore & Nemecek, 2019).

1.5.3 LCA role on GHGE diet impact.

Data from LCA can be used to quantify how dietary choices and modifications impact GHGE. One of the earliest studies by Audsley et al., (2009) proposed that dietary substitutions can reduce GHGE. Out of the eight dietary scenarios that were suggested, four of them included less or no meat and had the potential to lower GHGE by as much as 20%. (Audsley et al., 2009). Comparable results are reported in similar UK publications (Berners-Lee et al., 2012; Macdiarmid et al., 2012). There is general agreement from recent research that cutting back on meat and dairy would significantly lower diet-related GHGE (Aleksandrowicz et al., 2016; Kim et al. 2020; Mazac et al., 2023; Van Dooren et al., 2017; Willett et al., 2019). A study by Kim et al. (2020) estimates that eliminating meat and dairy from the diet can reduce GHGE by up to 40%–50%. Despite benefits on environmental impact, meat and dairy are large contributors to essential nutrients (Mensink et al., 2013). From figure 7, plant-based foods such as vegetables, fruits and legumes are often central components of a healthy diet and are critical components of a lower-GHGE diet (Clarck et al., 2019). An index proposed by Van Dooren et al. (2017) found that there was a positive correlation between energy density and GHGE and a negative correlation between nutrient density and GHGE. According to the Sustainable Nutrient Rich Food Index (SNRF index), numerous foods high in nutrients, like the plant-based foods, have been found to have a higher environmental impact (Van Dooren et al., 2017). Energy dense foods such as sweets/confectionary, fats and spreads, and savoury snacks tend to have moderate GHGE, a low nutrient density and are associated with poor health outcomes (Clark et al., 2019; Van Dooren et al. 2017). Few recommendations exist for substituting animal-derived foods to create a more sustainable and healthful diet, even though numerous studies show that lowering the amount of food derived from animals can lower diet-related GHGE (Davies et al., 2023).

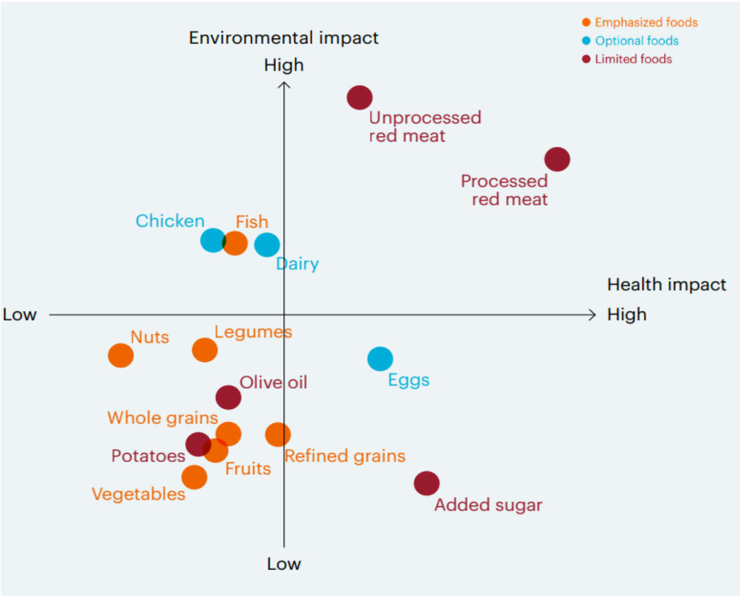

Figure 7. Health and environmental impacts of various foods (Clarck et al. 2019).

Even though the evidence base for sustainable healthy diets is still being developed, many health councils agree that we should move toward diets with fewer animal products and more plant-based foods (Ministers, (2014). All this evidence was gathered by the EAT-Lancet Commission on Food, Planet, Health and proposed scientific targets for healthy diets and sustainable food systems (Willett et al., 2019). They concluded that achieving healthy diets from sustainable food systems for 10 billion people by 2050 is possible, but only through an unprecedented global transformation of the food system that includes a major decrease of animal source foods in nations where they are overconsumed, cutting down on food loss and waste, and altering the way food is produced (Willett et al., 2019).

1.5.4 The outcomes of adopting a more sustainable diet.

According to the United Nations and nutrition and environment experts, to address the myriad environmental, social, and health challenges both caused by and affecting food systems, a shift towards healthy and environmentally responsible dietary patterns is needed within global populations (Aleksandrowicz et al., 2016; Gil et al., 2014; Soret et al., 2014b; Tilman & Clark, 2014b; Van Dooren et al., 2014; Willett et al., 2019). Trends in global food demand are estimated to increase by 100-110% by 2050 to keep up with predicted population growth and shifting consumption toward more animal products associated with increased wealth (Tilman et al., 2011). Increased demand for crops could require one billion additional hectares of land cleared and emit greenhouse gas (GHG) equivalent levels exceeding three gigatons per year if land continues to be cleared in poor nations for agricultural expansion by rich nations (Tilman et al., 2011). Reducing agricultural crop demand through sustainable dietary practices could reduce land clearing, water use, and associated species extinctions (Tilman & Clark, 2014b). Sustainable diets can offer health benefits while lowering global GHG emissions and excess nitrogen pollution in the environment (Tilman & Clark, 2014b; Willett et al., 2019). Diets, the environment, and health are tightly linked, presenting a global challenge as well as an opportunity for improvements in environment and public health (Tilman & Clark, 2014b).

Lower GHGE diets have been shown in prior research to be protective against premature deaths, which are mainly caused by chronic conditions like cardiovascular disease (CVD), type 2 diabetes mellitus (T2DM), colorectal cancer, and other cancers (Biesbroek et al., 2014; Hallström et al., 2017; Springmann et al., 2020b).

According to a secondary analysis of two large cohorts of plant-based eaters (EPIC-Oxford and Adventist Health Study-2), In comparison to traditional omnivore diets, plant-based diets have a lower incidence of obesity, hypertension, CVD, T2DM, and all-cause mortality (Segovia-Siapco & Sabaté, 2018). Recent data from the UK Biobank revealed that consuming less meat was linked to a lower risk of cancer and a lower level of inflammatory markers (Papier et al., 2022; Watling et al., 2022). It's possible that individuals who consume a higher proportion of plant-based foods have a lower risk of disease due to a well-balanced intake of both plant- and animal-based foods (Boushey et al., 2020). A study by Bergeron et al., (2019) discovered that lower LDL and total cholesterol in non-meat groups compared to red meat groups independent of saturated fat intake. These results would be consistent with the protective effect of plant-based diets, as opposed to diets that exclude any specific food group. If foods derived from animals are eliminated from the diet, nutrient deficiencies may develop that lead to poor health (Bakaloudi et al., 2021; Neufingerl et al., 2021). Parellel to this, a large body of work has emerged on the environmental impacts of various diets, with most studies concluding that a diet rich in healthy plant-based foods and with fewer animal source foods confers both improved health and environmental benefits like the Mediterranean diet (Serra-Majem et al., 2020b). Mediterranean diet is, in fact, rich in plant-based foods (cereals, fruits, vegetables, legumes, tree nuts, seeds and olives) with moderate-to-high consumption of fish and seafood, moderate consumption of eggs, poultry and dairy products (cheese, milk and yoghurt) and low consumption of red meat, with extra-virgin olive oil used as the principal source of added fat (Serra-Majem et al., 2020b). The Mediterranean diet (MD) could play an important role in EU climate targets, as it is recognized as a healthy dietary pattern (Herforth et al., 2019;

Springmann et al., 2020b; Trichopoulou et al., 2014;) that contributes to environmental (Springmann et al. 2020b) social and cultural services (Bach-Faig et al., 2011; Serra-Majem et al., 2020b). The promotion of fruits, vegetables, grains, and legumes is supported by these findings in that they can satisfy dietary requirements and may have a less negative effect on the environment than food items derived from animals.

1.5.5 Actions for the implementation of Sustainable Healthy Diets.

FAO and WHO, (2019) has conducted the following actions in food system that are required to make Sustainable Healthy Diets (SHD) available, affordable, safe, and desirable:

1. Establish an enabling environment through government mechanisms, incentives, and disincentives; legal frameworks; and regulatory instruments to promote the production, processing, distribution, labelling and marketing, and consumption of a variety of foods that contribute to Sustainable Healthy Diets.
2. Guarantee policy coherence by aligning policies across all sectors (agriculture, health, education, environment, water, trade, etc.) from local to national to international level and discussing with all actors of society.
3. Create a representative baseline of current diets, when needed conducting individual dietary assessment by age, gender, income, ethnic group, and geography. Use these data to identify which shifts in diet could potentially have the greatest positive impact on both health and environment.
4. Determine, in any given context, which foods are available and accessible in terms of quantity and quality and where and why mismatches in food supply and demand exist.
5. Evaluate existing food systems to identify potential changes needed to encourage the production, processing, packaging, storage, distribution, marketing and retailing, and consumption of a diversity of foods needed for Sustainable Healthy Diets.
6. Quantify and balance the potential trade-offs to make Sustainable Healthy Diets available, accessible, affordable, safe, and appealing for all.
7. Verify that affordable and desirable foods for a Sustainable Healthy Diet are available and accessible for the most vulnerable. Address inequities and inequalities and consider the perspective of people who experience poverty and deprivation.
8. Build national food-based dietary guidelines that define context-specific Sustainable Healthy Diets by considering the social, cultural, economic, ecological, and environmental circumstances.

9. Advocate capacity development strategies for behavior change, including consumer empowerment, and effective food and nutrition education.

Chapter 2

2. Aim and objectives of the study.

In recent years, there has been an increase in discussion and debate about the relationship between food production, healthy eating, and sustainability. Many studies on sustainable diets do not consider cultural acceptability, nutritional requirements, or long-term dietary change efficiency. This paper seeks to shed light on how to contribute to ongoing discussions about the need for dietary change by comparing the nutritional value of various foods to their potential to the climate change impact category. We investigated the relationship between the nutrient content of 82 food products and climate change. This enabled us to assess the efficiency of nutrient content sustainability for various food groups, including fruits, vegetables, legumes and cereals, meat and fish, and nuts and seeds. The study aims to:

- Analyze nutrient composition of different food groups and identify dietary patterns that promote sustainability.
- Assess the environmental impact of these food product patterns, particularly greenhouse gas emissions.
- Evaluate the sustainability of plant-based and animal-based food products in terms of their impact on carbon reduction.
- Provide recommendations for promoting sustainable dietary practices that are both nutritious and environmentally friendly.

Overall, this paper aims to contribute to the growing research body on sustainable diets by providing evidence-based insights that can inform policy, guide consumer choices, and support the transition to more sustainable food systems.

Chapter 3

3. Materials and methods.

This study considers one impact category and nutritional value of different food products. Carbon footprint is the main footprint included to estimate the environmental impact and to classify the sustainability of agriculture products. The nutrient content for 82 food products focused on protein, fat, carbohydrate, energy, water soluble vitamins, fat soluble vitamins, microminerals and microminerals, used for comparison with the emitted energy and to understand the chemical composition balance between clusters of agriculture food products. To compare and evaluate the weight of each single product, a stable unit of measure based on a kilogram of the food product is chosen.

3.1 Carbon footprint.

The CF measures the total amount of GHG emissions, both directly (on-site) and indirectly (off-site), caused by an activity or accumulated during the production and supply chain. The total amount of greenhouse gas emissions is expressed in the mass unit and not converted into an area unit for several reasons; one of the most important reasons is because the conversion needs many assumptions that give an estimation value with a high variability of error (Galli et al., 2012). GHG emissions identified by the Kyoto Protocol are evaluated in a single value expressed in kilograms of carbon dioxide equivalent per kilogram of the product according to the ISO 14067, as mentioned in the introduction. The mass unit of global warming effect refers to CO_2 because it is the most important GHG affecting global warming. Concerning global warming, the CH_4, N_2O, HFC, PFC, and SF_6 are normalized from their global warming potentials according to the United Nations Framework of Convention on Climate Change (IPCC, 2013). The CF value supplies an additional environmental meaning to the product, adopted by corporations to improve a sustainable consumer's awareness, according to the increasingly recognized global warming issue (Galli et al., 2012). The Carbon Footprint is the most used environmental indicator evaluating environmental performance and climate change. Currently, there is an increasing interest in comparing the environmental impact through multiple indicators. The unit of measure (functional unit) is the kg of CO_2eq per kg of product.

3.2 Food nutritional content.

Using a complete free-access food composition database provided by CIQUAL database, the national nutritional database (ANSES, 2023), we determined all the nutritional content per kg of 82 food products. They are divided into five groups as follows: fruits group (n=24), vegetables group (n=18), grains and legumes group (n=12), meat, poultry, and fish group (n=15) and the last group was for nuts and seeds (n=13). These 82 food products are selected due to their representability of the main global diet. These products represent 70% of the primary standard agricultural commodities for food consumption and transformation (FAOSTAT). No derivation of vegetal or animal foods is considered, except eggs and milk. These last food products are chosen because they are not processed goods, and the impact is directly due to farm production. The foods numbers that were selected from CIQUAL database ranged from 12 to 24 foods. CIQUAL nutrient composition data were used to derive the nutritional indicators for foods, and food groups.

3.3 Clustering and classification comparing different nutritional values with climate change.

Climate change environmental impact category values for 82 fresh foods were developed and provided by Agribalyase database V 3.1 (October 2022). Agribalyase provides reference data on 2,500 food products consumed in France (including imported products) based on the Life Cycle Assessment (LCA) method. Co-piloted by ADEME and INRAE, relying on the collaboration of agricultural and agrifood technical institutes, the AGRIBALYSE program has existed for over 10 years (Auberger et al., 2022). AGRIBALYSE is providing LCIs for 2500 food items registered in CIQUAL, the national nutritional database (ANSES, 2023), with similar ID number and boundaries, enabling consistent connections between nutritional and environmental properties. One of the main purposes of the AGRIBALYSE® program is to provide data useful for professionals in the agricultural and agrifood sectors (agricultural profession, agrifood industry, mass distribution) and final consumers.

A per-kg analysis done in the life cycle inventories does not represent a proper account of actual human nutrition needs emissions. Thus, the nutritional contents of foods which satisfy the human diet should be introduced. Here, we concentrate on protein, fat, carbohydrate, and energy, water soluble vitamins, fat soluble vitamins, microminerals and microminerals which are essential contributors to good nutrition. Then, we could correlate this with the climate change emissions obtained in the Agribalyase database V 3.1 (October 2022).

3.4 Ranking factor

A ranking factor is used to create the classification pattern. The ranking factor assigns a degree of sustainability to the food products based on their nutrient content in relation to climate change. The ranking factor assigns a degree of sustainability to the food products based on their nutrient content in relation to climate change. As indicated by equation, the Ranking Factor (RF) is the fraction of the nutrient content ratios and the climate change indicators.

- RF macronutrients = (log (protein value + carbohydrate value + fat value)/ log (carbon footprint)) = (g.kg + g.kg + g.kg)/(kgco_2eq).
- RF vitamins = (log (fat soluble vitamins value + water soluble vitamins value)/ (log (carbon footprint)) = (g.kg + g.kg)/(kgco_2eq).
- RF minerals = (log (macro-minerals value+ microminerals value)/ log (carbon footprint)) = (g.kg + g.kg)/(kgco_2eq).

3.5 Data analysis.

Data collection and preliminary processing have been performed with Microsoft Excel (v. 2112). A series of Excel tables has been constructed to select and order data in preparation for statistical analysis.

3.5.1 Principal Component Analysis (PCA).

The Principal Component Analysis (PCA) is a statistical test based on factor analysis. Principal Component Analysis (PCA) was applied on natives and indexes separately to understand which variable features were the most effective features. It has been decided to proceed with the PCA because it is a statistical procedure that allows us to summarize of the information contained in large data tables by means of a smaller set of “summary indices” that could be more easily visualized and analyzed (Granato et al., 2018).

Chapter 4

4. Results.

4.1 Principal Component Analysis (PCA).

Principal Component Analysis (PCA) was used to assess the relationships between the fruits and vegetables group, the grains and legumes group, the meat, poultry, and fish group, and the nuts and seeds group in terms of sustainable nutrient content. The score plot reveals each group product's position in respect to the principal components, whereas the loading plot shows each nutrient's contribution to the principal components. The score plot presents PCA food product sustainability, and the points represent all food product names. Meanwhile, the loading plot presents PCA nutrient content sustainability, and the points represent all nutrient content sustainability names.

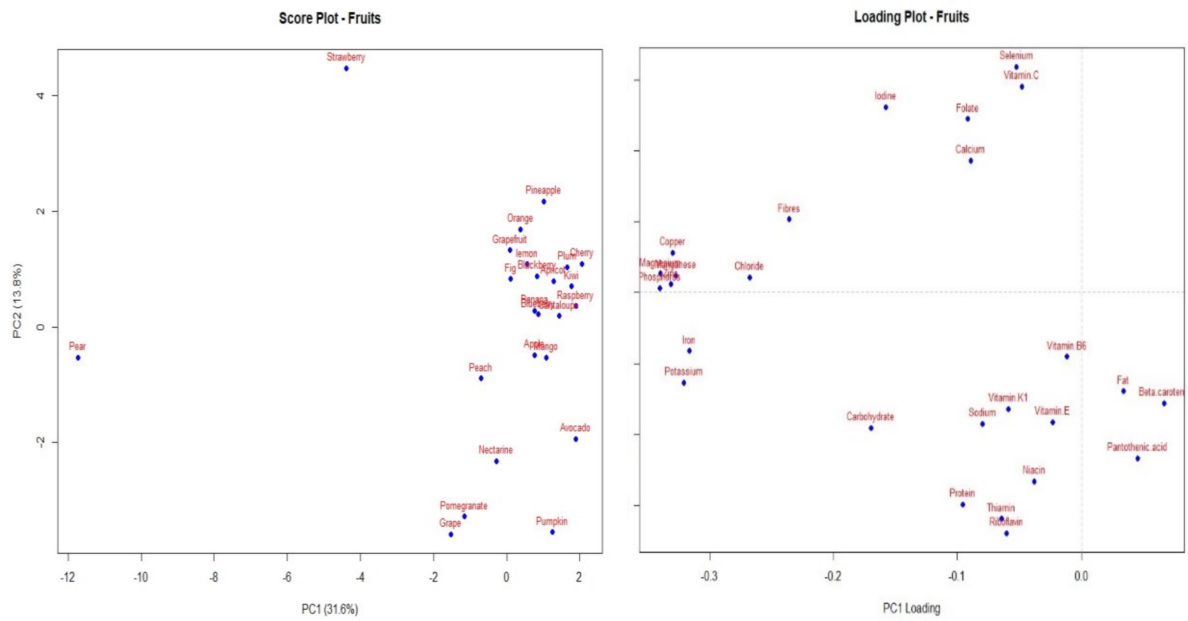

Figure 8. The score plot presents PCA fruit group scores distributed according to dimension one, the horizontal axis, and dimension two, the vertical axis. The points represent all the fruit group products names. Numbers 31.6% and 13.8% represent the portion of total variance explained by the first and the second PCA dimensions. The loading plot presents PCA nutrient content sustainability. The points represent all nutrient content sustainability names.

To evaluate the correlations between fruit products and nutrient content sustainability, principal component analysis (PCA) was carried out Figure (8). The PCA model identified two principal components that together account for 45.45% of the total variance within the dataset, with PC1 explaining 31.62% and PC2 explaining 13.83%. As revealed by the combined interpretation of the loading and score plots, different fruit products have distinct nutrient content sustainability. Pumpkin is considered as a sustainable source of vitamin E, beta-carotene, and riboflavin. Grapes are rich in carbohydrates and thiamin. Notably, kiwi can be considered as a sustainable source of vitamin C. The pear stands out as a sustainable fruit that is high in fiber, manganese, magnesium, copper, iron, and phosphorus. The score plot indicates that Strawberry has a higher sustainable content of folate, selenium, and calcium. Notably, one sustainable source of fat is avocado fruits. Peaches also show a good sustainable concentration of selenium, iodine, and potassium. Mango fruits can be regarded as a good source of vitamin E.

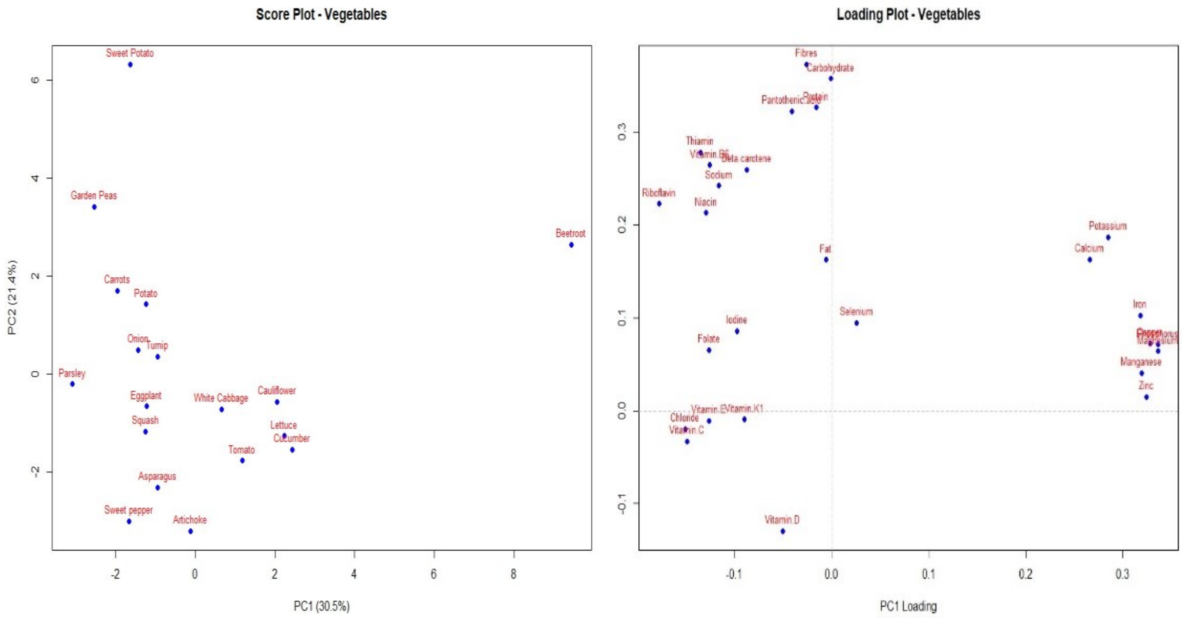

Figure 9. The score plot presents PCA vegetables products scores distributed according to dimension one, the horizontal axis, and dimension two, the vertical axis. The points represent all the vegetables products names. The numbers 30.5% and 21.4% represent the portion of total variance explained by the first and the second PCA dimensions. The loading plot presents PCA nutrient content sustainability. The points represent all nutrient content sustainability names.

The loading and score plots of the PCA analysis for the group of vegetable products reveal details about the nutrient sustainability profiles of these foods and their relative positions (figure 9). It identified two principal components that together account for 51.9% of the total variance within the dataset, with PC1 explaining 30.5% and PC2 explaining 21.4%. Based on the PCA analysis, we can derive the following interpretation regarding the sustainable nutrient content of various vegetables. Sweet potatoes can be a sustainable source of nutrients like carbohydrate, fiber beta-carotene and vitamin B_6. Beetroot appears on the extreme positive end of PC1, indicating that it may be rich in iron, phosphorus, magnesium, and copper. Parsley is considered a sustainable product of vitamin C, vitamin E, riboflavin, and folate. carrots may be lower in calories and still provide essential nutrients, especially fibers, beta-carotene, and folate. Interestingly, sweet pepper contains a high content of vitamin D. The sustainable content of niacin is garden peas.

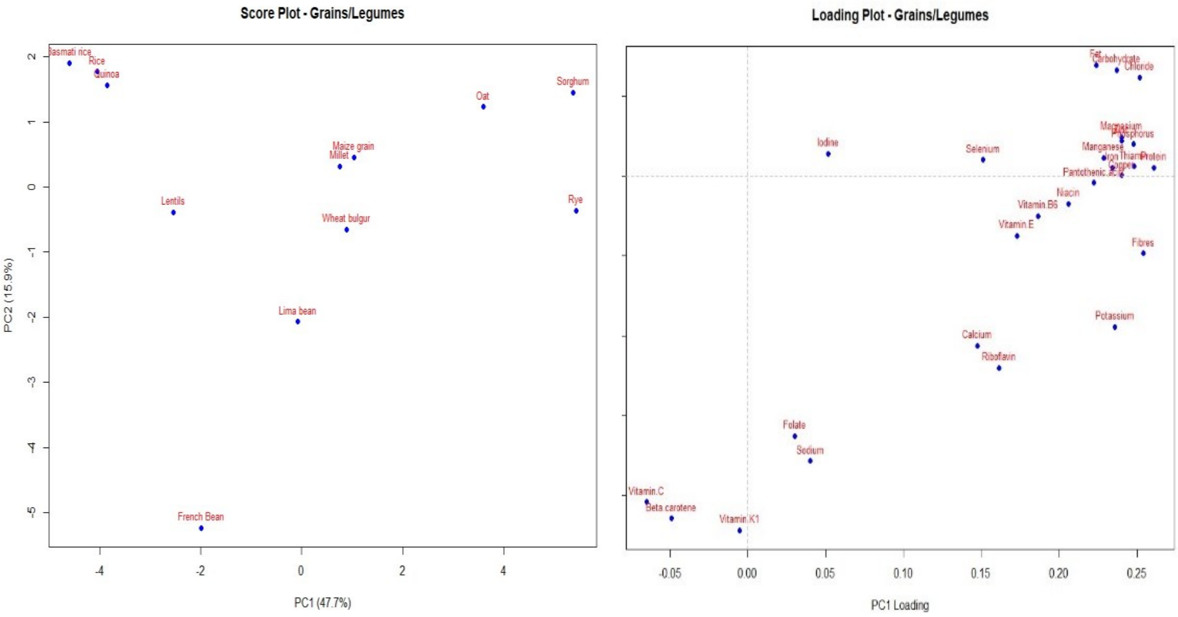

Figure 10. The score plot presents PCA grains and legumes group scores distributed according to dimension one, the horizontal axis, and dimension two, the vertical axis. The points represent all the grain and legumes group products names. Numbers 47.7% and 15.9% represent the portion of total variance explained by the first and the second PCA dimensions. The loading plot presents PCA nutrient content sustainability. The points represent all nutrient content sustainability names.

The PCA analysis's loading and score plots for grains and legumes group provide information about the nutrient sustainability profiles of these foods and how they are positioned in relation to one another (figure 10). The PCA model identified two principal components that together account for 63.6% of the total variance within the dataset, with PC1 explaining 47.7% and PC2 explaining 15.9%. Oat, sorghum, and rye are among the grains, may contain higher levels of sustainable protein and carbohydrates. According to the loadings plot, french bean may suggest a higher sustainable content of nutrients like beta-carotene, folate and vitamin C. Wheat bulgur, millet, and maize grain are close to the center suggesting a balanced sustainable nutrient profile related to the nutrients that have the greatest impact on PC1 and PC2, like protein, manganese, phosphorus, manganese, thiamin, and copper. Vitamin B6 and riboflavin are both abundant in millet. Maize grain can be considered as a sustainable source of vitamin E and calcium. Niacin, iron, and vitamin B_6 can all be obtained sustainably from sorghum.

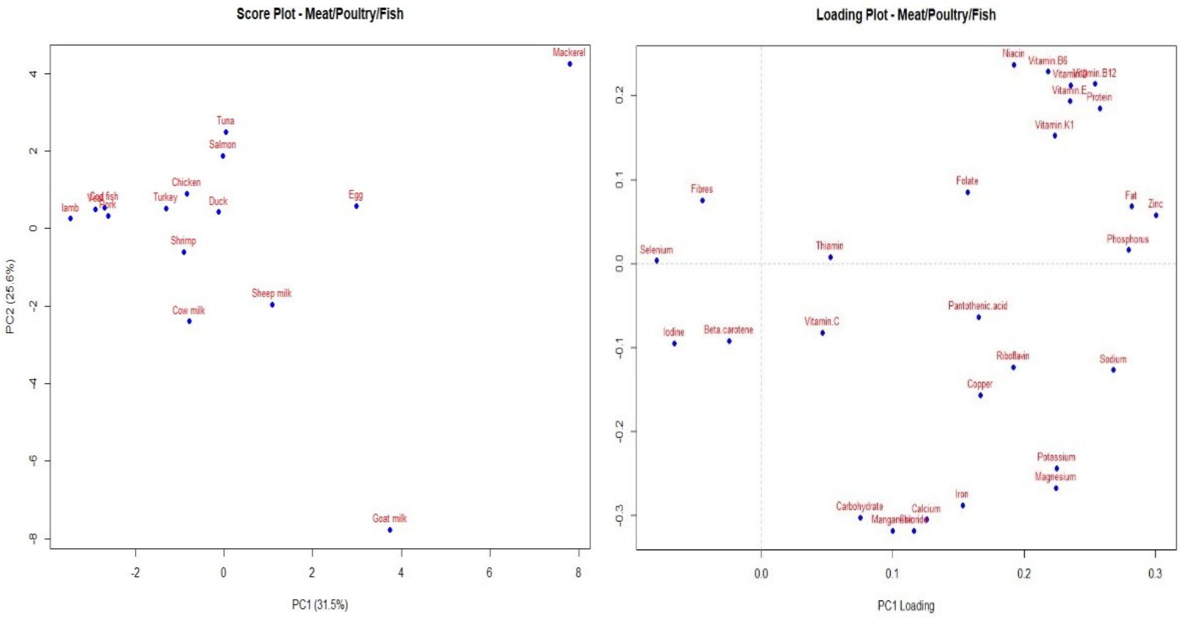

Figure 11. The score plot presents PCA meat, poultry and fish products scores distributed according to dimension one, the horizontal axis, and dimension two, the vertical axis. The points represent all the meat, poultry, and fish products names. Numbers 31.5% and 25.6% represent the portion of total variance explained by the first and the second PCA dimensions. The loading plot presents PCA nutrient content sustainability. The points represent all nutrient content sustainability names.

The loading and score plots of the PCA analysis for the group of meat, poultry, and fish reveal details about the nutrient sustainability profiles of these foods and their relative positions (figure 11). The PCA suggests a variation in the nutrient composition of animal-based foods. It identified two principal components that together account for 57.1 % of the total variance within the dataset, with PC1 explaining 31.5% and PC2 explaining 25.6%. Mackerel might be considered a sustainable nutrient-dense option, suitable for diets requiring high levels of vitamins B, niacin, vitamin D, phosphorus, and vitamin E. Goat milk has higher levels of iron, calcium, magnesium, and chloride. Beef milk contains a lot of selenium and beta-carotene. Beta-carotene and protein content also seem to be high in tuna. Lamb, cod fish, pork, veal are a good source of selenium, beta-carotene, and iodine. Niacin, vitamin B_6, B_{12}, E, protein, and K_1 are positioned near the origin, suggesting that most meat, poultry, and fish provide these nutrients in relatively balanced amounts.

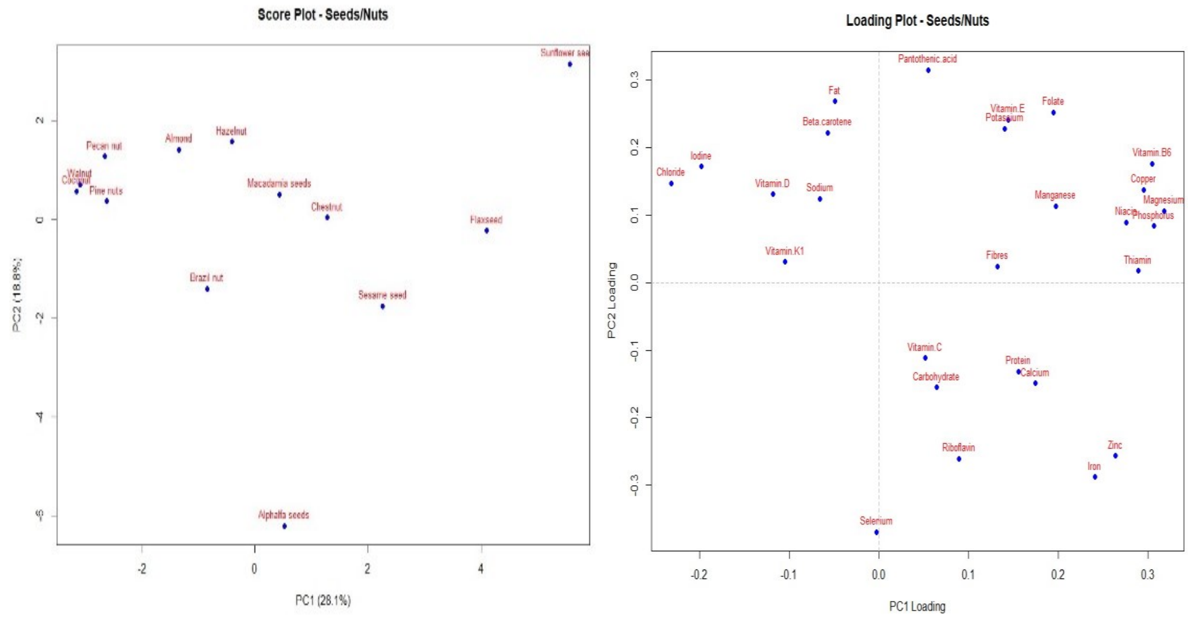

Figure 12. The score plot presents PCA seeds and nuts products scores distributed according to dimension one, the horizontal axis, and dimension two, the vertical axis. The points represent all the nuts and seeds products names. Numbers 28.1% and 18.8% represent the portion of total variance explained by the first and the second PCA dimensions. The loading plot presents PCA nutrient content sustainability. The points represent all nutrient content sustainability names.

The PCA analysis for seeds and nuts provides insights into their nutrient compositions as indicated by the loading and score plots (figure 12). It identified two principal components that together account for 46.9% of the total variance within the dataset, with PC1 explaining 28.1% and PC2 explaining 18.8%. The loading plot's nutrient clustering indicates that nuts and seeds products in general may offer a good balance of vital nutrients like potassium, magnesium, pantothenic acid, vitamin E, and niacin. Alfalfa seeds on PC1 and PC2 may have lower concentrations of the nutrients that are highly concentrated in these components, like fats and iodine, but they have higher sustainable levels of protein, riboflavin, and iron. Flaxseeds may be considered a nutrient-dense sustainable option, suitable for diets requiring high levels of thiamin and phosphorus. Almonds have a unique nutrient profile and may provide a different range of long-term nutritional benefits, especially in sodium and vitamin D. Macadamia seeds may be considered as a sustainable source of fat. Walnuts position on PC1 and PC2 reveals a high sustainable source of beta-carotene. Sunflower seeds is a sustainable source of vitamin E, thiamin, niacin, magnesium, vitamin B_6 and folate.

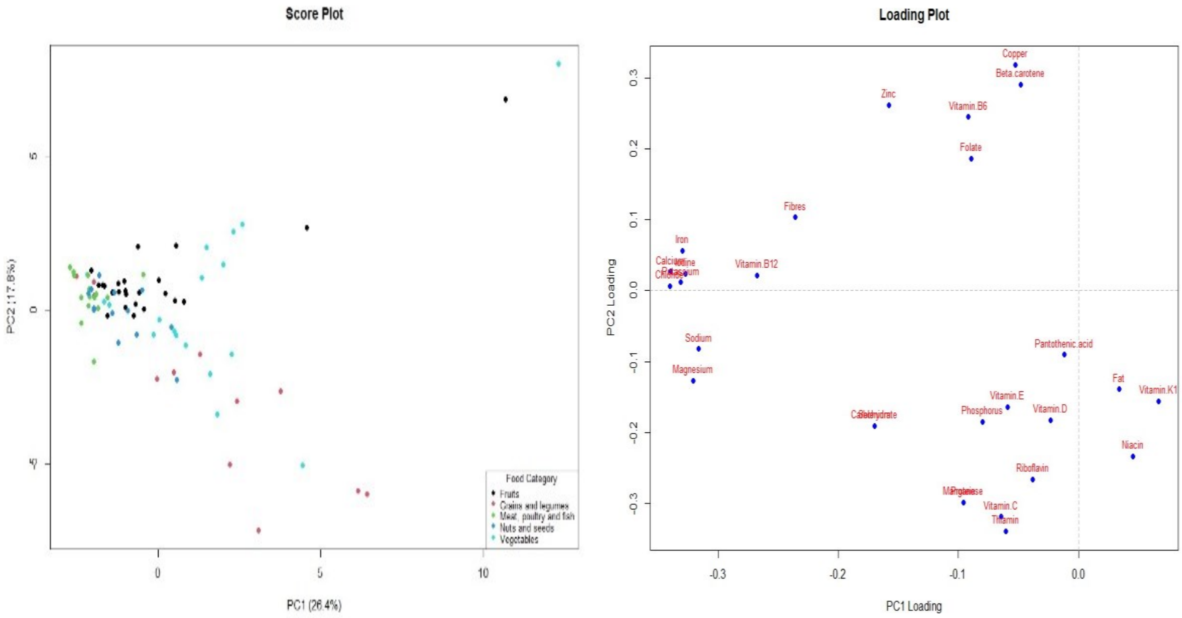

Figure 13. The score plot presents PCA all food groups scores distributed according to dimension one, the horizontal axis, and dimension two, the vertical axis. The points represent all the food groups' names. The numbers 26.4% and 17.8% represent the portion of total variance explained by the first and the second PCA dimensions. The loading plot presents PCA nutrient groups content sustainability. The points represent all nutrient groups content sustainability names.

The loading and score plots of the PCA analysis for all the food groups reveal details about the nutrient sustainability profiles of these food groups and their relative positions (figure 13). The PCA revealed that the first two principal components accounted for 26.4% and 17.8% of the variance in the dataset, respectively, suggesting a considerable spread of nutrient concentrations across the examined food categories. Fruits are generally lower in protein and fat but higher in carbohydrates, and fiber. This is reflected in their position on the score plot, which is usually on the side with the highest carbohydrate and fiber content. Vegetables, like fruits, are high in fiber and contain only moderate amounts of carbohydrates. They are also high in vitamins and minerals, which may cause them to spread out on the score plot depending on each vegetable's unique nutrient profile. Grains and legumes are generally high in carbohydrates and proteins, so they may appear near the regions of the plot that represent these macronutrients. Meat, poultry, and fish products as expected are high in protein and certain fats, which would place them prominently on the score plot, most likely along the protein and fat axes. Nuts and seeds products which are high in healthy fats, proteins, and fibers, would appear in the plot area designated for these nutrients.

4.2 The ranking factor.

The ranking factor utilizes the nutrient content related to climate change to rank the food products according to their degree of sustainability. The nutrient content includes protein ratio, carbohydrate ratio, fat ratio, fiber ratio, water soluble vitamins ratio, fat soluble vitamins ratio, macro-minerals ratio and microminerals ratio.

Food product	Protein ratio (kg/kgCO_2eq)	Carbohydrate ratio (kg/kgCO_2eq)	Fat ratio (kg/kgCO_2eq)	Climate change (kg CO_2eq)	Ranking factor*
Maize grain	99.78	827.83	45.58	0.81	973.19
Millet	125.60	734.18	48.07	0.88	907.85
Durum Wheat	104.45	538.67	19.34	1.16	662.46
Sweet Potato	49.59	600.97	4.93	0.30	655.49
Sorghum	1.68	10.34	54.72	0.63	66.74
Potato	43.67	327.51	3.64	0.49	374.82
Apple	6.29	291.84	6.29	0.40	304.42
Pomegranate	29.59	293.84	24.66	0.49	348.09
Grape	15.73	342.92	3.49	0.46	362.14
Almond	69.56	35.19	189.81	2.70	294.55
Rye	1.35	8.41	27.15	0.73	36.92
Pear	13.40	298.07	7.38	0.37	318.85
Sunflower seeds	65.52	31.07	170.72	3.25	267.31
Macadamia seeds	21.66	14.29	207.53	3.65	243.48
Lentils	97.44	208.95	6.38	0.91	312.76
Pecan nut	26.20	14.87	198.77	3.65	239.84
Beetroot	47.66	249.23	6.57	0.37	303.46
Rice	3.77	282.84	3.30	2.76	289.91
Oat	1.47	4.83	59.82	1.15	66.11
Pine nuts	32.90	15.15	156.11	4.16	204.17
Fig	19.30	218.92	3.24	0.62	241.46
Carrots	17.25	207.87	8.22	0.37	233.35
Banana	12.00	223.01	2.26	0.88	237.28
Chestnut	9.61	193.80	11.84	1.88	215.25
Mango	9.09	206.32	4.33	0.69	219.74
Wheat bulgur	0.99	5.77	14.76	1.16	21.52
Garden Peas	87.66	105.08	8.26	0.67	201.00
Flaxseed	56.16	18.35	100.93	3.60	175.44
Coconut	13.29	24.83	133.75	2.50	171.87
Onion	28.32	160.89	15.96	0.39	205.17
Hazelnut	30.90	15.36	122.09	4.66	168.35
Avocado	10.52	5.60	138.88	1.48	154.99
Walnut	26.37	22.75	76.24	4.17	125.36
Sesame seed	33.81	18.92	95.46	5.21	148.19
Peach	18.04	150.29	5.51	0.60	173.84
Cantaloupe	12.11	158.56	2.14	0.93	172.81
Alfalfa seeds	84.48	111.78	35.84	3.52	232.10
Turnip	20.81	128.72	2.74	0.37	152.28

Nectarine	18.10	138.88	4.84	0.64	161.82
Mackerel	80.32	0.00	59.91	2.25	140.23
Strawberry	12.65	121.07	6.02	0.50	139.75
Orange	11.79	126.27	6.29	0.64	144.35
Brazil nut	19.85	8.27	88.63	7.46	116.75
French Bean	41.10	91.98	4.67	0.45	137.75
Blueberry	9.83	119.78	3.73	0.88	133.34
Kiwi	8.87	110.84	6.05	0.99	125.76
Apricot	9.17	101.97	3.40	0.88	114.53
Plum	6.76	101.66	2.97	0.98	111.40
White Cabbage	20.80	69.78	9.04	0.66	99.62
Lima bean	0.89	1.98	11.15	0.77	14.02
Cherry	6.01	96.40	0.74	1.35	103.15
Blackberry	11.99	69.27	7.43	0.94	88.68
Pineapple	3.09	90.32	3.09	1.30	96.49
Eggplant	24.43	52.14	3.05	0.46	79.63
Sheep milk	27.18	21.53	33.35	2.09	82.06
Cow milk	22.11	32.30	24.17	1.50	78.57
Pumpkin	16.12	56.42	1.61	0.62	74.15
Egg	39.75	0.85	30.77	3.19	71.37
Parsley	34.12	32.01	5.79	1.09	71.92
Goat milk	22.88	29.36	19.10	1.48	71.35
Grapefruit	2.55	68.11	0.85	1.18	71.51
Cucumber	13.49	53.55	2.32	0.47	69.36
Duck	24.93	3.94	32.38	6.98	61.25
Tuna	54.54	0.00	12.23	4.40	66.77
Cauliflower	24.55	28.89	9.49	0.74	62.93
Basmati rice	0.19	1.90	2.05	4.10	4.13
Chicken	31.35	0.00	24.46	5.52	55.81
Raspberry	8.10	39.68	5.45	1.47	53.23
Salmon	32.26	0.00	19.51	6.35	51.77
Tomato	12.19	35.30	3.69	0.71	51.17
Turkey	42.40	0.00	7.81	5.52	50.21
Squash	17.73	25.79	2.74	0.62	46.26
lemon	4.21	21.89	5.61	0.71	31.71
Sweet pepper	6.75	38.38	2.28	1.19	47.41
Quinoa	0.15	0.68	7.11	8.54	7.94
Asparagus	17.22	14.21	1.89	1.43	33.32
Lettuce	13.71	14.02	2.11	0.95	29.84
Shrimp	25.78	4.20	1.10	7.64	31.08
Pork	20.38	0.00	3.46	10.40	23.85
Artichoke	8.24	12.67	0.46	3.88	21.37
Cod fish	16.68	0.00	0.53	10.85	17.21
lamb	3.44	0.00	8.36	41.25	11.81
Veal	11.91	0.00	1.41	18.30	13.32

Table 1 classify the food categories in a ranking concerning their degree of sustainability according to their protein value, carbohydrate value, fat value, and their interruption to global warming.

*Ranking factor is the sum of protein value, carbohydrate value, and fat value, and their interruption to global warming.

Table 1 classify the food categories in a ranking concerning their degree of sustainability according to their protein value, carbohydrate value, fat value, and their interruption to global warming. For grains and legumes products, we can see that maize grain, millet, durum wheat, and sorghum are the products that can be used in sustainable diets that are high in protein, carbohydrate, fat, energy, and fats. For fruit products, pomegranate, pear, apple, grapes are the products that have high amount of sustainable protein, carbohydrate, fat, energy, and fiber content. Sweet potatoes, potatoes, beetroot, carrots, and garden peas stand for the most sustainable vegetables that contain high amounts of protein, carbohydrate, fat, energy, and fiber. Finally, since they are high in protein, carbohydrates, fats, energy, and fiber, almond, sunflower, macadamia, and pecan nuts represent the best sustainable nuts and seed products. Mackerel, sheep milk, and cow milk are notable sources of high protein, carbohydrate, fat, energy, and fiber among the meat, poultry, and fish products.

Food Product	Fat soluble vitamins ratio (kg/kgCO_2eq)	Water soluble vitamins ratio (kg/kgCO_2eq)	Climate change (kg CO_2eq)	Ranking factor*
Strawberry	0.00000	0.00011	0.50	0.0001
Sweet pepper	0.00000	0.00010	1.19	0.0001
Kiwi	0.00000	0.00008	0.99	0.0001
Orange	0.00000	0.00008	0.64	0.0001
Rice	0.00000	0.00007	2.76	0.0001
Garden Peas	0.00000	0.00006	0.67	0.0001
Lemon	0.00000	0.00006	0.71	0.0001
Cauliflower	0.00000	0.00006	0.74	0.0001
Turnip	0.00000	0.00005	0.37	0.0001
Potato	0.00000	0.00004	0.49	0.0000
Sweet Potato	0.00003	0.00001	0.30	0.0000
Mango	0.00000	0.00004	0.69	0.0000
Grapefruit	0.00000	0.00004	1.18	0.0000
Pineapple	0.00000	0.00004	1.30	0.0000
Lima bean	0.00000	0.00003	0.77	0.0000
Carrots	0.00002	0.00001	0.37	0.0000
Squash	0.00000	0.00003	0.62	0.0000
Maize grain	0.00000	0.00002	0.81	0.0000
Tomato	0.00000	0.00002	0.71	0.0000
Chestnut	0.00000	0.00002	1.88	0.0000
Pumpkin	0.00001	0.00002	0.62	0.0000
Pomegranate	0.00000	0.00002	0.49	0.0000
Lettuce	0.00000	0.00001	0.95	0.0000
Apple	0.00000	0.00002	0.40	0.0000
Parsley	0.00001	0.00001	1.09	0.0000
Sunflower seeds	0.00001	0.00000	3.25	0.0000
Peach	0.00000	0.00001	0.60	0.0000
Pear	0.00000	0.00001	0.37	0.0000
White Cabbage	0.00000	0.00001	0.66	0.0000
Raspberry	0.00000	0.00001	1.47	0.0000
Durum Wheat	0.00000	0.00001	1.16	0.0000
Blackberry	0.00000	0.00001	0.94	0.0000
Blueberry	0.00000	0.00001	0.88	0.0000
Cantaloupe	0.00000	0.00001	0.93	0.0000
Nectarine	0.00000	0.00001	0.64	0.0000
Cucumber	0.00000	0.00001	0.47	0.0000
Onion	0.00000	0.00001	0.39	0.0000
French Bean	0.00000	0.00001	0.45	0.0000
Almond	0.00001	0.00000	2.70	0.0000
Banana	0.00000	0.00001	0.88	0.0000
Rye	0.00000	0.00001	0.73	0.0000
Sorghum	0.00000	0.00001	0.63	0.0000
Grape	0.00000	0.00001	0.46	0.0000
Alfalfa seeds	0.00000	0.00001	3.52	0.0000
Plum	0.00000	0.00001	0.98	0.0000

Lentils	0.00000	0.00001	0.91	0.0000
Eggplant	0.00000	0.00001	0.46	0.0000
Asparagus	0.00000	0.00001	1.43	0.0000
Apricot	0.00000	0.00000	0.88	0.0000
Wheat bulgur	0.00000	0.00001	1.16	0.0000
Mackerel	0.00000	0.00000	2.25	0.0000
Hazelnut	0.00000	0.00000	4.66	0.0000
Oat	0.00000	0.00000	1.15	0.0000
Avocado	0.00000	0.00000	1.48	0.0000
Millet. whole	0.00000	0.00000	0.88	0.0000
Artichoke	0.00000	0.00000	3.88	0.0000
Cherry	0.00000	0.00000	1.35	0.0000
Tuna	0.00000	0.00000	4.40	0.0000
Pine nuts	0.00000	0.00000	4.16	0.0000
Sheep milk	0.00000	0.00000	2.09	0.0000
Beetroot	0.00000	0.00000	0.37	0.0000
Salmon	0.00000	0.00000	6.35	0.0000
Duck	0.00000	0.00000	6.98	0.0000
Chicken	0.00000	0.00000	5.52	0.0000
Flax seeds	0.00000	0.00000	3.60	0.0000
Fig	0.00000	0.00000	0.62	0.0000
Coconut	0.00000	0.00000	2.50	0.0000
Macadamia seeds	0.00000	0.00000	3.65	0.0000
Pecan nut	0.00000	0.00000	3.65	0.0000
Turkey	0.00000	0.00000	5.52	0.0000
Sesame seeds	0.00000	0.00000	5.21	0.0000
Egg	0.00000	0.00000	3.19	0.0000
Brazil nut	0.00000	0.00000	7.46	0.0000
Walnut	0.00000	0.00000	4.17	0.0000
Goat milk	0.00000	0.00000	1.48	0.0000
Pork	0.00000	0.00000	10.40	0.0000
Cow milk	0.00000	0.00000	1.50	0.0000
Shrimp	0.00000	0.00000	7.64	0.0000
Quinoa	0.00000	0.00000	8.54	0.0000
Veal	0.00000	0.00000	18.30	0.0000
Cod fish	0.00000	0.00000	10.85	0.0000
Lamb	0.00000	0.00000	41.25	0.0000
Basmati rice	0.00000	0.00000	4.10	0.0000

Table 2 classify the food products in a ranking concerning their degree of sustainability according to their fat-soluble vitamins and water-soluble vitamins values and their interruption to global warming.

*Ranking factor is the sum of fat-soluble vitamins and water-soluble vitamins ratios and their interruption to global warming.

The food products are ranked in table 2 based on how sustainable they are in terms of global warming and the ratio of fat-soluble and water-soluble vitamins. Among fruit products, strawberries, kiwis, oranges, and lemons are noteworthy sustainable sources of high fat-soluble and water-soluble vitamins. The best sustainable vegetable products are sweet pepper, garden peas, cauliflower, and turnips because of their high water-soluble vitamin content and fat-soluble vitamin content. Furthermore, the findings demonstrate that water-soluble and fat-soluble vitamins are present in high sustainable levels in rice, lima beans, and maize grains. The ranking factor also determined that water-soluble and fat-soluble vitamins can be found in chestnut, sunflower seeds, almond and alfalfa seeds. Mackerel, tuna, and sheep's milk rank last among the sustainable foods that can be included in diets high in fat-soluble and water-soluble vitamins for the meat, poultry, and fish group.

Food product	Microminerals ratio (kg/kgCO_2eq)	Macro-minerals ratio (kg/kgCO_2eq)	Climate change (kg CO_2eq)	Ranking factor*
Beetroot	0.00002	0.007	0.37	0.0071
Pear	0.00004	0.004	0.37	0.0041
Lettuce	0.00001	0.002	0.95	0.0017
Strawberry	0.00001	0.002	0.50	0.0016
Sweet Potato	0.00000	0.002	0.30	0.0016
Sorghum	0.00001	0.001	0.63	0.0014
Tomato	0.00001	0.001	0.71	0.0014
Rye	0.00001	0.001	0.73	0.0014
Cucumber	0.00001	0.001	0.47	0.0013
Cauliflower	0.00001	0.001	0.74	0.0013
Peach	0.00000	0.001	0.60	0.0012
Pomegranate	0.00000	0.001	0.49	0.0012
White Cabbage	0.00000	0.001	0.66	0.0011
Potato	0.00000	0.001	0.49	0.0011
Oat	0.00001	0.001	1.15	0.0010
Grape	0.00000	0.001	0.46	0.0010
Carrots	0.00000	0.001	0.37	0.0010
Turnip	0.00000	0.001	0.37	0.0009
Lima bean	0.00000	0.001	0.77	0.0009
Onion	0.00000	0.001	0.39	0.0009
Nectarine	0.00000	0.001	0.64	0.0008
Lemon	0.00000	0.001	0.71	0.0008
Goat milk	0.00000	0.001	1.48	0.0008
Squash	0.00000	0.001	0.62	0.0007
Wheat bulgur	0.00001	0.001	1.16	0.0007
Grapefruit	0.00001	0.001	1.18	0.0007
Pumpkin	0.00000	0.001	0.62	0.0006
Apple	0.00000	0.001	0.40	0.0006
Garden Peas	0.00000	0.001	0.67	0.0005
Parsley	0.00000	0.000	1.09	0.0005
Eggplant	0.00000	0.000	0.46	0.0005
Flaxseed	0.00000	0.000	3.59	0.0005
French Bean	0.00000	0.000	0.45	0.0004
Sunflower seeds	0.00000	0.000	3.25	0.0004
Apricot	0.00000	0.000	0.88	0.0004
Durum Wheat	0.00000	0.000	1.16	0.0004
Blueberry	0.00000	0.000	0.88	0.0004
Mango	0.00000	0.000	0.69	0.0004

Orange	0.00000	0.000	0.64	0.0004
Cantaloupe	0.00000	0.000	0.93	0.0004
Maize grain	0.00000	0.000	0.81	0.0004
Chestnut	0.00000	0.000	1.88	0.0004
Fig	0.00000	0.000	0.62	0.0003
Pineapple	0.00000	0.000	1.30	0.0003
Mackerel	0.00000	0.000	2.25	0.0003
Banana	0.00000	0.000	0.88	0.0003
Hazelnut	0.00000	0.000	4.66	0.0003
Millet	0.00000	0.000	0.88	0.0003
Blackberry	0.00000	0.000	0.94	0.0003
Sesame seed	0.00000	0.000	5.2	0.0003
Egg	0.00000	0.000	3.19	0.0002
Brazil nut	0.00000	0.000	7.45	0.0002
Raspberry	0.00000	0.000	1.47	0.0002
Sheep milk	0.00000	0.000	2.09	0.0002
Lentils	0.00000	0.000	0.91	0.0002
Plum	0.00000	0.000	0.98	0.0002
Macadamia seeds	0.00000	0.000	3.65	0.0002
Almond	0.00000	0.000	2.70	0.0002
Cherry	0.00000	0.000	1.35	0.0002
Coconut	0.00000	0.000	2.50	0.0002
Asparagus	0.00000	0.000	1.43	0.0002
Avocado	0.00000	0.000	1.48	0.0002
Sweet pepper	0.00000	0.000	1.19	0.0002
Pecan nut	0.00000	0.000	3.65	0.0002
Quinoa	0.00000	0.000	8.54	0.0001
Turkey	0.00000	0.000	5.52	0.0001
Cow milk	0.00000	0.000	1.50	0.0001
Rice	0.00000	0.000	2.76	0.0001
Kiwi	0.00000	0.000	0.99	0.0001
Shrimp	0.00000	0.000	7.64	0.0001
Duck	0.00000	0.000	6.98	0.0001
Pine nuts	0.00000	0.000	4.16	0.0001
Artichoke	0.00000	0.000	3.88	0.0001
Pork	0.00000	0.000	10.40	0.0001
Salmon	0.00000	0.000	6.35	0.0001
Chicken	0.00000	0.000	5.52	0.0000
Cod fish	0.00000	0.000	10.85	0.0000

Tuna	0.00000	0.000	4.40	0.0000
Walnut	0.00000	0.000	4.17	0.0000
Veal	0.00000	0.000	18.30	0.0000
Lamb	0.00000	0.000	41.25	0.0000
Alfalfa seeds	0.00000	0.000	3.51	0.0000
Basmati rice	0.00000	0.000	4.10	0.0000

Table 3 classify the food categories in a ranking concerning their degree of sustainability according to their microminerals and macro-minerals ratios and their interruption to global warming.

*Ranking factor is the sum of microminerals and macro-minerals and their interruption to global warming.

Table 3 lists the food items according to their sustainability with respect to global warming and microminerals and macro-minerals values. Beetroot, lettuce, sweet potatoes, and tomatoes are notable, sustainable sources of macro- and microminerals among vegetable products. Due to their high content of macro- and microminerals, strawberries, peaches, and pomegranates make the best sustainable fruit products. Additionally, the results show that sorghum, rye, oats, and lima beans contain high sustainable levels of both macro- and microminerals. Goat milk, mackerel, and eggs all contain high concentrations of macro- and microminerals, according to the ranking factor. When it comes to sustainable foods that can be incorporated into diets high in macro- and micromineral, flax seed, sunflower seeds, chestnut, and hazelnut come in last.

Chapter 5

5. Discussion.

The scope of the work is to describe a sustainable pattern for agricultural products according to their degree of impact. This study includes one indicator of environmental impact which is climate change and the nutrient content of 82 unique foods in a dataset. Fruits have a high carbohydrate and fiber content but low protein and fat levels, which is consistent with the literature by Del Río-Celestino & Font (2020). Fruits are also an important source of essential vitamins and dietary fiber, both of which are important for digestive health and chronic diseases (Yahia et al., 2018). The variety of vegetables on the score plot reflects the range of nutrients they provide. Our result is in accordance with Conti et al., (2021) that suggests that vegetables have a sustainable role in nutrition, related to the intake of both macronutrients and micronutrients that are necessary for health. According to the study analysis and the correlation between global warming and nutrient content, fruits and vegetables can, in fact, function as sustainable sources of important vitamins and minerals. The carbon footprint, estimated through GHGEs, has become an important criterion for assessing the environmental sustainability of alternative diets. In the current analyses, fruits and vegetable products were associated with lowest GHGEs emissions when expressed per kilogram. However, even though fruits may have a low environmental impact, they cannot be viewed as the most-sustainable foods because the FAO definition of sustainable diets makes a direct reference to population well-being and health (FAO, 2010). From PCA analysis, we can focus on fruits and vegetables and their exceptional nutrient profiles that draws attention to their health advantages and also emphasizes how crucial sustainable agricultural methods are to reducing the effects of climate change. The highlighted products are, avocados for their fat content, pumpkin and carrots for their beta-carotene, folate, and riboflavin, kiwis for their vitamin C content, pears for their fiber and iron content, mangos and parsley for their vitamin E content, and strawberries for their fiber, folate, and calcium content. Garden peas are a good source of niacin and thiamin, and sweet peppers are a sustainable source of vitamin D.

Grains and legumes, have a higher content of carbohydrate and protein, have been confirmed as fundamental sources of these macronutrients (Ganesan and Xu, 2017). They play an especially important role in vegetarian and vegan diets, where they account for a substantial portion of protein intake (Melina et al., 2016). The PCA study highlights the potential of different grains and legumes as sustainable sources of important nutrients by offering insightful information about their nutrient profiles. We can take into consideration a few particular products made from grains and legumes as a sustainable source of some crucial nutrients based on the PCA analysis. Riboflavin and vitamin B_6 are abundant in millet. Maize grains support calcium and vitamin E. Oats are an excellent source of thiamin and protein. Sorghum contains high levels of iron, niacin, and carbohydrates. This data is essential for creating dietary recommendations that take environmental sustainability into account in addition to meeting nutritional needs. Following a balanced vegetarian diet can reduce systemic inflammation and the risk of diabetes, two factors that are closely linked to the onset and progression of cardiovascular disease (Kahleova et al., 2018). In a systematic review focusing on GHG emissions, land occupation, and water use, concluded that the least impacting diets on the environment, compared to omnivorous diets, were in descending sequence the vegan diet, followed by the vegetarian, and then the pesco-vegetarian (Aleksandrowicz et al., 2016). Borsato et al., (2018) indicated that a diet based on vegetables, fruits and cereals is environmentally convenient and more sustainable according to its water and energetic impact. Moreover, Vegan diets exhibited a reduced per capita GHG footprint by 70% compared to current diets (Kim et al., 2020).

Meats, poultry, and fish products, which are high in protein and fats, are clearly marked on the PCA to indicate their nutrient density. The PCA analysis clarifies how different meat, poultry, and fish may function as enduring sources of vital nutrients. Through in-depth analyses of these foods' nutrient profiles, the study provides important data for developing dietary recommendations that take environmental sustainability into account in addition to meeting nutritional needs. Vitamin B_{12}, niacin, vitamin D, and protein are all present in good amounts in mackerel. Selenium and beta-carotene are represented by cow milk. Goat milk is high in calcium, and sheep milk is high in riboflavin. However, the environmental impact of their production is gaining attention, with studies indicating a significant contribution to greenhouse gas emissions and water use (Godfray et al., 2018). In fact, many studies have shown that reducing meat consumption can reduce green gashouse emissions while remaining nutritionally adequate (Gerber et al., 2013; Hedenus et al., 2014). A recent study by Heller et al., 2020 showed that cutting 90% of beef consumption and replacing 50% of other animal-based foods with plant-based foods in the United States would save more than 2 billion tons of greenhouse gas emissions from being released into our atmosphere by 2030, the rough equivalent of taking nearly half the world's cars off the roads for a year. Other studies confirmed that diets lower in animal-based food products are linked with lower GHG emissions, less water and land use, and reduced all-cause mortality risk compared to high animal-based diets (Aleksandrowicz et al., 2016; Soret et al., 2014b; Tilman and Clark, 2014b). The higher GHGE cost of some meat and fish products may be compensated for, to some extent, by their higher nutritional value.

Nuts and seeds, which are high in fats, proteins, and fibers, are displayed in a way that emphasizes their importance in a balanced diet. The results of the Principal Component Analysis (PCA) highlight the nutritional value and sustainability of specific nuts and seeds, emphasizing their potential as essential elements of a diet that is both balanced and environmentally conscious. Walnuts and sunflower seeds are good sources of beta-carotene, vitamin E, thiamin, niacin, vitamin B_6, and folate, respectively. Alfalfa seeds are high in protein, riboflavin, and iron, while flaxseeds are high in phosphorus. When sourced sustainably, nuts and seeds can be included into a sustainable eating pattern and are linked to a decreased risk of cardiovascular illnesses (Ros & Mataix, 2006). Additionally, for millennia, they have been a component of diets all over the world (Casas-Agustench et al., 2011). These food items are extremely nutrient-dense, high in proteins, fiber, and macronutrients like MUFAs and PUFAs (Bolling et al., 2011; Ros & Mataix 2006). Compared with not eating nuts, a handful of nuts per day is associated with a risk reduction of cardiovascular disease and mortality by a fifth, and cancer deaths by a tenth. (Balakrishna et al., 2022). They are usually situated in different stage of the food pyramid with recommendations to consume it every day with small amounts, and furthermore, they are placed in a different step of the food chain. Agreed by previous studies that strongly supports nut consumption as part of a healthy but also sustainable diet, in terms of greenhouse gas emissions, land and energy use, and potential for acidification and eutrophication (Van Dooren et al., 2015; Fischer & Garnett, 2016; Willett et al., 2019; Vanham et al., 2020).

Based on the ranking factor tables, we can conclude that foods high in macronutrients are maize grains, apples, sweet potatoes, almonds, and mackerel, respectively. The foods that ranked highest for vitamins are strawberries, sweet pepper, rice, chestnuts, and mackerel, respectively. Lastly, foods high in sustainable minerals values included beetroot, strawberries, sorghum, goat milk, and flaxseed, respectively. Product placement in tables 1, 2, and 3 indicates that higher-ranking products are more sustainable than lower-ranking ones, however products in the middle of the ranking might not follow this pattern. Owing to their higher nutrient content and reduced carbon footprint, these agricultural products ought to be given more consideration in a future diet.

In the present and future development of humankind, healthy food systems have an important role to play in both contributing to keeping greenhouse gas emissions (GHG) within planetary limits of sustainability and in improving health outcomes (Willett et al., 2019; IPCC, 2019). In terms of the latter, non-communicable diseases, such as diabetes, cardiovascular diseases, cancer and chronic respiratory diseases, are responsible for 41 million deaths each year, and one in five deaths are attributed to unhealthy diets globally (Stanaway et al., 2018). The Mediterranean diet is, in fact, rich in plant-based foods (cereals, fruits, vegetables, legumes, tree nuts, seeds and olives) with moderate-to-high consumption of fish and seafood, moderate consumption of eggs, poultry and dairy products (cheese, milk and yoghurt) and low consumption of red meat, with extra-virgin olive oil used as the principal source of added fat (Serra-Majem et al., 2020b). These findings are consistent with the promotion of fruits, vegetables, grains, and legumes to meet dietary requirements and possibly have a less environmental impact than food products derived from animals. Moreover, support the Mediterranean diet (MD) that play an important role in achieving EU climate targets (Herforth et al., 2019; Springmann et al., 2020b) as a healthy eating pattern that supports environmental (Springmann et al. 2020b), social, and cultural services (Bach-Faig et al., 2011; Serra-Majem et al., 2020b).

6. Conclusion

In conclusion, GHGEs and nutrient content analyses for 82 food products demonstrated that some agricultural products are more deserving of attention due to their high nutrient value and reduced carbon footprint. Moreover, the nutritional value of many foods with low GHGEs is also low. Fruits and vegetables have some of the lowest GHGE values. On the other hand, higher GHGEs are connected to higher nutritional value in products made from meat, poultry, and fish as well as nuts and seeds. Further research is required to ascertain the correlation between the nutritional sufficiency of food items and various sustainability metrics, such as carbon emissions. One query is if the higher nutritional value of some foods makes up for their higher GHGE cost. In summary, this research indicates that a varied diet high in plant-based foods and low in animal-based foods can support the attainment of environmental sustainability and health objectives. When weighing diet expenses, environmental effect, and nutrition, there might be some trade-offs to consider. More research is needed to find foods and diets that offer the best nutrient content at the lowest possible cost in terms of both money and carbon emissions.

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