UNIVERSITÀ DEGLI STUDI DI PADOVA

Department of Land, Environment Agriculture and Forestry

Second Cycle Degree (MSc) in Food and Health

Food-chain sustainability: from the EU policies to the environmental foot-prints of our diets

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Abstract (EN)

Sustainable food production is so crucial, it's right at the intersection of agriculture and environmental science. It's all about being responsible with how we produce food, cutting waste, and using resources wisely. This report goes into detail about important strategies like the Farm-to-Fork initiative, which aims to make our food systems more sustainable, reduce greenhouse gas emissions, and encourage healthier eating habits. There was a survey that looked at the carbon and water footprints of different diets which spread online between a group of family and friends. It had 14 questions and ran from November 2023 to March 2024. People from Iran and Italy participated the most, and they shared info about where they live, what they eat, their ages, and how much of things like grains, meat, dairy, milk, eggs, sugar, and tea they consume every week. The survey found that different foods have different environmental footprints. Analysis reveals that cereals and vegetables have lower CO2 footprints compared to meat and dairy, which shows how important it is to consider plant-based diets for cutting emissions. It also highlighted how complex our food choices are when it comes to reducing emissions and why it's crucial to take local conditions into account when managing water resources. Overall, this study gives us an overview for how policymakers, stakeholders, and consumers can all team up to create a more sustainable, strong, and fair future for food. It shows us that our food choices have a big impact on the environment.

Keywords: Food Sustainability – CO_2 footprint – water footprint – Farm to Fork-European Green Deal – One health

Abstract (IT)

La produzione alimentare sostenibile è fondamentale, poiché affronta le pressanti sfide globali all'intersezione tra agricoltura e scienza ambientale. Agisce sul modo in cui produciamo il cibo, riducendo gli sprechi e utilizzando le risorse con saggezza. Questo studio approfondisce strategie importanti come l'iniziativa Farm-to-Fork, che mira a rendere i nostri sistemi alimentari più sostenibili, ridurre le emissioni di gas serra e incoraggiare abitudini alimentari più sane. Il lavoro di ricerca ha previsto la realizzazione e somministrazione di un questionario che ha permesso di esaminare le impronte di carbonio e idriche di diverse diete. Il questionario è composto di 14 domande ed è stato somministrato da novembre 2023 a marzo 2024. Le persone dall'Iran e dall'Italia hanno partecipato maggiormente, condividendo informazioni su dove vivono, cosa mangiano, la loro età e quanto consumano settimanalmente di cereali, carne, latticini, latte, uova, zucchero e tè. Il sondaggio ha rilevato che diverse diete hanno impatti diversi sull'ambiente. Le persone che consumano più cereali e verdure generalmente hanno un impatto inferiore rispetto a chi consuma maggiormente prodotti a base di carne e latticini, il che dimostra quanto sia importante considerare le diete a base vegetale per ridurre le emissioni. I risultati hanno anche evidenziato quanto siano complesse le nostre scelte alimentari quando si tratta di ridurre le emissioni e perché è cruciale tenere conto delle condizioni locali nella gestione delle risorse idriche. In generale, questo studio ci offre spunti per politici e amministratori, consumatori e altri portatori di interesse per collaborare al fine di creare un futuro alimentare più sostenibile, forte ed equo. Mostra infine che le nostre scelte alimentari hanno un grande impatto sull'ambiente.

Parole Chiave: Alimentazione sostenibile – Impronta di CO_2 – Impronta idrica– Farm to Fork - European Green Deal – One health

1 Chapter 1

1.1 Introduction

Food sustainability is a fundamental principle at the intersection of agriculture and environmental science. It encompasses a range of practices that are aimed at producing food in an environmentally responsible manner, minimizing waste, optimizing the use of our limited natural resources, supporting the economic stability of farmers, and promoting the health and well-being of both humans and animals. Achieving food sustainability is of paramount importance in the face of the challenges posed by climate change, population growth, and resources. This paradigm catalyzes a burgeoning movement aimed at confronting the pressing challenge of resource inefficiency within our worldwide food production system. A critical observation underscores that our global food system currently expends a disproportionately greater quantity of resources compared to the net yield it generates. Central to the discourse on food sustainability is the imperative to reconcile the divergent objectives of environmental protection and agricultural productivity. It posits that agricultural practices should be ecologically sound, avoiding environmentally detrimental actions such as the overuse of chemical inputs and deforestation while endeavoring to optimize resource utilization. Furthermore, the concept emphasizes the pivotal role of farming communities, emphasizing the need for their economic sustenance through fair compensation and incentives for sustainable practices. Simultaneously, it recognizes the interconnectedness of ecosystems, wherein the welfare of animals and the communities engaged in food production are inextricably linked with broader environmental considerations. In summary, food sustainability epitomizes a multidimensional approach, aligning ecological preservation, efficient resource utilization, livelihood support, and community enhancement at its core. This overarching framework spearheads a global movement that strives to redress the current resource imbalance prevalent in our world's food production systems. The salience of this concept lies in its capacity to harmonize ecological and economic imperatives, thereby fostering a more sustainable and equitable future for food production and consumption (Ching-Hui *et al.,* 2019; United Nations, 2015).

Food sustainability assumes paramount significance due to a multitude of intertwined factors. However, its foremost importance lies in its pivotal role in shaping humanity's capacity to ensure an adequate food supply for both the present global population and generations to come. Presently, the prevailing circumstances reveal a stark reality wherein we confront challenges in providing sustenance to the entirety of the world's inhabitants, as evidenced by the alarming statistic that indicates a deficiency in food access for approximately 9 percent of the global populace (McKenzie & Williams, 2015).

Given the projected increase in the global population, estimates indicate a surge to 10 billion individuals by the year 2050 (United Nations, 2022; Nabi *et al*., 2021).

The global population is expected to reach 9.7 billion by 2050 and could surpass eleven billion by 2100 (Silva, 2018). According to the United Nations Department of Economic and Social Affairs, food production will need to increase by 60 to 70 percent during this time to meet the growing demand for sustenance. To achieve this, it may be necessary to convert millions of hectares of forested land into agricultural fields, resulting in significant environmental consequences. Furthermore, it is worth noting that the agriculture sector presently emits a greater quantity of greenhouse gases than the entire transportation industry combined, encompassing road transportation, aviation, and shipping (FAO, 2018). Expanding this sector by 60 to 70 percent would inflict severe harm on the environment, and it could even be unattainable. At present, food production consumes 70 percent of the world's freshwater resources. Elevating this consumption to meet the escalating food demand would exacerbate the strain on already limited resources (Merry*et al*., 2007).

The 2030 Agenda for Sustainable Development, supported by global leaders at the United Nations Sustainable Development Summit in September 2015, marks a significant turning point in the world's approach to sustainable development. Central to this agenda are the 17 Sustainable Development Goals (SDGs), which prioritize the crucial role of food. The primary argument presented in this book is that food is pivotal to achieving the SDGs, and it intends to engage researchers, policymakers, entrepreneurs, and professionals from a range of sectors related to the food industry. The SDGs provide a comprehensive framework that aims to inspire collective efforts towards sustainable development on a global scale. These goals encompass reducing poverty and inequalities, fostering economic growth, and addressing climate change and environmental conservation. This multifaceted agenda implies that we must make immediate and profound changes to our food production and consumption methods. The SDGs highlight the intrinsic link between food and a sustainable future, extending beyond mere sustenance to encompass broader social, economic, and environmental dimensions. Therefore, achieving these goals requires a paradigm shift in our food systems, emphasizing the urgency of transformative changes that align with the aspirations of the 2030 Agenda for Sustainable Development (Valentini *et al*., 2019; Sage *et al*., 2021; Chu *et al*., 2022).

Within the array of Sustainable Development Goals, the 12th goal holds a distinct position. Termed as "Responsible Production and Consumption," this goal places particular emphasis on the inherent challenges confronting agriculture and the intricate food supply chains. At its heart, this goal establishes a precise objective: to halve food waste across various channels, by 2030 (Kumar *et al*., 2022).

Since the mid-1960s, there has been a growing recognition that the current industrial socioeconomic system is not environmentally or socially viable. This awareness gained prominence after the Earth Summit held in Rio de Janeiro in 1992, where the concept of sustainability emerged as a strategic response to address socio-environmental challenges linked to modern societal activities. Since then, sustainability has become a central and formidable issue in international politics. The idea behind sustainable development is based on three interconnected principles: economic progress, environmental preservation, and social equality. Its ultimate objective is to ensure that all societal groups have their needs met in a fair and balanced manner while sustaining the vital resources and ecosystem services provided by natural systems. Sustainable development can be defined as economic growth that satisfies the present needs of humanity while safeguarding the ability of future generations to fulfill their requirements (Ronaldi*et al*., 2021).

Presently, humanity's impact on the planet has significantly disrupted natural cycles. The degradation or loss of crucial ecosystem services can have adverse repercussions on human security, well-being, and biodiversity. There are pressing global challenges associated with the depletion of finite natural resources such as land and water, as well as the capacity of the earth to absorb escalating pollutants like carbon dioxide emissions and methane. Additionally, the burgeoning global population heavily relies on the goods and services furnished by the Earth's ecosystem (such as food, water, and energy). The rapid growth of the global population, particularly in urban areas experiencing robust economic expansion, has led to an increased demand for natural resources. If the consumption of these resources continues to go unregulated, it could have severe implications for both public health and the environment. Although economic growth and the process of global urbanization have benefited human well-being, the increasing demand for natural resources has created mounting pressure on the environment. This pressure, in turn, contributes to climate change and the global warming of our planet (Petkoska*et al*., 2021).

Food production involves substantial water and energy usage, releases pollutants into the air, water, and soil, and is accountable for approximately 11.3% of greenhouse gas emissions within the European Union (EU). The food system of the EU is a major contributor to environmental degradation and loss of biodiversity. At the same time, it fails to provide fair livelihoods to farmers and promotes unhealthy dietary patterns and wastage of food. Europeans need to move towards sustainable food production and consumption practices to effectively reduce global warming. On May 20th, the European Commission introduced its 'Farm to Fork' strategy, which aims to improve the sustainability of the EU food system. The insights garnered from this survey will enable us to play a role in implementing the EU's strategy to ensure that it aligns with the needs and expectations of consumers (The European Consumer Organization, 2020).

The challenges surrounding the sustainability of food systems and our ability to provide nourishment for current and future generations are substantial. These challenges are caused by numerous factors, such as population growth, climate change, depletion of resources, and pollution. It is worth noting that the current agricultural and supply chain systems are a significant contributor to these challenges. (Camarena,2007; Fanzo, 2019)

Food sustainability entails the endeavor to provide sustenance for the global populace both today and in the years to come, not by merely expanding the current agricultural system but by orchestrating its transformation into a novel entity. This undertaking is encumbered by substantial challenges, given its multifaceted nature with numerous contributing factors. Ensuring food security is a complex task that goes beyond meeting the present population's nutritional needs. It requires a long-term approach that safeguards the future generations' well-being. This means considering various aspects, including health and nutrition, social equity, responsible use of natural resources, and animal welfare. Prioritizing soil health is critical to cultivating productive farms that produce healthy food. Similarly, minimizing food waste through sustainable practices is crucial to achieving sustainability. Additionally, equitable distribution of the benefits of food systems beyond affluent nations and urban areas is essential. This includes creating an environment where farmers can thrive and improve overall sustainability. Consumer choices also shape the future of food sustainability. Every decision, from choosing food products to dietary preferences, reflects a vision for the future. To meet the projected global food demand for 2050, significant changes in our dietary habits are necessary. This involves doubling the consumption of fruits, vegetables, nuts, and legumes while reducing red meat and sugar intake by at least fifty percent. Embracing sustainable food choices means prioritizing plant-based options over animal-based ones (Willett *et al*., 2019).

2 Chapter 2

2.1 Nurturing Sustainability: The European Green Deal's Holistic Approach to Climate-Neutral Food Systems

The European Green Deal presents a unique opportunity to harmonize our food system with the planet's needs and cater to the European citizens' aspirations for healthy, fair, and environmentally friendly food. The goal of the European Green Deal is to achieve climate neutrality in the EU by 2050 and the objective of it is to establish the EU food system as a global standard for sustainability. To accomplish this, the European Commission has put forth several measures, such as the Biodiversity Strategy 2030, the Farm to Fork initiative, and the European Climate Law, and requires a collaborative approach involving public authorities at all governance levels (including rural and coastal communities and cities), private-sector players throughout the food value chain, non-governmental organizations, social partners, academics, and citizens. These measures encompass a range of actions aimed at safeguarding soil and encouraging sustainable agriculture (European Commission Report, 2019).

For years, European cuisine has been known worldwide for its safe, nutritious, and high-quality food. This is all thanks to the EU's policies that prioritize the protection of human, animal, and plant health, as well as the challenging work of farmers, fishers, and aquaculture producers. But now, it is time for Europe to take the lead in sustainability as well. The new strategy aims to incentivize those who have already adopted sustainable practices, help others transition, and create new opportunities for their businesses. The EU's agricultural system is the only major system in the world that has managed to reduce greenhouse gas emissions, achieving a 20% decrease since 1990. However, this progress has not been consistent across all member states. Additionally, the production, processing, packaging, transportation, and retailing of food contribute significantly to pollution, greenhouse gas emissions, and biodiversity loss. While the EU has made strides in transitioning to sustainable food systems, food systems remain one of the primary causes of climate change and environmental damage (Eurostat, 2019).

2.1.1 Farm-to-Fork Strategy

The Farm to Fork Strategy, integral to the Green Deal, takes a holistic approach to address sustainable food systems' challenges. Recognizing the interconnectedness of healthy individuals, societies, and the planet, aligns with the United Nations' Sustainable Development Goals. Embracing a sustainable food system promises environmental, health, and social progress, fostering economic growth. Prioritizing primary producers' sustainable livelihoods is crucial for a successful recovery and addressing income disparities.

This strategy innovatively promotes food sustainability in Europe, creating a conducive food environment for adopting healthy and sustainable diets. It aims to improve lifestyles, enhance health outcomes, and reduce societal costs linked to health issues. In response to growing concerns about sustainability, ethics, and social responsibility in food, individuals, even in urban areas, seek a connection to fresh, minimally processed, and sustainably sourced options. The COVID-19 pandemic has underscored the importance of shorter supply chains. Empowering consumers to make sustainable choices is pivotal, requiring collective responsibility from all stakeholders in the food industry to prioritize sustainability and recognize the opportunities it presents (BSDC, 2017; Eurostat, 2019; European Commission, 2019).

Figure 2-1Farm-to-Fork Strategies

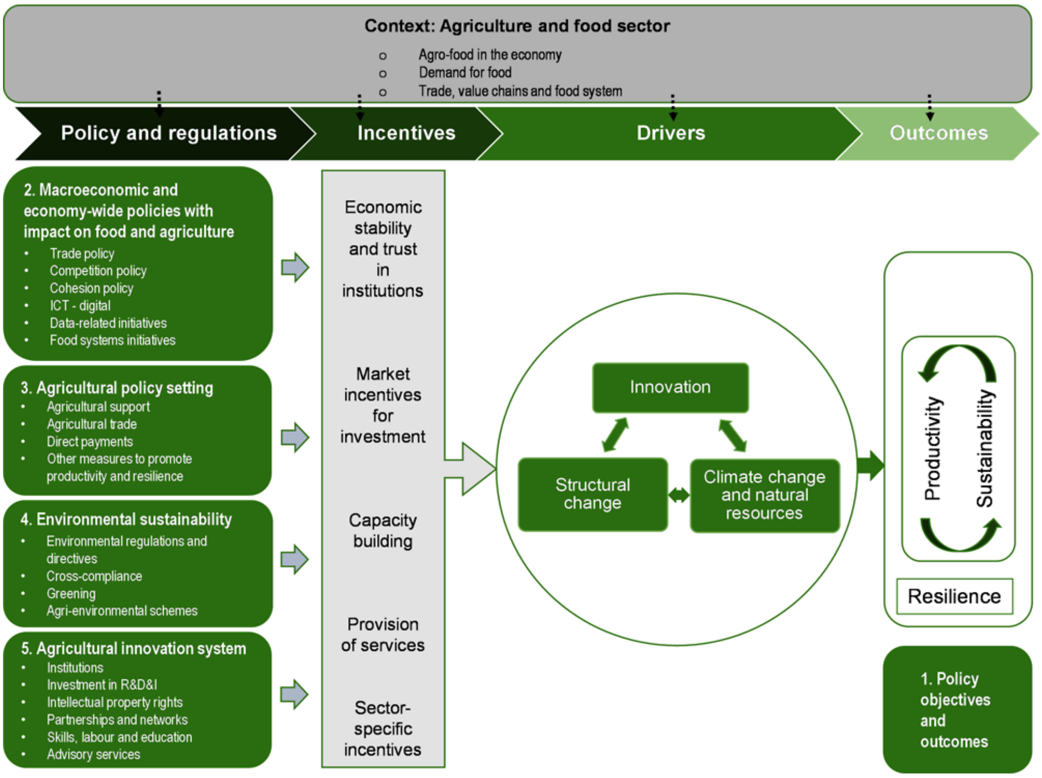


Figure 2-2 Policies and Regulations

2.1.2 Nurturing a Holistic and Inclusive European Food System

To build a food system that is sustainable and beneficial for all, it is crucial to reduce our reliance on pesticides and antimicrobial agents, minimize excessive fertilization, increase organic farming, improve animal welfare, and reverse the decline of biodiversity. Moreover, transitioning to sustainable food systems presents significant economic potential. As consumers' expectations evolve, the food market is undergoing substantial changes, providing an opportunity for farmers, fishers, and aquaculture producers, as well as food processors and services, to establish sustainability as their hallmark. By embracing sustainability, these entities can secure the future of the EU food chain before their competitors outside the EU have the chance to do the same. This shift towards sustainability creates a 'first mover' advantage for all players within the EU food chain(Eurostat, 2021).

For a successful transition, it is necessary to shift people's diets. However, within the EU, a considerable number of people - approximately 33 million - cannot afford a quality meal every other day, making food assistance crucial for part of the population in many Member States. The challenge of food insecurity and affordability during an economic downturn is a significant concern, making it imperative to act promptly to change consumption patterns and prevent food waste. Despite producing enough food, around 20% of it goes to waste, while obesity rates continue to rise. More than half of the adult population is now overweight, leading to a high prevalence of diet-related illnesses such as cancer, which results in elevated healthcare costs. In general, European diets do not align with national dietary recommendations, and the food environment does not ensure that the healthiest options are always the easiest to access. Aligning European diets with dietary recommendations would significantly decrease the environmental footprint of food systems (Eurostat, 2018; EU Fusions, 2016; Eurostat, 2023; Nutrition and Food Systems, 2017).

2.1.3 Nurturing Global Food Harmony: The EU's Role in Sustainable Food Systems

The EU, as a major player in the global food market, recognizes its pivotal role in shaping the trajectory of the global food system. Acknowledging the potential negative environmental and social impacts of commodity production abroad, the EU emphasizes the necessity for sustainable food system initiatives supported by global policies. This ensures that unsustainable practices are curbed beyond the EU's borders. The pursuit of a sustainable food system aligns with the Green Deal's environmental and climate objectives and aims to uplift the livelihoods of primary producers while enhancing the EU's competitiveness.

The EU envisions a future where its food system minimizes environmental and climate impact, addressing challenges like climate change and biodiversity loss. This transformative approach involves creating a food chain with a neutral or positive environmental impact, ensuring universal access to healthy food, maintaining affordability, and guaranteeing fair economic returns throughout the supply chain. The EU, aware of the global nature of the challenge, commits to establishing worldwide standards through strategic objectives. It emphasizes the importance of enforcing existing regulations related to animal welfare, pesticide usage, and environmental preservation while introducing new policies. The EU's sustainable food system development strategy recognizes regional variations among Member States, considering diverse starting points and potential improvements. To facilitate this transition, existing EU mechanisms, including cohesion funds and the European Agricultural Fund for Rural Development (EAFRD), will provide technical and financial support (European Commission, 2020; EAFRD, 2020).

2.1.4 Paving the Way for a Sustainable Food Future: EU's Better Regulation Approach

The European Commission will utilize better regulation tools in the development of new legislative initiatives, which will involve public consultations, environmental, social, and economic impact assessments, and analyses of the impact on small and medium-sized enterprises (SMEs) during the transition. Efficient policy decisions that align with the Green Deal objectives will depend on impact assessments. By the end of 2023, the European Commission will propose a legislative framework for a sustainable food system that will expedite and facilitate the transition while promoting policy coherence at both the EU and national levels. This framework will integrate sustainability into every food-related policy and strengthen the resilience of food systems. Following consultation and impact assessment procedures, the European Commission will work towards establishing common definitions, principles, and requirements for sustainable food systems and food products while specifying the responsibilities of all stakeholders involved in the food system. The introduction of certification and labeling mechanisms that assess the sustainability performance of food products and incentivize sustainable practices will encourage operators to embrace sustainability practices and gradually elevate the standards to become the norm for all food products available in the EU market(European Commission, 2020).

The formulation of a sustainable food policy across national, regional, and local assemblies is encouraged by the Commission. They invite all citizens and stakeholders to take part in a broad debate on the matter. The Commission also urges the European Parliament and Council to endorse the strategy and facilitate its implementation. A coordinated approach will be taken by the Commission to encourage citizen participation and transform food systems. The Commission will ensure close coherence between this strategy and other aspects of the Green Deal, such as the Zero Pollution ambition, the new CEAP, and the Biodiversity Strategy for 2030. Progress on targets and the reduction of the EU food system's environmental and climate footprint will be monitored to keep the transition to a sustainable food system within planetary boundaries. The Commission will conduct regular data collection, including Earth observation, to comprehensively evaluate the strategy's cumulative impact on competitiveness, the environment, and health(FAO, 2019).

2.1.5 Transforming EU Dietary Habits

The dietary habits of European Union citizens pose health and environmental concerns as they lack sufficient whole-grain cereals, fruits, vegetables, legumes, and nuts. Instead, they consume excessive amounts of energy, red meat, sugars, salt, and fats, which exceed the recommended intake. The prevalence of overweight and obesity in the European Union is expected to increase by 2030, and adopting a plant-based diet with less red and processed meats while increasing fruit and vegetable intake is crucial to addressing this issue. Such a dietary shift can reduce the risk of life-threatening diseases and positively impact the environment. In 2017, unhealthy dietary habits resulted in over 950,000 deaths and a loss of over sixteen million healthy life years in the European Union, primarily due to cardiovascular diseases and various forms of cancer. The European Union's 'Beating Cancer' plan underscores the significance of promoting healthy eating habits as a key part of cancer prevention (European Commission, 2020; Willett *et al*., 2019).

2.1.6 Empowering Consumers

To aid consumers in making informed choices, the European Commission has proposed the implementation of standardized and compulsory front-of-pack nutritional labeling. Additionally, the Commission will investigate approaches to standardize voluntary environmental claims and create a comprehensive labeling structure that encompasses the nutritional, environmental, climatic, and social aspects of food products. The Commission plans to explore new ways of disseminating information to consumers. Furthermore, it will establish minimal obligatory standards for sustainable food procurement to encourage the availability and affordability of sustainable food items and promote healthy and sustainable diets in institutional catering. This initiative will help local and regional authorities, as well as public institutions, to source sustainable food for schools, hospitals, and governmental establishments. Finally, the Commission will continue to maintain high sustainability standards in its catering contracts and will also evaluate the European Union school scheme to enhance its role in promoting sustainable food consumption and educating people about the importance of healthy nutrition, sustainable food production, and food waste reduction (Europarl.europa.eu., 2023).

2.1.7 Reducing Food Waste

The goal of the Commission is to reduce food waste by 50% per capita at retail and consumer levels by the year 2030 in line with SDG Target 12.3. With the help of the new food waste measurement methodology and data expected from Member States in 2022, the Commission aims to establish a baseline and propose legally binding objectives to reduce food waste throughout the EU. The Commission will additionally include measures to prevent food loss and waste in other EU policies. Food wastecan result from misunderstanding and misusing date marking ('use by' and 'best before' dates) (EU., 2019). Hence, the Commission plans to revise EU regulations to reflect consumer research. The Commission plans to investigate food losses during the production phase and seek methods to prevent them, as well as measure levels of food waste.By coordinating action at the EU level, the Commission expects to reinforce action at the national level, and the EU Platform on Food Losses and Food Waste will provide recommendations to assist all players in moving forward (ec.europa.eu., 2019).

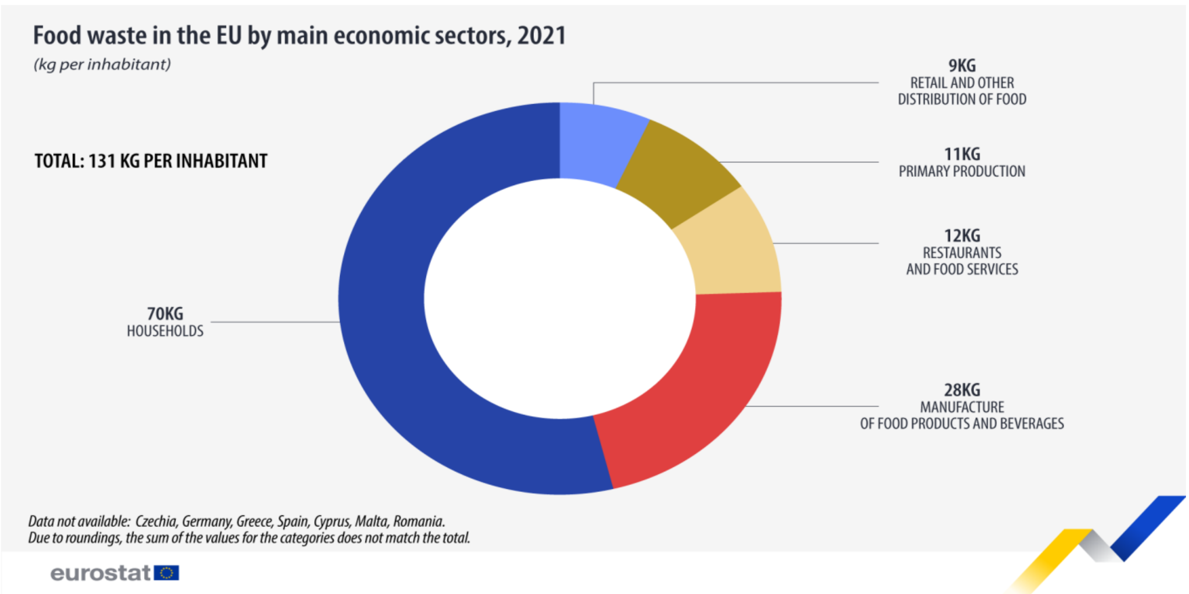


Figure 2-3 Food waste in EU, 2021

2.1.8 The Role of Research and Innovation

Research and innovation (R&I) play a crucial role in speeding up the shift towards sustainable, healthy, and inclusive food systems - from the start of production to consumption. R&I is instrumental in devising and testing solutions to overcome hurdles and explore new opportunities in the market (European Research and Innovation for Food and Nutrition Security, 2016).

Horizon Europe proposes to allocate EUR 10 billion to R&I in the areas of food, economy, natural resources, agriculture, fisheries, aquaculture, and the environment, in addition to digital technologies and nature-based solutions for agri-food. A key area of research will center on microbiomes, food from oceans, urban food systems, and the availability and source of alternative proteins such as plant, microbial, marine, and insect-based proteins, and meat substitutes. A mission in the soil health and food sector will focus on developing remedies for restoring soil health and functions. To scale up agroecological approaches in primary production, a dedicated partnership on agroecology living laboratories will be set up to enhance research and innovation. This will contribute to reducing the use of pesticides, fertilizers, and antimicrobials. To accelerate innovation and the exchange of knowledge, the Commission will collaborate with member states to enhance the importance of the European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) in the Strategic Plans. Additionally, the European Regional Development Fund will encourage innovation and collaboration along food value chains through smart specialization investment.

A partnership named Safe and Sustainable Food Systems for People, planet, and Climate under Horizon Europe will establish a governance mechanism for research and innovation involving Member States and food systems participants from farm to fork. The objective is to deliver creative solutions that benefit nutrition, food quality, climate, circularity, and communities. The European Union will assist the world in transitioning to sustainable agri-food systems, aligning with the objectives of this strategy and the Sustainable Development Goals (SDGs). The creation of Green Alliances on sustainable food systems with all its partners in bilateral, regional, and multilateral forums through its external policies, such as international cooperation and trade policy, will be pursued by the EU. It will include collaboration with Africa, neighboring countries, and other partners, considering the unique challenges in distinct parts of the world. The EU will promote and support the creation of inclusive, interconnected initiatives that promote the well-being of humans, the environment, and economic advancement to guarantee a smooth global shift (European Commission, 2020)

2.2 Revitalizing Europe's Ecosystems: The EU's 2030 Biodiversity Strategy

The European Union's 2030 Biodiversity Strategy outlines a comprehensive plan of promises and initiatives aimed at restoring Europe's biodiversity by 2030. This effort is geared toward benefiting individuals, the environment, the climate, and the economy aligning with both the 2030 Sustainable Development Agenda and the goals of the Paris Agreement on Climate Change.

2.2.1 Urgent Action Required to Address Biodiversity

The Strategy's objective is to tackle the primary drivers of biodiversity decline, bolster governance, close policy gaps, and reinforce existing initiatives while ensuring the full execution of current EU laws. Safeguarding and reviving nature necessitates more than just regulations; it demands engagement from citizens, businesses, social partners, the research community, and robust collaborations across local, regional, national, and European levels. The Strategy outlines steps to galvanize these actions and enable transformative change.

Biodiversity and climate crises are fundamentally interconnected. Climate change expedites natural world degradation through events like droughts, floods, and wildfires, and the loss and unsustainable utilization of nature, in turn, contributes to climate change. The crises are interconnected, and so are the remedies. Nature plays a role in climate regulation, and nature-based solutions, such as safeguarding and restoring wetlands, peat lands, coastal ecosystems, and sustainable management of marine areas, forests, grasslands, and soils, are crucial for reducing emissions and adapting to climate change. Since biodiversity, climate, and economic crises are interrelated, actions taken to address each of these issues must be coherent and mutually supportive. Experience has demonstrated that what benefits nature also benefits the economy. It is no longer a matter of choosing between nature and the economy, but rather a necessity to make them mutually beneficial for the well-being of society.

This is why the EU Biodiversity Strategy plays a significant role in both the EU's Green Deal and its economic Recovery Package. These initiatives signify a renewed commitment to building our economy's strength and competitiveness on sustainability, paving the way for a future that prioritizes resource efficiency, climate neutrality, and social equity. Biodiversity preservation offers direct economic advantages for numerous sectors. For instance, safeguarding marine resources could boost the annual profits of the seafood industry by over €49 billion, while the preservation of coastal wetlands could save the insurance industry approximately €50 billion annually by reducing flood-related damage costs. Moreover, an effective global program for preserving the world's remaining natural habitats is estimated to yield a benefit-to-cost ratio of at least 100 to 1. (BSDC, 2017; Eurostat, 2019)

2.2.2 Revitalizing Earth: A Call for Sustainable Recovery and Biodiversity Restoration

Investing in natural capital, which includes activities like restoring carbon-rich habitats and implementing climate-friendly agriculture, is acknowledged as one of the top five essential fiscal recovery strategies. These initiatives have the potential to yield substantial economic benefits and positively impact the climate. Leveraging this potential will be crucial for the EU to ensure prosperity, sustainability, and resilience in its recovery efforts. Furthermore, biodiversity plays a pivotal role in securing both EU and global food supplies. Biodiversity decline poses a threat to our food systems, jeopardizing food security and nutritional well-being. Biodiversity also forms the foundation for nutritious diets, enhances rural livelihoods, and boosts agricultural productivity. For example, over 75% of global food crops depend on animal pollination (Eurostat,2018 &EU Fusions, 2016 &EC.europa.eu., 2019)

Despite the pressing ethical, economic, and environmental necessity, nature is currently experiencing a crisis. The primary culprits behind biodiversity decline alterations in land and sea usage, overexploitation, climate change, pollution, and invasive non-native species – are causing nature to vanish rapidly (Commission Delegated Decision (EU) 2019). These changes are observable in our daily lives: urban structures encroaching on green areas, the vanishing of wilderness right before our eyes, and an increasing number of species facing the threat of extinction, a situation unparalleled in human history. Over the past four decades, global wildlife populations have plummeted by 60% due to human activities. Furthermore, three-quarters of the Earth's surface has undergone modifications, pushing nature into increasingly smaller pockets on the planet (Europarl.europa.eu., 2023).

2.2.2.1 Interconnected Solutions for Biodiversity and Climate Resilience

The biodiversity crisis and the climate crisis are inherently interconnected. Climate change intensifies the degradation of the natural environment through events like droughts, floods, and wildfires, and, conversely, the loss and unsustainable exploitation of nature are fundamental contributors to climate change. However, just as these crises are intertwined, so are the solutions. Nature plays a crucial role in combating climate change. It acts as a climate regulator, and nature-based approaches, such as safeguarding and rejuvenating wetlands, peat lands, and coastal ecosystems, or the sustainable management of marine regions, forests, grasslands, and agricultural soils, are indispensable for reducing emissions and adapting to a changing climate. The planting of trees and the implementation of green infrastructure will assist in cooling urban areas and mitigating the impact of natural disasters (Nutrition and Food Systems, 2017).

Biodiversity decline and the collapse of ecosystems represent one of the most significant threats to humanity in the coming decade. They also jeopardize the foundations of the economy, and the costs of inaction are considerable and expected to rise. For example, the world suffered estimated annual losses ranging from €3.5 trillion to €18.5 trillion due to changes in land cover between 1997 and 2011, along with losses of about €5.5 trillion to €10.5 trillion annually from land degradation (European Commission, 2019). More specifically, the diminishing biodiversity leads to decreased crop yields and fish catches, heightened economic damage from floods and other disasters, and the loss of potential new sources of medicine.

All new initiatives and proposals will be guided by the Commission's improved regulatory tools. Through public consultations and evaluations of environmental, social, and economic impacts, impact assessments will contribute to ensuring that all initiatives achieve their goals in the most efficient and least burdensome manner, upholding a commitment to a green oath of do not harm (European Commission, 2020).

2.2.3 Safeguarding and rejuvenating the natural environment within the European Union

The EU has established legal frameworks, strategies, and action plans for the preservation of nature and the revival of ecosystems and species. However, these efforts have fallen short in terms of comprehensiveness, scale of restoration, and the effective enforcement of legislation.

To set biodiversity on the course of recovery by 2030, it is imperative to enhance both the protection and revitalization of nature. This can be achieved by enhancing and expanding our network of protected areas and by formulating an ambitious EU Nature Restoration Plan (European Research & Innovation for Food & Nutrition Security, 2016).

2.2.3.1 Charting a Sustainable Future: EU's Ambitious Biodiversity and Economic Recovery Blueprint

For the benefit of both our environment and the European economy, and to aid the EU's rebound from the COVID-19 pandemic, it is essential to increase our conservation efforts. In line with this goal, a minimum of 30% of the land and 30% of the sea within the EU should be designated as protected areas. This represents a minimum expansion of 4% for land and 19% for marine areas compared to the current levels. This target aligns perfectly with the proposals outlined in the forthcoming post-2020 global biodiversity framework (European Commission, 2019).

Particular attention should be directed towards regions with exceptionally high biodiversity significance or potential. These areas, which are the most susceptible to climate change, ought to receive special attention through rigorous protective measures. Currently, only 3% of terrestrial and less than 1% of marine territories in the EU fall under strict protection. Protecting these areas requires more effort. Therefore, at least one-third of protected areas, accounting for 10% of EU land and 10% of EU marine environments, should be designated for strict protection. This aligns with the global aspiration being proposed as well (European Commission, 2019).

Furthermore, to establish a genuinely unified and robust Trans-European Nature Network, it's crucial to establish ecological pathways that prevent genetic isolation, facilitate species migration, and uphold and enhance the health of ecosystems. In this regard, investments in green and blue infrastructure should be encouraged and backed, as well as cross-border collaboration among Member States, including through the European Territorial Cooperation (Eurostat, 2019).

Safeguarding existing nature will not suffice to reintegrate nature into daily existence. To counteract biodiversity decline, a more ambitious approach to nature restoration is required worldwide. With the introduction of the EU's Nature Restoration Plan, Europe will take the lead in this endeavor.

2.2.3.2 Addressing Deficiencies: Enhancing Nature Restoration Legislation in the EU

While some degree of nature restoration is currently mandated by existing EU legislation for Member States, substantial gaps in execution and regulation are impeding progress (European Commission, 2020). For instance, there is no mandate for Member States to establish biodiversity restoration plans. Clear, binding targets and timelines are not consistently specified, and there is a lack of definitions or criteria regarding restoration or the sustainable utilization of ecosystems. Furthermore, there is no obligation to systematically map, monitor, or assess ecosystem services, health, or restoration initiatives. These issues are further exacerbated by implementation shortfalls that hinder the realization of the intended objectives outlined in the existing legislation (Eurostat, 2019).

2.2.3.3 2-2-2-3 EU Forest Strategy 2021: Nurturing Resilient Ecosystems for Biodiversity and Climate Harmony

Forests hold immense importance for biodiversity, climate regulation, water management, the provision of food, medicines, and resources, carbon capture and storage, soil stabilization, as well as air and water purification. They also serve as natural settings for recreation and environmental education. Foresters play a critical role in ensuring sustainable forest management and the preservation and enhancement of biodiversity within forests. In addition to enforcing strict protection measures for all remaining primary and ancient EU forests, the European Union must work towards increasing the quantity, quality, and resilience of its forests, particularly concerning factors such as fires, droughts, pests, diseases, and other threats, which are likely to intensify with climate change. To maintain their essential functions for both biodiversity and climate, it's imperative to maintain the overall health of all forests. A stronger economy can be supported by more durable forests, and they are essential to the circular economy by supplying materials, products, and services. To realize these goals, the Commission will introduce a strategy that encompasses a plan to plant at least three billion trees in the EU by 2030, with full adherence to ecological principles. This effort will create significant employment opportunities linked to seed collection, seedling cultivation, and their subsequent growth. Tree planting is particularly advantageous in urban areas and can be complemented in rural regions with agroforestry, landscape features, and increased carbon capture. Concurrently, the Commission will continue collaborating with Member States to ensure the EU is adequately prepared to prevent and respond to substantial forest fires, which can cause extensive harm to forest biodiversity.

To gain a more comprehensive understanding of European forest health, the Commission will collaborate with other data providers to enhance the Forest Information System for Europe. This system will facilitate real-time assessments of the status of European forests and connect all EU forest-data platforms, a part of the forthcoming EU Forest Strategy (European Commission, 2019).

2.2.3.4 2-2-2-4 Safeguarding Seas: A Call to Action for the Revitalization and Preservation of European Marine Ecosystems

Reviving and adequately safeguarding marine ecosystems offers significant advantages in terms of public health, societal well-being, and economic prosperity for coastal communities and the entire European Union. The urgency for more decisive action is heightened by the fact that the loss of biodiversity in marine and coastal ecosystems is further exacerbated by global warming. The pursuit of an optimal environmental state for marine ecosystems, which includes the establishment of strictly protected areas, should encompass the rejuvenation of carbon-rich ecosystems and critical fish breeding and nursery grounds. Some current maritime activities pose threats to food security, the livelihoods of fishers, and the sustainability of the fisheries and seafood industries. It is essential to ensure the sustainable harvesting of marine resources and take a zero-tolerance approach towards illegal practices. In this context, the comprehensive implementation of the EU's Common Fisheries Policy, the Marine Strategy Framework Directive, and the Birds and Habitats Directives is of utmost importance (European Commission, 2020).

2.2.3.5 2-2-2-5 Revitalizing Europe's Waters: Overcoming Implementation Challenges in EU Water Management

The European Union has an ambitious legal framework for water management, but its practical implementation lags, necessitating an intensified enforcement effort(Hepburn *et al.*, 2020). To fulfill the goals of the Water Framework Directive, there is a pressing need to revitalize freshwater ecosystems and the inherent functions of rivers. This can be accomplished by addressing or adapting obstacles that hinder the migration of fish and enhancing water and sediment flow. To facilitate this, a target of restoring at least 25,000 kilometers of rivers into free-flowing conditions by 2030 will be pursued, primarily through the removal of outdated barriers and the rehabilitation of floodplains and wetlands. In 2021, the European Commission, in collaboration with relevant authorities, will provide technical guidance and assistance to Member States in identifying suitable sites and mobilizing funding for these efforts. Furthermore, Member State authorities should review permits for water abstraction and impoundment to implement ecological flow requirements, aiming to achieve a good status or potential for all surface waters and good status for all groundwater by 2027, as mandated by the Water Framework Directive. In support of this objective, the Commission will offer technical assistance to Member States for their measures by 2023 (europa.eu., 2019&europa.eu., 2022).

2.2.3.6 2-2-2-6 Enhancing the EU Framework for Pollution Mitigation

Pollution represents a significant driver of biodiversity decline and poses detrimental effects on both human health and the environment. Despite the European Union having established a robust legal framework for pollution mitigation, additional measures are essential. Biodiversity is adversely affected by the discharge of nutrients, chemical pesticides, pharmaceuticals, hazardous substances, urban and industrial wastewater, and various forms of waste, including litter and plastics. It is imperative to address and alleviate all these environmental stressors.

2.2.4 Fostering revolutionary change

Within the European Union, there is currently a lack of an all-encompassing governance structure to oversee the execution of biodiversity agreements at national, European, or international levels. To bridge this gap, the Commission intends to establish a fresh European framework for biodiversity governance. This framework will serve the purpose of identifying obligations and commitments, while also providing a roadmap for their effective implementation.

As a component of this new framework, the Commission will institute a monitoring and assessment mechanism. This system will encompass a well-defined set of mutually agreed indicators, facilitating periodic progress evaluations and prescribing corrective measures when needed. This mechanism will contribute to the Environmental Implementation Review and become a part of the European Semester process.

Effective implementation and enforcement are the cornerstones of all environmental laws. In the past three decades, the EU has established a robust legal framework aimed at safeguarding and revitalizing its natural assets (FAO, 2019). Nevertheless, recent assessments indicate that despite the suitability of the legislation, practical implementation falls short of expectations. This discrepancy is having profound repercussions on biodiversity and is accompanied by significant economic implications. Consequently, the strategy places a strong emphasis on the complete implementation and enforcement of EU environmental laws, highlighting the need for prioritizing political backing, financial resources, and human capital to achieve this goal (European Commission, 2020).

In the collaborative spirit of this strategy, all sectors of the economy and society must contribute. Industry and business not only impact nature but also generate valuable innovations, partnerships, and expertise that can aid in addressing biodiversity loss.

Addressing biodiversity decline and restoring ecosystems will necessitate substantial public and private investments at both the national and European levels. This involves optimizing the utilization of all pertinent EU programs and financial instruments. The Commission will enhance its biodiversity assessment framework, including the judicious application of criteria outlined in the EU taxonomy, to ensure that EU funding promotes environmentally friendly investments (European Commission, 2019).

Efforts to combat biodiversity loss should be firmly grounded in solid scientific research. Investing in research, innovation, and the exchange of knowledge will be pivotal in acquiring the best data and developing optimal nature-based solutions. Research and innovation can assess and refine the prioritization of 'green' solutions over 'grey' ones and assist the Commission in supporting investments in nature-based solutions, particularly in regions that have faced industrial decline, economic challenges, or disaster impacts.

2.2.5 The European Union is advocating for a bold global biodiversity agenda.

Biodiversity holds a prominent position within the EU's external actions and is an integral component of its endeavors to achieve the United Nations Sustainable Development Goals. Biodiversity considerations will be incorporated into bilateral and multilateral interactions through the EU's 'Green Deal diplomacy' and forthcoming green alliances. The Commission will collaborate closely with the European Parliament and Member States to ensure an elevated level of EU ambition and mobilize collective efforts to benefit global biodiversity.

Safeguarding biodiversity is a worldwide challenge, and the upcoming decade will be crucial. Previous global initiatives under the United Nations Convention on Biological Diversity have often fallen short of the mark. Nature cannot afford any partial measures or a lack of ambition.

2.2.5.1 EU's Vision for Global Ocean Conservation: A Commitment to Biodiversity Beyond Borders

By the International Ocean Governance agenda, the EU supported the establishment of a robust legally binding agreement on marine biological diversity in areas beyond national jurisdiction (BBNJ) by the end of 2020. This agreement was to define global procedures for the identification, designation, and effective management of ecologically representative marine protected areas in international waters. Swift ratification and implementation of this agreement were of utmost importance. Furthermore, the EU was to leverage its diplomatic influence and outreach capabilities to facilitate an agreement on the creation of three extensive Marine Protected Areas in the Southern Ocean, two of which were jointly proposed by the EU for East Antarctica and the Weddell Sea. If approved, this would have represented a monumental step in the history of nature conservation (Willett *et al.*, 2019).

The collaboration has persisted with partner countries and regional organizations to implement measures for safeguarding and sustainably using fragile marine ecosystems and species, particularly in areas beyond national jurisdiction, with a specific focus on marine biodiversity hotspots. The EU has also continued its support for Small Island Developing States and other pertinent partner countries in their participation in regional and global forums and the implementation of relevant international commitments and regulations (European Commission, 2020 & World Resources Institute, 2019).

Trade policy actively contributed to and was integrated into the ecological transition. To achieve this, the Commission guaranteed the comprehensive implementation and enforcement of biodiversity clauses in all trade agreements, with the involvement of the EU Chief Trade Enforcement Officer. The Commission enhanced its evaluation of the impact of trade agreements on biodiversity, taking follow-up measures to reinforce biodiversity provisions in both existing and future agreements, where applicable. In 2021, the Commission also presented a legislative proposal and other measures aimed at preventing or minimizing the introduction of products linked to deforestation or forest degradation into the EU market. These actions also encouraged imports and supply chains that are considered forest conservation (European Commission, 2020).

The Commission took a series of actions to combat illegal wildlife trade, which was a significant contributor to the depletion or extinction of entire species. It ranked as the world's fourth most lucrative illicit market and was believed to be a potential factor in the emergence of zoonotic diseases. It was a collective responsibility, both morally and environmentally, to dismantle this trade.

Preserving and revitalizing biodiversity is the sole means to ensure the quality and continuity of human life on Earth. The commitments outlined in this strategy lay the foundation for ambitious and imperative changes, ensuring the well-being and economic prosperity of current and future generations within a healthy environment. The execution of these commitments will be mindful of the diverse challenges spanning different sectors, regions, and Member States. It will also acknowledge the necessity of ensuring social justice, fairness, and inclusiveness by the European Pillar of Social Rights. Achieving these goals will require a profound sense of responsibility and robust collaboration between the EU, its Member States, stakeholders, and citizens.

The Commission invited the European Parliament and the Council to endorse this strategy ahead of the 15th Conference of the Parties to the Convention on Biological Diversity. To guarantee full political commitment to this strategy, the Commission proposed a regular progress review within both the Council and the European Parliament. A comprehensive review of the strategy will be conducted by 2024 to assess progress and determine if further action is necessary to achieve its objectives.

The European Commission did indeed launch a significant initiative called the "European Green Deal Call" in 2020. This call for proposals was part of the Horizon 2020 program, with a substantial budget of approximately EUR 1 billion. The objective of this initiative was to fund projects aligned with the priorities outlined in the European Green Deal. The European Green Deal is a comprehensive plan to make the EU's economy sustainable by transforming it into a green and circular economy. The call aimed to support projects contributing to environmental sustainability, climate action, and green innovation. This initiative reflects the EU's commitment to addressing environmental challenges and promoting a greener future.

2.3 Nurturing Earth's Foundations: The EU's Vision for Healthy Soils by 2050

The European Union has set a goal to achieve good soil health by 2050, which involves ensuring that all soil ecosystems are in good condition and more resilient. To achieve this, significant changes are needed in the next decade with a focus on protecting, sustainably using, and restoring soil becoming the norm. Healthy soil plays a vital role in achieving climate neutrality, developing a clean and circular economy, reversing biodiversity loss, safeguarding human health, and halting desertification. The EU's biodiversity strategy for 2030 and the Climate Adaptation Strategy are both anchored in this vision. The Soil Strategy builds on the objectives of the Green Deal and aims to combat desertification, restore degraded land and soil, achieve a land degradation-neutral world, restore significant areas of degraded and carbon-rich ecosystems, achieve a net greenhouse gas removal of 310 million tons of CO2 equivalent per year for the land use, land use change, and forestry sector, reach good ecological and chemical status in surface waters and groundwater by 2027, reduce nutrient losses by at least 50%, and reduce the overall use and risk of chemical pesticides (Montanarella, 2007&Arrouays *et al*., 2008).

Figure 2-4 links between the EU Soil Strategy and other EU initiatives.

The health and viability of Europe's soils are essential to support human activities and ecosystems. To counteract negative trends, the European Commission is developing a strategy that establishes a unified framework for action within the European Union. This framework aims to safeguard, preserve, and rehabilitate soil quality while giving Member States the flexibility to adapt the strategy to their specific local conditions effectively. The Thematic Strategy on soil protection includes a Communication and a legislative proposal, which may require Member States to address issues such as landslides, pollution, erosion, diminishing organic content, soil compaction, salinization, and sealing on their national territories (Montanarella, 2010).

The European Commission has issued a comprehensive report concerning the EU Soil Strategy for 2030, with the primary objective of safeguarding and preserving the multifaceted benefits of healthy soils for the welfare of individuals, sustenance, biodiversity, and climatic stability. The report underscores the pivotal role of soil in facilitating the provision of sustenance, biomass, fibrous materials, and raw resources, as well as regulating essential ecological processes involving water, carbon, and nutrient cycles. Furthermore, the document emphasizes the preeminent status of healthy soils as the largest terrestrial reservoir of carbon globally, underscoring their paramount significance in the realm of climate change mitigation and adaptation. The EU possesses a diverse array of soil types, encompassing 24 out of the world's 32 principal soil categories, underscoring the richness of its soil patrimony. Nevertheless, prevailing estimates indicate that approximately 60 to 70% of soils within the EU exhibit signs of diminished vitality. This decline in soil health is attributable to pronounced degradation processes, including erosion, compaction, organic material degradation, contamination, diminution of biodiversity, salinization, and sealing. These adverse developments are a direct consequence of unsustainable land utilization and management practices, excessive exploitation, and the emission of environmental contaminants (Arrouays, 2008).

To fully harness the benefits of healthy soils for the benefit of people, food, nature, and the climate, the EU is calling for a revitalized Soil Strategy. This strategy will

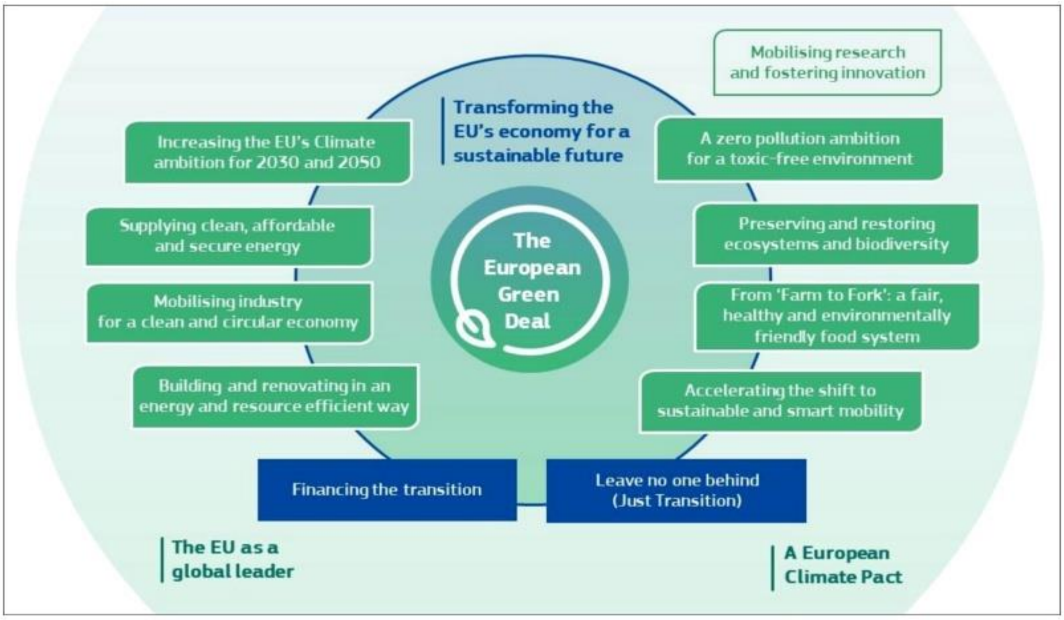


Figure 2-5 soil strategy

provide a comprehensive framework and set of specific actions for the protection, restoration, and sustainable use of soil while working in synergy with other EU policies stemming from the European Green Deal. It will serve as the cornerstone for global soil action at the international level. Achieving this objective will require the implementation of new measures, both voluntary and legally binding, that respect subsidiarity and build upon existing national soil policies (Panagiotakis, 2022).

Ensuring that soil receives the same level of protection as air, water, and marine environments is an important challenge. This requires considering the significance of soil-dwelling organisms. To achieve this goal, we need to strive for comprehensive and inclusive governance structures at national, EU, and global levels. All relevant stakeholders should be involved in discussions and collaboration. To facilitate this, we will establish the EU Coalition4HealthySoils (C4HS), modeled after the successful Coalition4Oceans. At its core, C4HS will expand the EU Soil Expert Group to include a well-balanced representation of stakeholders. Policy decisions will rely on data and insights from the EU Soil Observatory, the EIONET National Reference Centre on Soil, and the Mission 'A Soil Deal for Europe.' C4HS will also work with other relevant EU expert groups, the Global Soil Partnership, and its European Soil Partnership. The EU has always been a dedicated supporter of the FAO's Global Soil Partnership and its regional divisions. We will continue to support the partnership to enhance governance in sustainable soil management at both regional and global levels. This strategy outlines the vision and commitments needed to bring about ambitious and necessary changes (European Commission, 2021; European Commission, 2005; Enydron, 2021).

2.3.1 Soil Erosion and Reuse

Every year in Europe, approximately one billion tons of soil are lost due to erosion. From 2012 to 2018, the EU lost more than 400 km² of land annually on a net basis. Croplands and grasslands in the EU provide ecosystem services worth EUR 76 billion per year, of which less than one-third come from crop production, while the remaining comes from other ecosystem services. It makes economic sense to invest in preventing and restoring soil degradation because healthy soils sustain various sectors of the economy, whereas soil degradation costs the EU several tens of billion Euros per year. Practices that support and improve soil health and biodiversity not only enhance cost efficiency but also limit the inputs required to maintain yields. Stopping and reversing the current trends of soil degradation globally could generate up to EUR 1.2 trillion per year in economic benefits (FAO, 2020).

Figure 2-6- Soil health: Reaping the benefits of healthy soils
Source: European Union, 2021

The EU has introduced a new Soil Strategy that aims to set achievable and specific priorities for the reuse of excavated soil. The strategy primarily focuses on investigating the flows of generated, treated, and reused excavated soil and aims to assess the market situation in Member States by 2023. In addition, the new EU Soil Strategy will be an assessment of the necessity and feasibility of implementing obligatory regulations for a 'soil passport' for excavated soil. This passport will reflect the quantity and quality of the excavated soil and ensure safe transportation, treatment, and reuse (Olazábal, 2006).

3 Chapter 3

3.1 Food Footprints

Environmental footprints are indicators that can be used to estimate the impacts of diet on the environment (Souza *et al*., 2022), in other words, the environmental impacts resulting from food demands have been termed by some "food print" (Billen *et al*., 2008; Chatzimpiros & Barles, 2013). A variety of environmental factors and global influences are currently posing challenges to agriculture. These emerging problems have immense challenges to local food security, with serious implications for the environment and global peace and security (Khan & Hanjra, 2009). Food production can negatively impact human health and modern society's food choices have been associated with impacts on the environment and the health of individuals (Leach *et al*., 2016; Veeramani *et al*., 2017) and the environment and consumers are becoming increasingly conscious of the consequences of their food purchases since unhealthy eating patterns represent the greatest risk factor for morbidity and mortality worldwide (Murray *et al*., 2019). As a result of globalization, an increase in the consumption of ultra-processed foods and meats has been observed, being associated with the development of some non-communicable diseases (NCDs) and malnutrition, as well as increased emissions of greenhouse gases (GHG), water pollution, soil degradation and other negative environmental impacts, on the other hand anthropogenic greenhouse gas (GHG) emissions are the dominant cause of the global warming (Fiolet*et al*., 2018; Rojas-Downing *et al*., 2018; Swinburn *et al*., 2019; Mullen, 2020; Matos *et al*., 2021).

The cultivation of crops also needs energy; the use of fossil fuels for making fertilizers, automated farming, and transportation releases greenhouse gases and pollutants like carbon dioxide and nitrogen oxides(Burnley *et al.,* 2010). In addition, livestock enteric fermentation is an important contributor to methane. The livestock sector of food production alone is expected to exceed humanity's sustainable contributions to global climate change and nitrogen by 2050 (Pelletier & Tyedmers, 2010; Steinfeld & Gerber, 2010; Leip *et al*., 2015).

Food footprints refer to the environmental impacts associated with the production, distribution, consumption, and disposal of food. They are a measure of the resource use and emissions that result from the entire life cycle of food products. Distinct types of food footprints are used to assess various aspects of the environmental impact of the food system. These assessments are crucial for understanding the sustainability of our food choices and for making informed decisions to reduce the environmental burden of our diets. The major food footprints include:

Carbon Footprint: The carbon footprint of food measures the total amount of greenhouse gas emissions (carbon dioxide, methane, and nitrous oxide) produced throughout the entire life cycle of a food product. This includes emissions from agricultural practices, transportation, processing, packaging, and food waste. It is expressed in terms of CO_2 equivalents and is a key indicator of a food's contribution to climate change (Vermeulen *et al*., 2012). The values for selected food products are expressed in tons of CO2 equivalent (MT CO_2e) (Goodier, 2010).

Water Footprint: The water footprint of food measures the volume of freshwater used throughout the entire life cycle of food production. This includes the water used for irrigation, processing, and cleaning. It is divided into three components: green water (rainwater stored in the soil and used by the vegetation through the evapotranspiration), blue water (used surface and ground waters that are not returned to the soli), and gray water (the water volume required to dilute pollutants and to recover the ecological equilibrium). Understanding the water footprint helps assess the sustainability of water use in agriculture (Mekonnen & Hoekstra, 2012). For this goal, the volume of freshwater used is typically measured in cubic meters (m^3) or liters (L) (Boulay *et al*. 2018).

Land Footprint: The land footprint of food measures the total land area required for food production, including crop cultivation and livestock grazing. It accounts for the direct land use for agriculture as well as the indirect land use due to associated factors such as deforestation, habitat conversion, and infrastructure development. It provides insights into the land-use impact of food consumption (Foley *et al*., 2011). The area of land required is often measured in hectares (ha) or square meters (m^2) (Fehrenbach*et al*., 2019).

Biodiversity Footprint: The biodiversity footprint of food assesses the impact of food production on species diversity and ecosystems. It includes the loss of habitat, fragmentation, and chemical contamination that affect ecosystems and wildlife. A high biodiversity footprint indicates a potential threat to the environment and species diversity (Tilman *et al*., 2011). Human impact on biodiversity can be measured both in theory and in practice. There is already the knowledge and skills to calculate biodiversity footprints – and then use the information to act (Miettinen, 2024).

Nutritional Footprint: The nutritional footprint evaluates the nutritional value of a food product relative to its resource use and environmental impact. It considers the balance between the energy, macronutrients, and micronutrients provided by food and the associated greenhouse gas emissions, water use, and land use. It aims to promote foods that offer a high nutritional value for a lower environmental footprint (Eshel *et al*., 2016). Typically measured in terms of nutrient content, such as grams or milligrams of specific nutrients like protein, vitamins, or minerals, per serving or per unit of food (Vallat*et al*., 2017).

Food Waste Footprint: The food waste footprint assesses the environmental impact of food waste generated at various stages of the food supply chain, from production and distribution to consumer-level waste. It quantifies the resource loss, energy use, and emissions associated with discarded food. Reducing food waste is crucial for minimizing this footprint (FAO, 2011). This can be measured in numerous ways, such as the weight (kilograms or pounds) of wasted food per individual or household, or as a percentage of total food consumed (FAO, 2019).

Energy demand: The total energy requirement (primary energy) is determined as the use of non-renewable energy (NREU).The values for food products are expressed in kilowatt-hours of primary energy equivalents (Verein Deutscher Ingenieure, 2012).

These food footprints offer valuable insights into the environmental sustainability of food choices and help consumers, producers, and policymakers make informed decisions to reduce the environmental impact of the food system. By considering these footprints, it is possible to promote more sustainable and resource-efficient food production and consumption practices.

The evaluation of the sustainability of diets has become increasingly important for shaping public policies. Therefore, it is imperative to comprehensively assess the sustainability of food in different contexts, considering various populations and regions with distinct characteristics. This is essential for crafting healthier and more environmentally friendly food and environmental policies. To address this need, there is a requirement to develop indices and methodological approaches that categorize diets based on their levels of sustainability, ranging from more sustainable to less sustainable (Saxe *et al.,* 2013; Masset *et al*., 2014; Hallström *et al*., 2015; Bryngelsson *et al*., 2016).

When initially examining this topic, it becomes apparent that there are various methodologies employed to gauge the environmental impact of population diets. These methodologies range from one-dimensional indicators to multidimensional ones. Some studies focus on specific groups within the population, while others estimate the environmental impact of populations representing entire countries. It is crucial to understand the methodology used, the type of study, the data source, and its limitations. Some dietary assessment methods may either underestimate or overestimate individuals' actual food consumption. For instance, using FAOSTAT data on food availability per capita at the national level may not accurately represent individual consumption (Heller *et al*., 2013; Vanham *et al*., 2013; Grace, 2015; Nelson *et al*., 2016).

Similarly, environmental footprints can vary based on the data source used. Depending on the source, the estimate may not fully capture the impact of a population's food consumption, as some sources may be specific to one country or based on global averages. Consideration of the origin and consumption location of food is essential to provide more realistic estimates. Additionally, clearly defining system boundaries in life-cycle assessments is crucial as it can affect the accuracy of the analysis. "Cradle-to-grave" assessments, which encompass the entire life cycle of products, are not commonly used in many studies and may exclude stages like transport, storage, consumption, and waste management, potentially leading to underestimated footprint values (Heller *et al*., 2013; Saxe *et al*., 2013; Hallström *et al*., 2015; Bryngelsson *et al*., 2016; Springmann *et al*., 2018).

Consumers can drive market demand for products that promote sustainable food systems by making more informed choices based on various indicators of food consumption sustainability. This, in turn, can bolster the development of public policies aimed at promoting educational initiatives, healthier environments, and sustainable food systems (Souza *et al*., 2022).

3.2 One Health

The One Health Approach underscores the significance of population demographics in tackling worldwide health challenges. With the global population on the rise, there is a heightened need for food, and the interconnected human food chain confronts risks from international animal and plant diseases, pests, and food safety issues. These risks have the potential to affect human health, food security, people's livelihoods, national economies, and the global marketplace. Although the projected growth in demand for most food commodities is expected to be slower than in the previous decade, the issue of food insecurity remains a critical global concern. Trade is anticipated to maintain a relatively constant portion of the industry's output in the next decade, with food imports gaining greater significance for food security, especially in regions like Africa and the Middle East (Pettan-Brewer *et al*., 2021; Schneider *et al*., 2021).

The concept of "One Health" is a multidisciplinary approach that emphasizes the interconnectedness of humans, animals, and the environment. This approach is crucial in responding to the challenges facing the world today, as it aims to improve understanding of health and disease processes, and predict, detect, prevent, and control infectious hazards and other issues affecting health and well-being in the human-animal-ecosystem interface. One Health approach is essential in addressing the challenges faced by the world and promoting better understanding and performance in this context. Collaboration among multiple disciplines is crucial for achieving sustainable development goals and improving equity in the world (Pettan-Brewer *et al*., 202; Schneider *et al*., 2021).

A comprehensive definition of One Health considers the interconnectedness of animals, humans, and their shared environment, all of which are influenced by human socioeconomic interests and external pressures. Collaboration among multiple disciplines is essential for understanding the One Health concept. A transdisciplinary definition of One Health calls for various disciplines to work together to provide new methods and tools for research and implementation of effective services to support the formulation of norms, regulations, and policies for the benefit of humanity, animals, and the environment for current and future generations (Schneider *et al*., 2021).

Food production and consumption have a significant impact on human health, animal health, and the environment. The concept of One Health emphasizes the interconnectedness of these areas and the importance of addressing them holistically. Food footprints are related to One Health in several ways, including environmental impact, nutritional quality, zoonotic disease transmission, antibiotic resistance, ecosystem health, global health equity, food security, interdisciplinary approach, and consumer choices. Promoting sustainable and responsible food systems is crucial to improve the health and well-being of all living beings on the planet while preserving the ecosystem (Grace, 2015; Röös*et al.*, 2015; Robinson *et al.*, 2017; Springmann *et al.*, 2018; Willett *et al.*, 2019).

3.3 Food Sustainability Index

The Food Sustainability Index (FSI) is a tool developed by Economist Impact with the support of the Barilla Center for Food & Nutrition Foundation (BCFN). It measures the sustainability of food systems in seventy-eight countries around three key issues outlined in the 2015 BCFN Milan Protocol and designed around the Sustainable Development Goals (SDGs): food loss and waste, sustainable agriculture, and nutritional challenges. The Food Sustainability Index (FSI) assesses the sustainability of food systems in seventy-eight countries, focusing on three key issues: food loss and waste, sustainable agriculture, and nutritional challenges.

3.3.1 Country Selection

The Food Sustainability Index (FSI) underwent a significant expansion in its country scope in 2021. This expansion aimed to provide a more comprehensive understanding of global food systems and included the addition of eleven new countries. The FSI now assesses food sustainability in a total of seventy-eight countries, encompassing a diverse range of economies, including high-, middle-, and low-income nations. This expanded coverage ensures a holistic depiction of food sustainability on a global scale.

The selection of countries for evaluation in the FSI is strategic, representing a broad geographic distribution and a mix of economic profiles. The chosen countries collectively account for a substantial portion of the global population, covering 92% of both global GDP and the overall world population. The selection process adheres to the income groupings defined by the World Bank.

Importantly, the decision to include new countries in the FSI was made through consultation with experts, ensuring a thoughtful and informed expansion. This process contributes to the FSI's goal of offering a robust assessment of food sustainability across various regions and economic landscapes.

3.3.2 Weighting Approaches

The Food Sustainability Index 2021 employs two distinct weighting approaches: expert-assigned weights and uniform weights. The default setting, expert-assigned weights, is established through extensive discussions involving Economist Impact, the BCFN research team, and the BCFN Advisory Board. This process determines the relative value of each indicator and sub-indicator, offering a real-world perspective crucial for guiding policy actions.

On the other hand, the uniform weights option assumes equal importance for all categories and their respective sub-indicators, distributing weight evenly across the index. While this option provides simplicity and eliminates subjective judgment, a drawback is its assumption that all categories hold equal significance.

The model recognizes the need for flexibility and incorporates adjustable weighting functionality. Users can customize the weights, assigning importance to specific themes and indicators based on their relevance. This feature enhances the understanding of performance on issues, allowing for a more nuanced and tailored analysis. Customizable weightings allow users to assign importance to themes and indicators that they deem more relevant. This functionality can help users better understand performance on specific issues. Sub-indicator weights include food loss as % of total food production of the country, policy response to food loss, causes of distribution-level loss, quality of road infrastructure, and food security. In the FSI model, there is a weightings function that permits users to allocate varying degrees of importance to themes and indicators that they consider to be more significant.

3.3.3 Data modeling

The Food Sustainability Index (FSI) employs sophisticated data modeling techniques to assess and measure the sustainability of food systems. The methodology involves a comprehensive approach, incorporating various indicators and sub-indicators to provide a holistic understanding of food sustainability in different countries.

The FSI utilizes a data modeling framework that considers the interplay of factors such as food loss and waste, sustainable agriculture, and nutritional challenges. The model considers expert-assigned weights and uniform weights for indicators, allowing for flexibility in the assessment process. This dual-weighting system ensures a nuanced evaluation, considering both the expertise-based perspectives and an equal-weight approach.

Additionally, the FSI model features adjustable weightings functionality, enabling users to customize weights based on their priorities, thereby enhancing the relevance of the analysis. The methodology is dynamic, adapting to changes in global challenges and incorporating insights from extensive discussions with experts and advisory boards.

The data collection period for the Food Sustainability Index 2021 is provided on page 35 of the Methodology Paper. The research phase for the G20 index took place in March-April 2021, with minor follow-ups in May. The quantitative research for the full index was conducted between July 26th and August 16th, 2021. The full index will be released in January 2022, and the data collection period for the qualitative research for non-G20 countries will take place between June and August 2021, with minor follow-ups in September.

This Index utilizes key performance indicators (KPIs) to evaluate policies and outcomes related to environmental, social, and economic sustainability of food systems and diets. The development of this work was overseen by Economist Impact, with backing from the Barilla Center for Food & Nutrition Foundation (BCFN) (Food Sustainability Index, 2021).

The FSI addresses three paradoxes identified in the 2015 BCFN Milan Food Protocol:

- **Food loss and waste:** A third of food is lost or wasted, with wasted food volume four times the amount needed to feed the undernourished worldwide.
- **Sustainable agriculture:** Climate change impacts on agriculture are visible but challenging to estimate. The shift to renewable energy, like biofuels, reduces land available for food production.
- **Nutritional challenges:** Hunger and obesity coexist, straining healthcare systems economically.

- **Food Environment:** This category includes sub-indicators such as food affordability, food safety, and access to healthy food.
- **Societal Framework:** This category includes sub-indicators such as gender equality in agriculture, food-related health outcomes, and food education policies.

Each sub-indicator is assigned a weight based on its relative importance within the category, and the categories themselves are assigned weights based on their overall importance to food sustainability. The scores for each sub-indicator are then combined to produce an overall score for each category and for the FSI.

The FSI research program aims to raise awareness and monitor progress in addressing food sustainability issues among governments, institutions, and the public. It aligns with various SDGs, including Zero Hunger, Climate Action, Life below Water and on Land, No Poverty, Industry and Innovation, Sustainable Cities and Communities, and Responsible Consumption and Production (Food Sustainability Index, 2021).

The three key issues that the Food Sustainability Index (FSI) measures sustainability around are food loss and waste, sustainable agriculture, and nutritional challenges. These three categories were defined in the 2015 BCFN Milan Protocol and are designed around the Sustainable Development Goals (SDGs). The Food Sustainability Index (FSI) assesses the effectiveness of sustainable food systems and diets using several key performance indicators (KPIs) that evaluate environmental, social, and economic sustainability. The FSI aims to raise awareness among governments, institutions, and the public about the need to address food sustainability issues and to monitor progress in addressing these.

4 Chapter 4

4.1 Methodology: Questionnaire design and sampling method

A questionnaire was used to gather data needed to measure the carbon and water footprint of our diet. The questionnaire was composed of 14 questions and was created using the StartQuestion software. It was distributed through links and QR codes in November and December 2023, along with the first three months of 2024. The responses were collected and categorized, then analyzed using Excel software. The results are presented in detail in the tables below. The majority of the responses came from Iran and Italy.

The approach used for evaluating this study's carbon and water footprint involved certain methodological components.

Carbon footprint:

The ISO 14067 standard for measuring the carbon footprint of products [ISO2018] considers all greenhouse gas emissions, including methane (CH4) and nitrous oxide (NO2), which are converted to CO_2 equivalents. This is done by applying the conversion factors outlined in the IPCC 2013 guidelines (Reinhardt *et al.*, 2020).

Calculation of the CO_2 footprint for each person per week has been realized: multiplying CO2 footprint of specific assumed foods (kg of CO_2 / kg of food consumed; data from Reinhardt et al., 2020) by the mass of food consumption (kg) found in the survey. For example: a consumption of 0.525 kg of meat correspond to a CO_2 footprint of 5.79 kg of CO_2, as the conversion factor for meat is 11.03 kg of CO_2 / kg of meat.

Water footprint:

The actual water footprint was determined by multiplying the mass of food consumption (kg) obtained from the survey with the relative water footprint (lit/kg of food). Conversion factors was obtained from Mekonnen & Hoekstra (2011).

For example: a consumption of 0.525 kg of meat correspond to a water footprint of 4900.2 lit, as the conversion factor for meat is 9333.75 lit / kg of meat.

Although the awareness of global warming and the issue of carbon footprint have increased, it is still difficult to change the diet in different communities and countries, because the production and storage of food is related to food security. The agricultural sector is the second-largest GHG emitter, leading to approximately 13.5%

of the total global anthropogenic greenhouse gas emissions and estimated for 25% of the sum of CO_2 emissions (Pandey *et al*., 2014).

From the above tables, animal foods have more CF compared to plant products. Sheep and beef are the highest CF contributors among animal products, with a combined value of 26 Kg CO_2eq/kg (NabipourAfrouzi*et al*., 2023). Among the types of meat used, pork and its products produce the lowest amount of CF - an average of 4.6 kg CO_2eq/kg - while beef and its products produce the highest amount of CF - an average of 13.6 kg CO_2eq/kg. In addition, citizens of some countries with a dietary pattern high in animal protein, such as milk, egg, and cheese production, also have a larger share of CF compared to countries that implement a vegetarian diet (Nabipour Afrouzi *et al*., 2023). It should be noted that people in Islamic countries who do not consume pork and replace it with beef, sheep, or goat can have a much greater contribution to CF production, however, Nabipour Afrouzi *et al*., (2023) stated that protein diets can be replaced with chicken, fish, and pork, which have lower CF.

At the same time, by comparing the carbon footprint of animal and plant products in the above tables, the carbon produced can be significantly reduced by replacing the dishes. For example, compared to chicken and fish, red meat produces 150% more greenhouse gas during its life cycle (Marino *et* al., 2016). Westhoek *et a*l., (2014) estimated that by replacing a quarter to a half percent of meat in the daily diet with plant-based foods, GHG emissions would decrease by 19 percent (Westhoek *et al*., 2014). However, choosing an all-vegetarian diet around the world may not be a practical proposition, as it was assessed in the Iranian diet (Taghipour Zarei and Zarghami, 2021). The focus of dietary only on macronutrients may lead to a diet based on starchy plant products such as rice, wheat, soy, and corn, which provide energy but lack many micronutrients (Biesalski *et al*., 2017) that people generally try to get micronutrients by overeating (Esteghamati *et al*., 2012).

4.2 Results of the survey

After the questionnaire was closed and the completed answers were considered there are 123 answers from countries in the following tables.

Question 1

The table shows the breakdown of survey respondents based on their country of residence. It includes data from 14 countries, displaying both the percentage and number of responses for each. The table highlights notable participation from Iran and Italy, with minimal to no responses from several other countries.

Table 4-1 Country of residence

	Answer	Number of answers
1)	United States	1
2)	Canada	0
3)	United Kingdom	1
4)	Australia	0
5)	Germany	2
6)	France	2
7)	Spain	2
8)	Italy	35
9)	Iran	80
10)	China	0
11)	Japan	0
12)	India	0
13)	Saudi Arabia	0
14)	United Arab Emirates	0

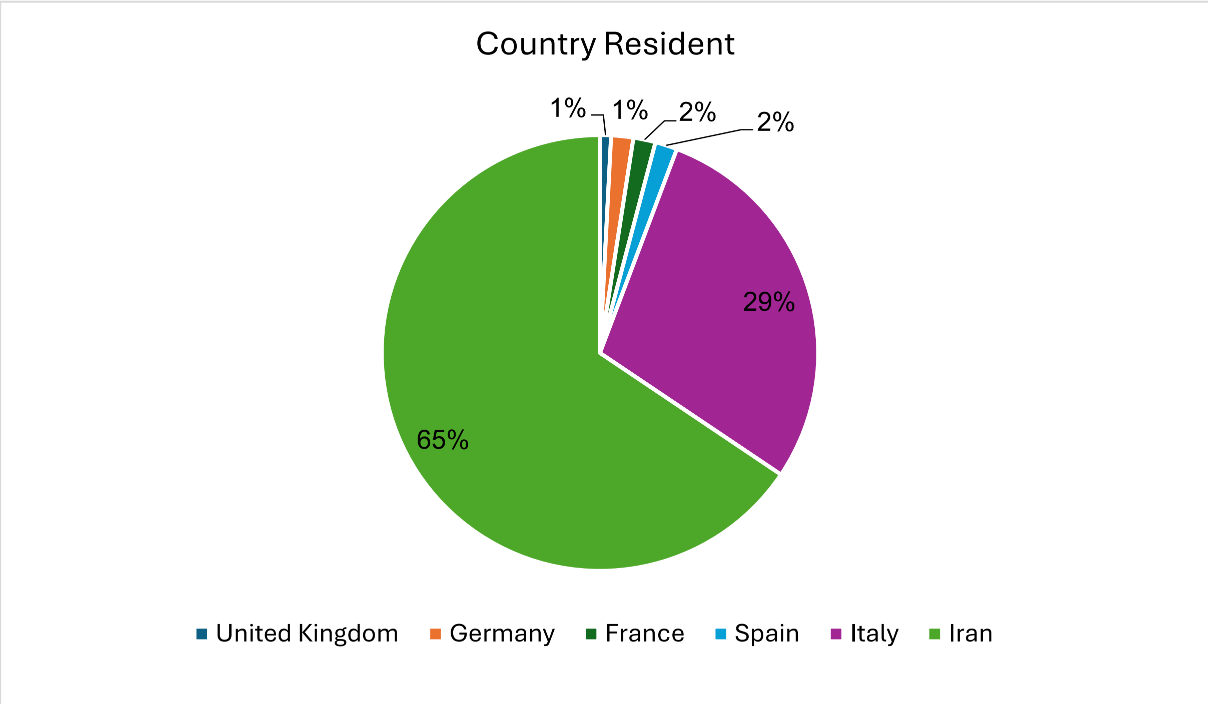


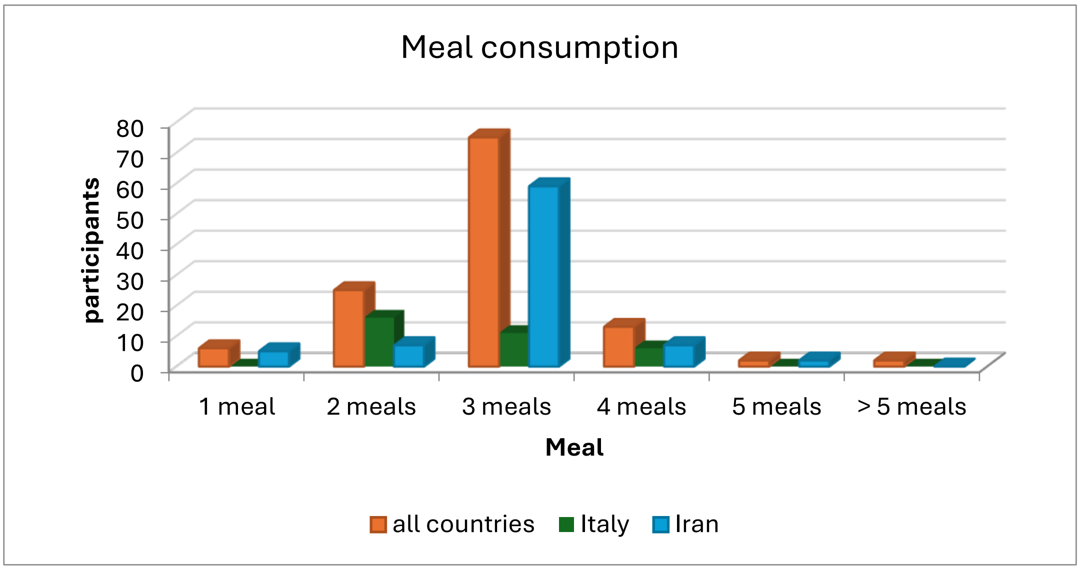
Figure 4-1 Country resident of Correspondants

Question 2

Table 4-2 shows the average number of meals consumed per day. As shown, the majority of people consume three meals a day, which accounts for 60.98%. On the other hand, the percentage of people who consume more than five meals a day is the lowest.

Table 4-2 Food Consumption

	Answer	Number of answers	Italy	Iran
1)	1 meal	6	0	5
2)	2 meals	25	16	7
3)	3 meals	75	11	59
4)	4 meals	13	6	7
5)	5 meals	2	0	2
6)	> 5 meals	2	0	0



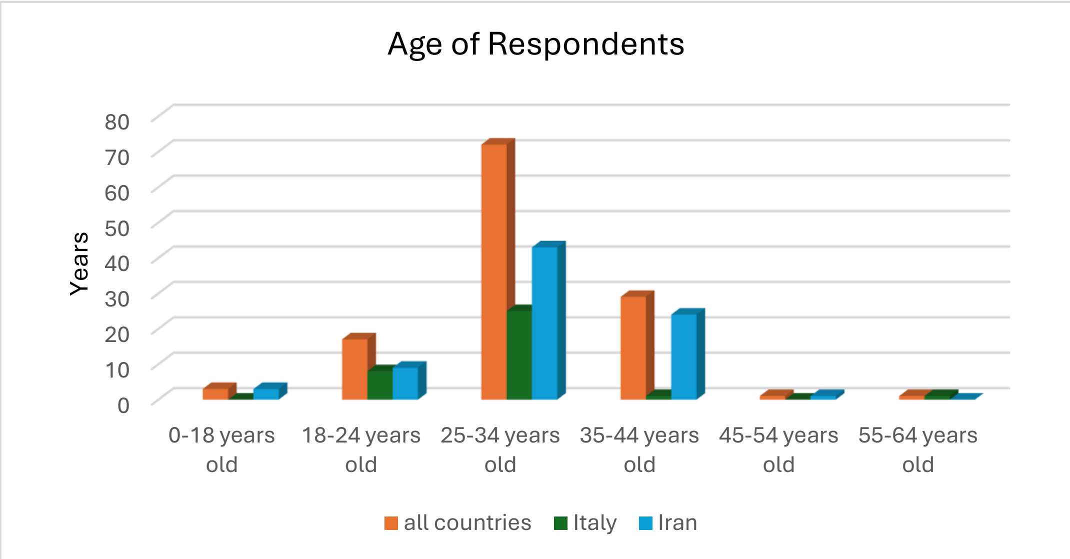
4-2 Consumption of meal

Question 3

Table 4-3 shows that most participants are aged between 25-34, with the lowest number of respondents aged between 45-64. In general, the respondents skew towards younger age groups.

Table 4-3 Age Of Respondents

Answer		Number of answers	Italy	Iran
1)	0-18 years old	3	0	3
2)	18-24 years old	17	8	9
3)	25-34 years old	72	25	43
4)	35-44 years old	29	1	24
5)	45-54 years old	1	0	1
6)	55-64 years old	1	1	0



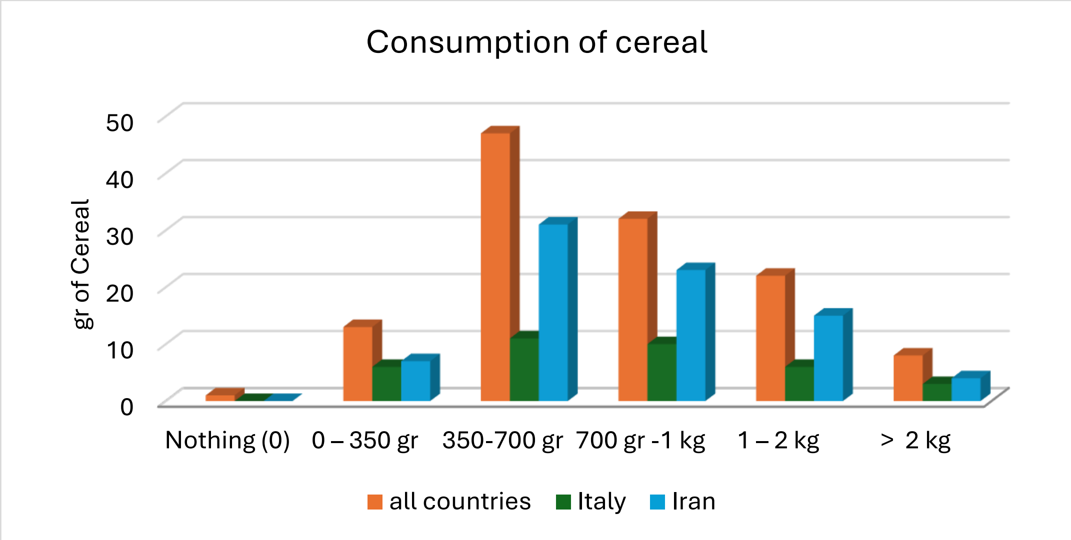
4-3 Age of Respondents

Question 4

Table 4-4 shows the weekly consumption of cereals including wheat, rice, pasta, and gnocchi. Most participants consume between 350-700 grams of cereals per week, while the least of the people questioned consume more than 2 kg per week.

Table 4-4 Cereal consumption (kg per week)

Answer		*Number of answers*	*Italy*	*Iran*
1)	Nothing (0)	1	0	0
2)	0 – 350 gr	13	6	7
3)	350-700 gr	47	11	31
4)	700 gr -1 kg	32	10	23
5)	1 – 2 kg	22	6	15
6)	> 2 kg	8	3	4



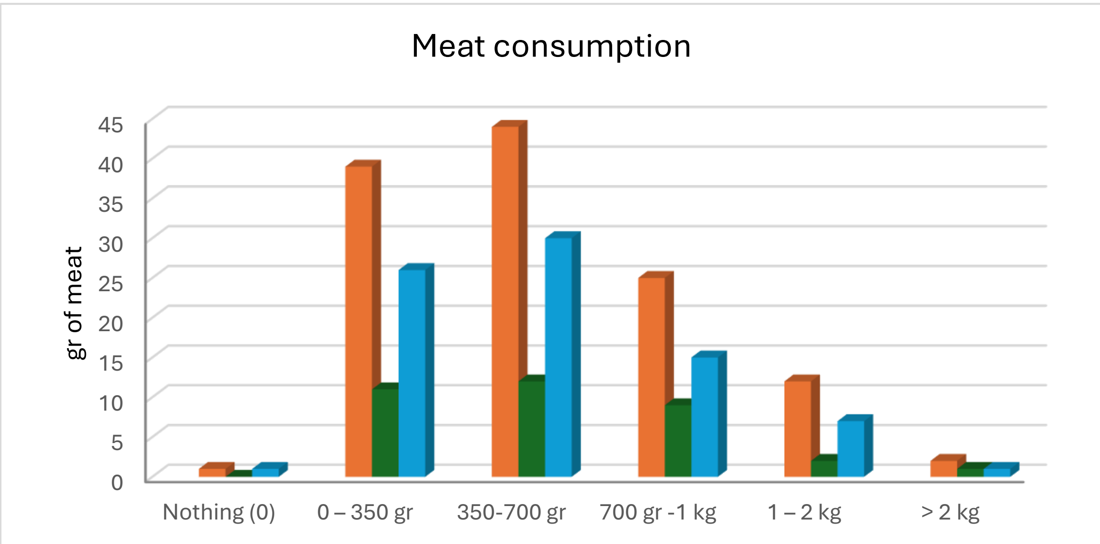
4-4 Consumption of cereal (kg per week)

Question 5

Table 4-5 shows the weekly consumption of meat. Most respondents consumed between 350 and 700 g of meat, while a few consumed more than 2 kg.

Table 4-5 Meat products consumption (kg per week)

Answer		Number of answers	Italy	Iran
1)	Nothing (0)	1	0	1
2)	0 – 350 gr	39	11	26
3)	350-700 gr	44	12	30
4)	700 gr -1 kg	25	9	15
5)	1 – 2 kg	12	2	7
6)	> 2 kg	2	1	1



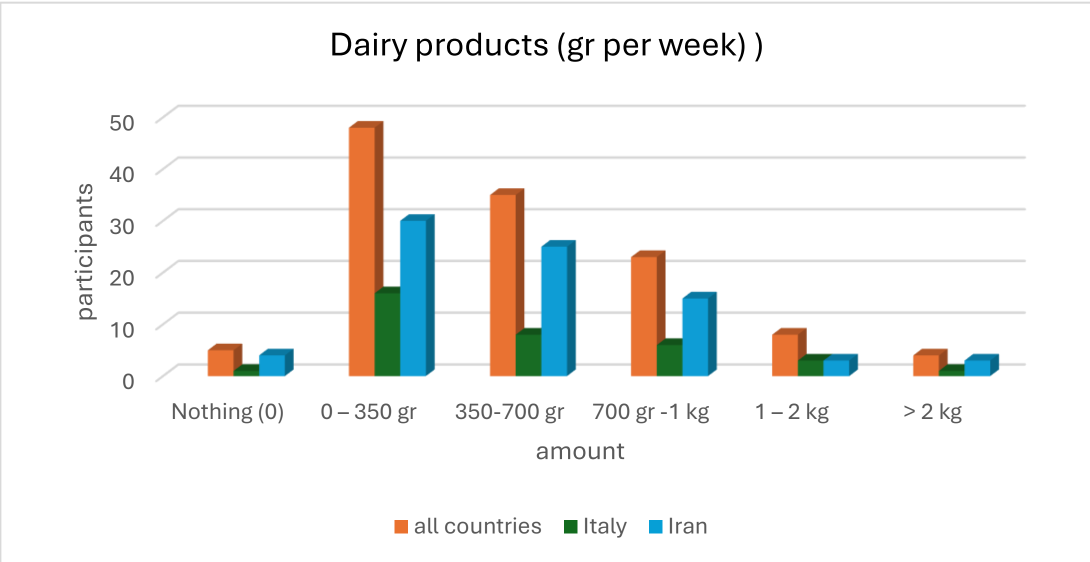
4-5 Meat consumption (kg per week)

Question 6

Table 4-6 shows the data related to the consumption of dairy products including butter, cheese, yogurt, and cream. Most participants consumed between 0 and 350 g/week, while a very small number consumed more than 2 kg/week of meat. A total of 4% of participants reported not consuming any dairy products.

Table 4-6 Dairy products (gr per week)

	Answer	Number of answers	Italy	Iran
1)	Nothing (0)	5	1	4
2)	0 – 350 gr	48	16	30
3)	350-700 gr	35	8	25
4)	700 gr -1 kg	23	6	15
5)	1 – 2 kg	8	3	3
6)	> 2 kg	4	1	3



4-6 Dairy product consumption (gr per week)

Question 7

Table 4-7 shows the weekly milk consumption per person, with the highest consumption, 30 % of the respondents consume 0-350 ml per week while just 2.44 % of respondents consume more than 2 lit per week.

Table 4-7 Milk consumption (ml per week)

	Answer	*Number of answers*	*Italy*	*Iran*
1)	Nothing (0)	37	9	25
2)	0 – 350 ml	37	13	24
3)	350-700 ml	20	5	13
4)	700 ml -1 liter	16	6	8
5)	1 – 2 liters	10	1	8
6)	> 2 liters	3	1	2

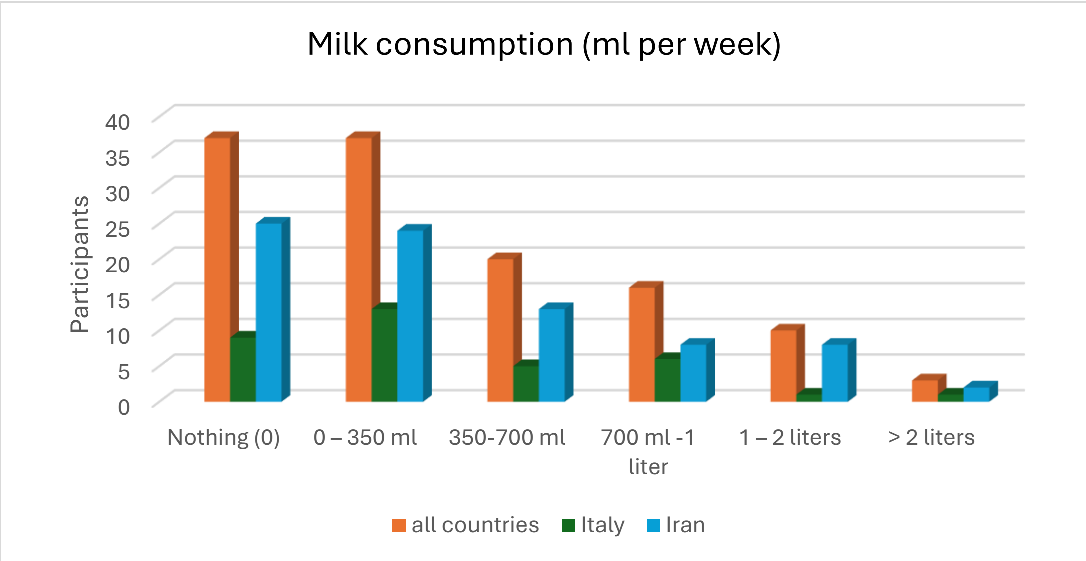


Figure 4-7 Milk consumption (ml per week)

Question 8

Table 4-8 displays the amount of eggs consumed per week. The most frequent is between 0-7 eggs/week, while the lowest is for those who consume >21 eggs (only one person).

Table 4-8 Egg consumption (per week)

	Answer	*Number of answers*	*Italy*	*Iran*
1)	Nothing (0)	8	5	3
2)	0-7	90	26	2
3)	7-14	22	3	15
4)	14-21	2	0	2
5)	> 21	1	1	0

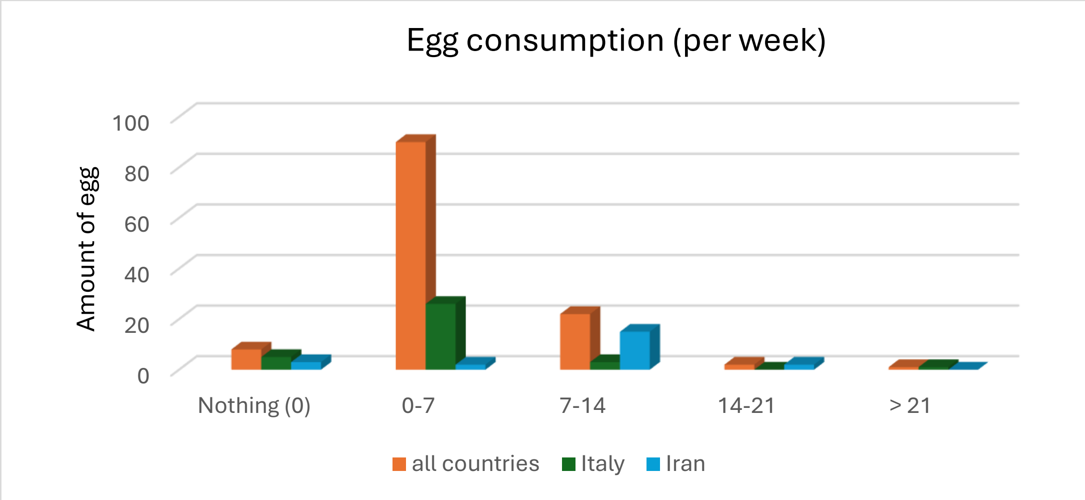


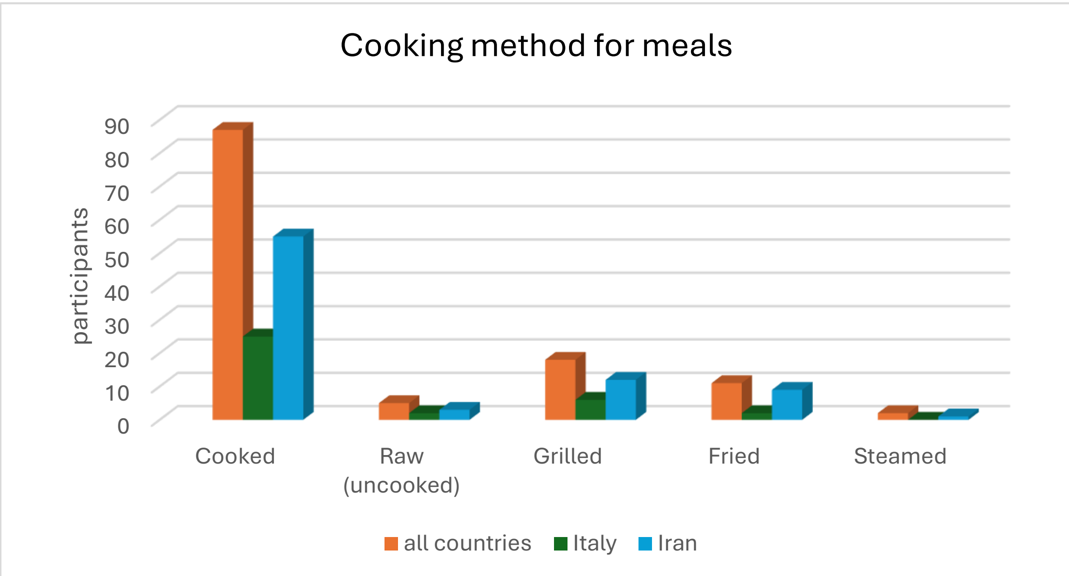
Figure 4-8 Amount of egg consumption per week

Question 9

Table 4-9 shows the prevalence of different cooking methods for meals, with the highest percentages associated with cooked foods and the lowest percentages associated with steamed foods.

Table 4-9 Cooking method for meals

	Answer	Number of answers	Italy	Iran
1)	Cooked	87	25	55
2)	Raw (uncooked)	5	2	3
3)	Grilled	18	6	12
4)	Fried	11	2	9
5)	Steamed	2	0	1



4-9 Method of food cooking

Question 10

Table 4-10 illustrates the weekly consumption of sugar and sweets. Most of the respondents, equivalent to 54%, consumed 0-200 grams per week. In contrast, only 3.25 percent consume more than 800 grams of sugar per week.

Table 4-10 Sugar and sweets consumption (kg per week)

	Answer	Number of answers	Italy	Iran
1)	Nothing(0)	11	4	6
2)	0-200 gr	67	20	42
3)	200-400 gr	32	8	22
4)	400-800 gr	9	0	9
5)	> 800 gr	4	3	1

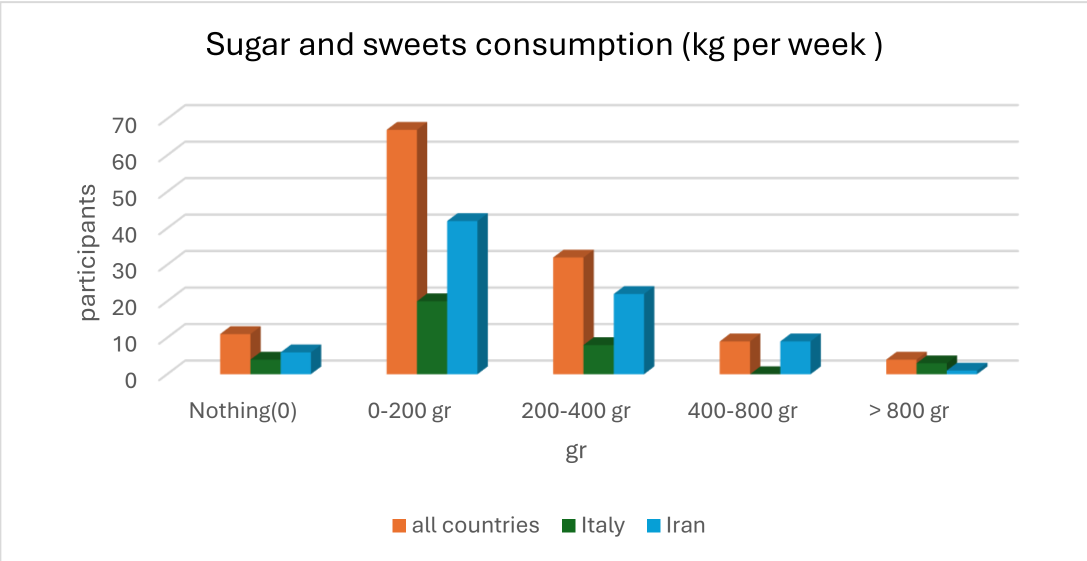


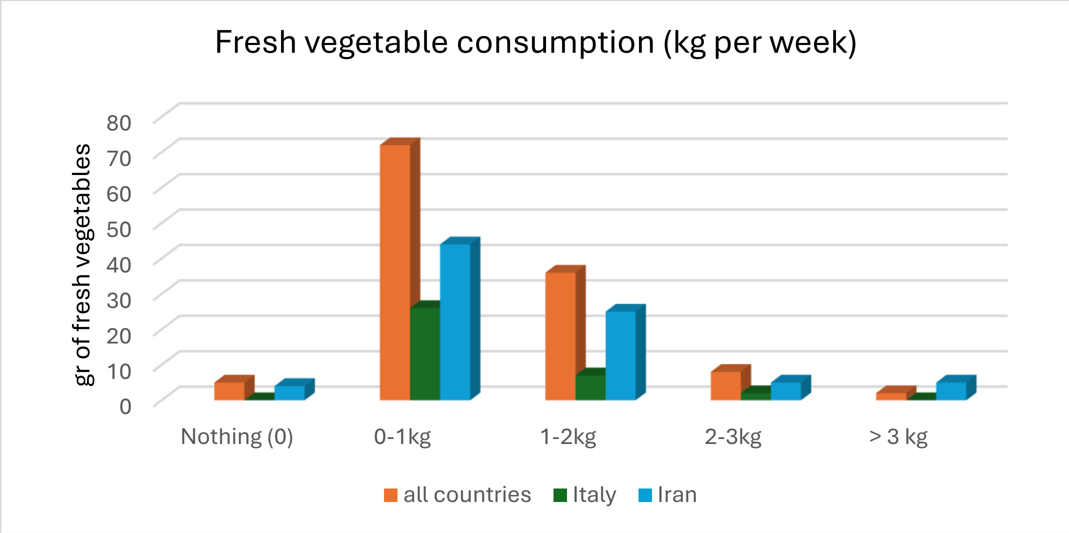
Figure 4-10 Sugar and sweets consumption (kg per week)

Question 11

Table 4-11 displays the level of fresh vegetable consumption, 58.54% of consumers, consume between 0-1 kg, while only 1.63% have 3 kg per week.

Table 4-11 Fresh vegetable consumption (kg per week)

	Answer	Number of answers	Italy	Iran
1)	Nothing (0)	5	0	4
2)	0-1kg	72	26	44
3)	1-2kg	36	7	25
4)	2-3kg	8	2	5
5)	> 3 kg	2	0	5



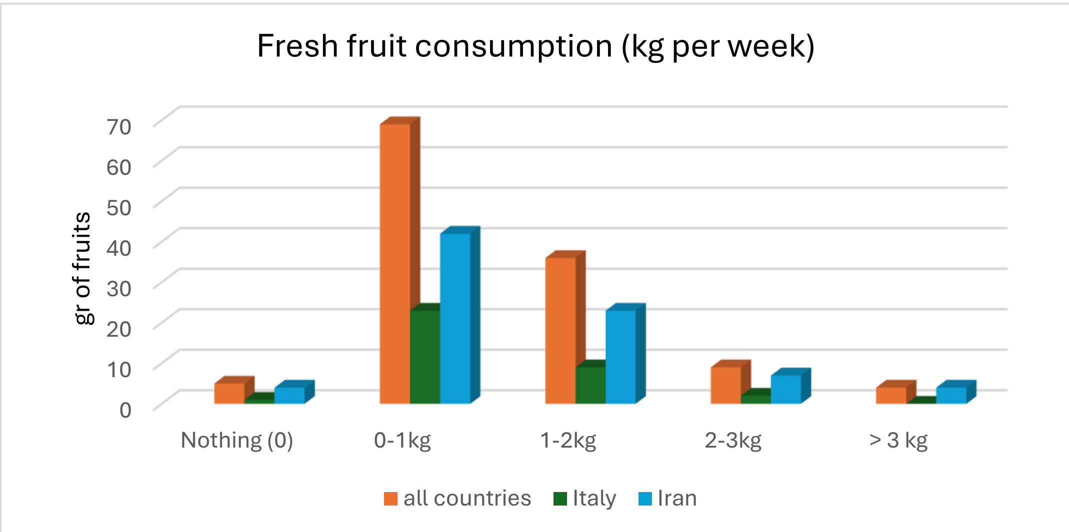
4-11 Consumption of fresh vegetables (kg per week)

Question 12

Table 4-12 shows the amount of fresh fruit consumed per person per week. The highest consumption is between 0-1 kg per week and the lowest percentage of respondent's consume over 3 kg per week.

Table 4-12 Fresh fruit consumption (kg per week)

	Answer	Number of answers	Italy	Iran
1)	Nothing (0)	5	1	4
2)	0-1 kg	69	23	42
3)	1-2 kg	36	9	23
4)	2-3 kg	9	2	7
5)	> 3 kg	4	0	4



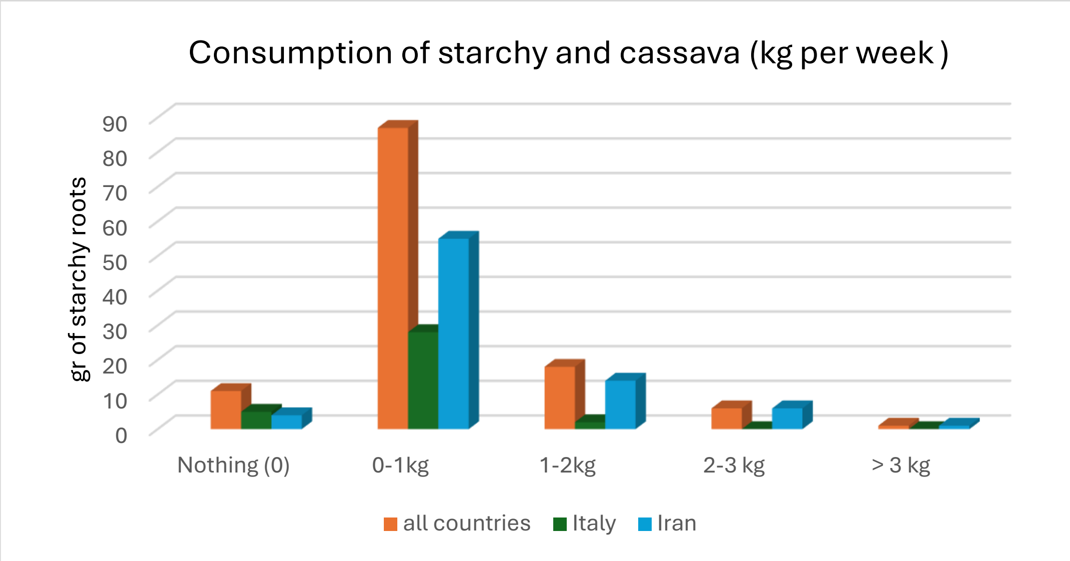
4-12 Consumption of fresh fruits (kg per week)

Question 13

Table 4-13 clarifies the consumption of starchy roots such as potatoes and cassava. Most of the consumers consume between 0-1 kg, while few people consume more than 3 kg per week.

Table 4-13 Consumption of starchy and cassava (kg per week)

	Answer	Number of answers	Italy	Iran
1)	Nothing (0)	11	5	4
2)	0-1kg	87	28	55
3)	1-2kg	18	2	14
4)	2-3 kg	6	0	6
5)	> 3 kg	1	0	1



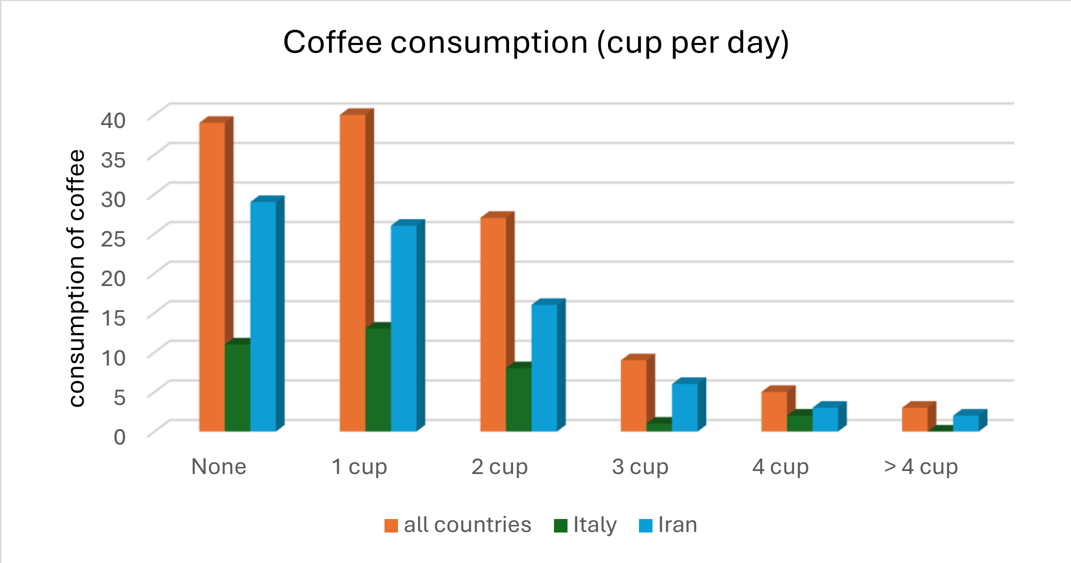
4-13 Consumption of starchy roots and cassava (kg per week)

Question 14

Table 4-14 displays the quantity of coffee consumed daily. The highest percentage of people drink one cup a day, on the other hand, the lowest drink over four cups per day.

Table 4-14 Coffee consumption (cup per day)

	Answer	Number of answers	Italy	Iran
1)	None	39	11	29
2)	1 cup	40	13	26
3)	2 cup	27	8	16
4)	3 cup	9	1	6
5)	4 cup	5	2	3
6)	> 4 cup	3	0	2



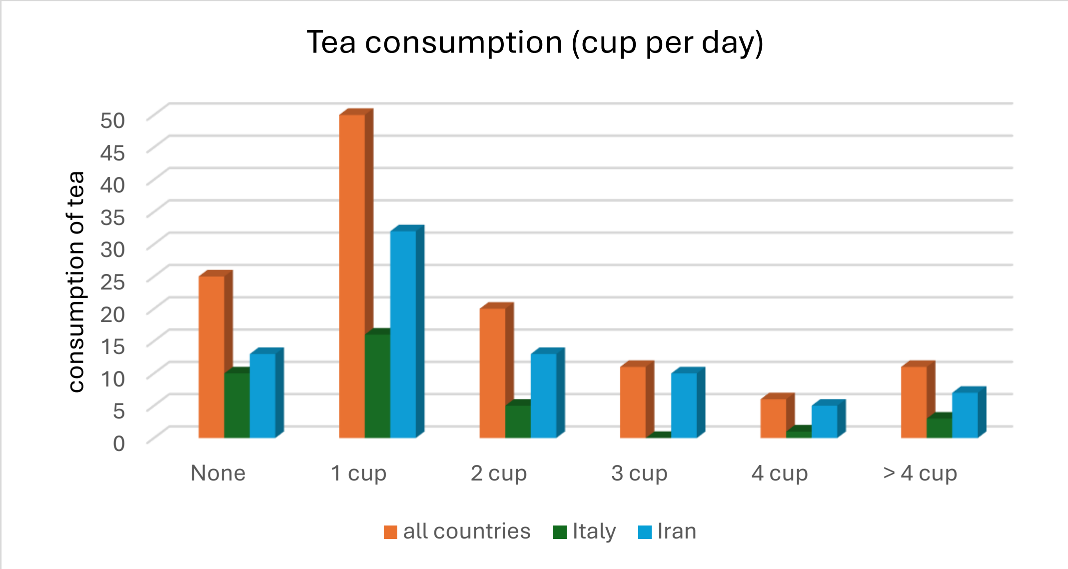
4-14 Consumption of coffee (cup per day)

Question 15

Table 4-15 demonstrates the amount of daily consumption of green and black tea, ranging from one cup to four cups per day. Most of the respondents drink 1 cup of tea per day while the fewest consume 4 cups or more a day.

Table 4-15 Tea consumption (cup per day)

	Answer	Number of answers	Italy	Iran
1)	None	25	10	13
2)	1 cup	50	16	32
3)	2 cup	20	5	13
4)	3 cup	11	0	10
5)	4 cup	6	1	5
6)	> 4 cup	11	3	7



4-15 Consumption of tea (cup per day)

4.2.1 CO_2 Footprint Data

Tables are essential for data analysis as they provide a structured format for presenting information. The data is arranged in rows and columns, where each row corresponds to a unique record and each column corresponds to a specific characteristic. This organization makes it easier to compare and analyze different sets of information.

4.2.1.1 CO2 Footprint of Various Foodstuffs

The provided table lists the CO_2 footprint of various food types, categorized into cereals, meat products, dairy, milk, egg, sweets and sugar, vegetables, fruits, starchy roots, and beverages like tea and coffee. Each entry specifies the CO_2 equivalent emissions per kilogram of food, offering a clear comparison of the environmental impact of different foods. The data was taken from Reinhardt, 2020 and the calculated mean values have been used for the successive analysis.

Cereals:

For cereals, the CO_2 footprints vary significantly. The average CO_2 footprint for cereals is calculated to be 1.192 kg CO_2 eq/kg of food, highlighting the wide range of emissions within this category (Reinhardt, 2020). The highest contribution among plant-based diets belongs to rice (Nabipour Afrouzi, 2023).

Table 4-16 CO_2 Footprint of Cereals (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq / kg food]
1	wheat	0.7
2	rice	3.1
3	maize	0.9
4	pasta	0.7
5	**mean**	**1.35**

Meat products:

Meat products have a higher CO_2 footprint (Reinhardt, 2020; Nabipour Afrouzi, 2023). The mean footprint for meat products stands at 10.87 kg CO_2 eq/kg food, underscoring the significant environmental impact of meat production (Reinhardt, 2020).

Table 4-17 CO_2 Footprint of Meat (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq/kg food]
1	Beef, average	13.6
2	Beef (organic)	21.7
3	Beef patty, frozen	9
4	Minced beef	9.2
5	Minced beef (organic)	15.1
6	Game meat, deer	11.5
7	Pork (organic)	5.2
8	Pork, average	4.6
9	Sausage slices, beef, cold cuts	7.9
10	**mean**	**10.87**

Dairy:

Dairy products also show a broad range. The mean CO_2 footprint for dairy is 5.15 kg CO_2 eq/kg food, indicating variability within this category as well (Reinhardt, 2020).

Table 4-18 CO_2 Footprint of Dairy (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq/kg food]
1	Butter	9
2	Butter (organic)	11.5
3	Cheese (organic), average	7.2
4	Cheese (organic), cream cheese	6.9
5	Cheese, average	5.7
6	Cheese, cream cheese	5.5
7	Cheese, feta	7
8	Cheese, hard cheese, like Emmental	6
9	Cheese, hard cheese, like parmesan	6.3
10	Cream	4.2
11	Cream (organic)	5.3
12	Curd (organic), 40 % fat	4.1
13	Curd, 40 % fat	3.3
14	Curd, low-fat curd, 10 % fat	2.4
15	Sour cream	3
16	Yoghurt (organic), natural, plastic cup, paper coated	1.9
17	Yoghurt, fruit, plastic cup, paper coated	1.7
18	Yoghurt, natural, plastic cup, paper coated	1.7
19	**mean**	**5.15**

Milk:

Milk products have lower footprints. The mean footprint is 1.34 kg CO_2 eq/kg food, making milk one of the lower-impact categories.

Table 4-19 CO_2 Footprint of Milk (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq/kg food]
1	Milk (organic), ESL, whole milk, composite carton	1.7
2	Milk, ESL, low-fat, composite carton	1.2
3	Milk, ESL, whole milk, composite carton	1.4
4	Milk, UHT milk, low-fat, composite carton	1.1
5	Milk, UHT milk, whole milk, composite car-ton	1.3
6	**mean**	**1.34**

Egg:

To measure the carbon footprint of eggs, we consider each egg to be sixty grams and then convert it to kilograms and multiply it by the consumption amount to get the appropriate amount of CO_2 in kilograms (Reinhardt, 2020).

Table 4-20 CO_2 Footprint of Egg (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq / kg food]
1	Egg	3

Sweets and Sugar:

The mean for sweets and sugar is 0.94 kg CO_2 eq/kg food, reflecting moderate emissions (Reinhardt, 2020).

Table 4-21 CO_2 Footprint of Sweets and Sugar (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq / kg food]
1	Sugar (organic), beet sugar	0.5
2	Sugar (organic), cane sugar	0.9
3	Sugar, beet sugar	0.7
4	Sugar, cane sugar	1
5	Pastry products	1.6
6	**mean**	**0.94**

Vegetables:

Vegetables have low CO_2 footprints. The mean footprint for vegetables is 0.84 kg CO_2 eq/kg food, emphasizing their lower environmental impact (Reinhardt, 2020).

Table 4-22 CO_2 Footprint of Vegetables (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq / kg food]
1	Asparagus	0.7
2	Avocado (organic), from Peru	0.8
3	Avocado, average	0.6
4	Avocado, from Peru	0.8
5	Beans, in can	1.3
6	Beans, fresh	0.8
7	Beetroot, fresh	0.2
8	Beetroot, in glass jar	1.3
9	Bell pepper	0.6
10	Broccoli, fresh	0.3
11	Broccoli, frozen	0.7
12	Brussels sprouts, fresh	0.3
13	Brussels sprouts, frozen	0.6
14	Carrots	0.1
15	Cauliflower	0.2
16	Celery	0.2
17	Chickpeas, in can	1.3
18	Corn, in can	1.2
19	Courgetti	0.2
20	Cucumber (organic) with plastic film packaging	0.4
21	Cucumber (organic) without plastic film packaging	0.4
22	Cucumber with plastic film packaging	0.4
23	Cucumber without plastic film packaging	0.4
24	Eggplant	0.2
25	Fennel	0.2
26	Flax seed	1.4
27	Kale, fresh	0.3
28	Kale, in glass jar	0.9
29	Kohlrabi (cabbage turnip)	0.2
30	Lamb's lettuce	0.3
31	Leek	0.2
32	Lentils (organic), dried	1.7
33	Lentils, in can	1.7
34	Lentils, dried	1.2

35	Mushrooms, fresh, bright, or dark	1.3
36	Mushrooms, in can	2.4
37	Onions	0.2
38	Peas, dried	2.3
39	Peas, fresh, green, in pods	0.4
40	Peas, frozen	1.2
41	Peas, green, in can	1.7
42	Peas, green, in glass jar	1.7
43	Potato puree powder	0.9
44	Potatoes (organic	0.2
45	Potatoes, fresh	0.2
46	Pumpkin	0.2
47	Radish	0.2
48	Red cabbage, fresh	0.2
49	Red cabbage, in glass jar	0.7
50	Rocket	0.3
51	Spinach, fresh	0.2
52	Spinach, leaf spinach, frozen	0.6
53	Tomato puree	4.3
54	Tomatoes (organic), fresh	1.1
55	Tomatoes, cherry tomatoes	0.9
56	Tomatoes, fresh, average	0.8
57	Tomatoes, from Germany, heated green-house,	2.9
58	Tomatoes, from Southern Europe, open land	0.4
59	Tomatoes, from Germany, seasonal	0.3
60	Tomatoes, strained, in can	1.8
61	Tomatoes, strained, composite carton	1.6
62	Tomatoes, strained, in a glass jar	1.9
63	White cabbage	0.1
64	**Mean**	**0.84**

Fruits:

This table shows the CO_2 footprint of various fruits. The average CO_2 footprint for all fruits listed is 1.34 kg CO_2 eq/kg food, demonstrating the variability among different fruits and their production or transportation methods (Reinhardt, 2020).

Table 4-23 CO_2 Footprint of Fruits (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq/kg food]
1	Apple (organic), average	0.2
2	Apple, average	0.3
3	Apple, from New Zealand	0.8
4	Apple, regional in April	0.4
5	Apple, regional in autumn	0.3
6	Banana	0.6
7	Grapes, fresh, average	0.4
8	Grapes, fresh, from Germany, seasonal	0.3
9	Grapes, fresh, from Italy, seasonal	0.3
10	Orange	0.3
11	Peach, in can	1.6
12	Peach, fresh	0.2
13	Pear	0.3
14	Pineapple, by air	15.1
15	Pineapple, by ship	0.6
16	Pineapple, in can	1.8
17	Pineapple, fresh, according to real transport average	0.9
18	Strawberries, fresh, "winter strawberries	3.4
19	Strawberries, fresh, average	0.3
20	Strawberries, fresh, from Spain	0.4
21	Strawberries, fresh, regional, seasonal	0.3
22	Strawberries, frozen	0.7
23	**Mean**	**1.34**

Starchy Roots:

The table on starchy roots presents the CO_2 footprint of different potato products. The mean CO_2 footprint for these starchy roots is 0.5 kg CO_2 eq/kg food (Reinhardt, 2020).

Table 4-24 CO_2 Footprint of Starchy Roots(Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq/kg food]
1	Potato; puree powder	0.9
2	Potatoes (organic)	0.2
3	Potatoes, fresh	0.2
4	fries frozen	0.7
5	**Mean**	**0.5**

Tea and Coffee:
These beverages have high CO_2 footprints, particularly tea. To get the amount of coffee consumed in kilograms, we considered that to make a cup are necessary 18 grams of coffee. The CO_2 footprint of 1 kilogram of coffee is 5.6 kg CO_2eq/kg food (Reinhardt, 2020). As a consequence, each cup of coffee produces 101 grams of CO_2.

According to Lim et al. (2022) in each cup of tea, there are 2 grams of tea and 200 grams of water. The CO_2 footprint of 1 kilogram of tea is 15.9 kilograms of CO_2 (Lim et al., 2022). As a consequence, each cup of tea produces 0.032 grams of CO_2.

Table 4-25 CO_2 Footprint of Tea and Coffee (Reinhardt, 2020)

No.	Food Stuff	CO_2 Footprint [kg CO_2eq / cup]
1	Tea	0.032
2	Coffee	0.101

4.2.1.2 Water Footprint of Various Foodstuffs

To measure water footprint (WF) values, the method of Hoekstra *et al*. (2011) is used. WFs are composed of blue, green, and grey components. According to Rockström *et al*. (2009), green water is the soil moisture in the unsaturated zone, originating from precipitation and accessible to plants. Blue water denotes liquid water found in rivers, lakes, wetlands, and aquifers. Irrigated agriculture utilizes both blue water (through irrigation) and green water (from rainfall), whereas rainfed agriculture only uses green water. Therefore, the green WF represents the rainwater utilized by crops. The grey WF indicates the volume of water required to dilute pollutants to meet water quality standards (Hoekstra *et al*. 2011), serving as a measure of water pollution.

This analysis covers the water footprint of various food categories, including cereals, meat, dairy, milk, eggs, sweets and sugar, vegetables, fruits, starchy roots, and beverages like coffee and tea. Water footprint data is segmented into three types: green (rainwater), blue (surface and groundwater), and gray (water required to assimilate pollutants). We also compare the water footprint of food consumption patterns in different countries, specifically focusing on overall averages and specific data from Italy and Iran.

Cereals:

Cereals like wheat, rice, maize, and pasta have varying water footprints, with rice having the highest overall footprint of 2497 liters per kg due to its cultivation method (Mekonnen, 2012).

Table 4-26 Water Footprint of Cereals (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (lit/kg)			
		green	blue	gray	Global Average
1	Wheat	1277	342	207	1827
2	Rice	1710	509	278	2497
3	Maize (corn)	941	85.5	195.5	1222
4	Pasta (dry)	1292	347	210	1849
5	**Mean**	**1305**	**321**	**223**	**1848.75**

Meat production:

Beef, goat, pork, and sheep production have significant water footprints, with beef having the highest water footprint at 14413.03 liters per kg (Mekonnen, 2012; Mirzaie *et al*., 2020).

Table 4-27 Water Footprint of Meat Production (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (lit/kg)			
		green	blue	gray	Global Average
1	Beef	14413.03	539.525	462.45	14413.03
2	Goat	5189.74	331.26	0	5189.74
3	Pork	4910.16	479.04	598.8	4910.16
4	Sheep	9787.28	520.6	104.12	9787.28
5	**Mean**	**8575.05**	**467.60**	**291.34**	**8575.05**

Dairy Production:

Dairy products like butter and cheese have substantial water footprints, with butter having a higher footprint compared to cheese (Mekonnen, 2012).

Table 4-28 Water Footprint of Dairy (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (liter/kg)			
		green	blue	gray	Global Average
1	Butter	4720	444	389	5553
2	Cheese	2701.5	254.3	222.2	3178
3	**Mean**	**3710.75**	**349.15**	**305.6**	**4365.5**

Milk:

The water footprint of milk varies based on its form, with milk powder having a higher footprint compared to liquid milk (Mekonnen, 2012).

Table 4-29 Water Footprint of Milk (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (lit/kg)			
		green	blue	gray	Global Average
1	Milk	867	81.6	71.4	1020
2	Milk powder	4011	398	336	4745
3	**Mean**	**2439**	**239.8**	**203.7**	**2882.5**

Egg:

Eggs have a moderate water footprint compared to other food items, with an average of 196 liters per egg (Mekonnen, 2012).

Table 4-30 Water Footprint of Egg (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (lit/kg)			
		green	blue	gray	Global Average
1	Egg (one 60 g egg)	157	14	25	196

Sweets and Sugar:

Sugar cane and sugar beet have different water footprints, with sugar cane having a higher footprint compared to sugar beet (Mekonnen, 2012).

Table 4-31 Water Footprint of Sweets and Sugar (Mekonnen, 2012)

No.	Food Stuff	Water Footprint(lit/kg)			
		green	blue	gray	Global Average
1	sugar cane	1184	487	111	1782
2	sugar beet	570	175	175	920
3	**Mean**	**877**	**331**	**143**	**1351**

Vegetables:

Various vegetables have different water footprints, with leafy greens like spinach having lower footprints compared to water-intensive crops like tomatoes and peppers (Mekonnen, 2012).

Table 4-32 Water Footprint of Vegetables (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (lit/kg)			
		green	blue	gray	Global Average
1	Asparagus	478	242	98	818
2	Lettuce	133	28	77	238
3	Spinach	118	14	160	292
4	Tomatoes	108	63	43	214
5	Cauliflower and broc-coli	189	21	75	285
6	Pumpkin & squash	228	24	84	336
7	cucumber	206	42	105	353
8	Eggplants	234	33	95	362
29	Chili & pepper	240	42	97	379
10	Onion	176	44	51	271
11	Garlic	337	81	170	588
12	Bean	320	54	188	562
13	Pea	382	63	150	595
14	Carrot & turnips	106	28	61	195
15	Maize green	455	157	88	700
16	Lemons & limes	432	152	58	642
17	**Mean**	**258.9**	**68**	**100**	**426.9**

Fruits:

Fruits have varying water footprints, with fruits like figs and mangoes having significantly higher footprints compared to others.

Table 4-33 Water Footprint of Fruits (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (lit/kg)			
		green	blue	gray	Global Average
1	Banana	660	97	33	790
2	Orange	401	110	49	560
3	Tang&mand&clement	479	118	152	749
4	Grape f	367	85	45	497
5	Apples	561	133	127	821
6	Pears	645	94	183	922
7	Apricots	694	502	92	1288
8	Cherries	961	531	112	1604
29	Peach& Nectar	583	188	139	910
10	Strawberry	201	109	37	347

11	Raspberry	293	53	67	413
12	blueberries	341	334	170	845
13	Grape	425	97	87	609
14	Watermelon	147	25	63	235
15	Figs	1527	1595	228	3350
16	Mangos	1314	362	124	1800
17	Avocados	849	283	849	1981
18	Pineapple	215	9	31	255
19	Kiwi	307	168	38	513
20	**Mean**	**577.3**	**257.5**	**138.211**	**973.1**

Starchy Roots:

Starchy roots like potatoes and cassava have moderate water footprints compared to other food categories.

Table 4-34 Water Footprint of Starchy Roots (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (liter/kg)			
		green	blue	gray	Global Average
1	Potatoes	191	33	63	287
2	Cassava	550	0	13	563
3	**Mean**	**370.5**	**16.5**	**38**	**425**

Coffee and Tea:

Coffee and tea have moderate water footprints compared to other food items, with coffee having a slightly higher footprint.

Table 4-35 Water Footprint of Tea and Coffee (Mekonnen, 2012)

No.	Food Stuff	Water Footprint (lit/kg)			
		green	blue	gray	Global Average
1	Coffee(cup)	126.72	1.32	3.96	132
2	Tea (cup)	22.14	2.7	2.16	27

4.3 Results and Discussion

4.3.1 Summary and analysis

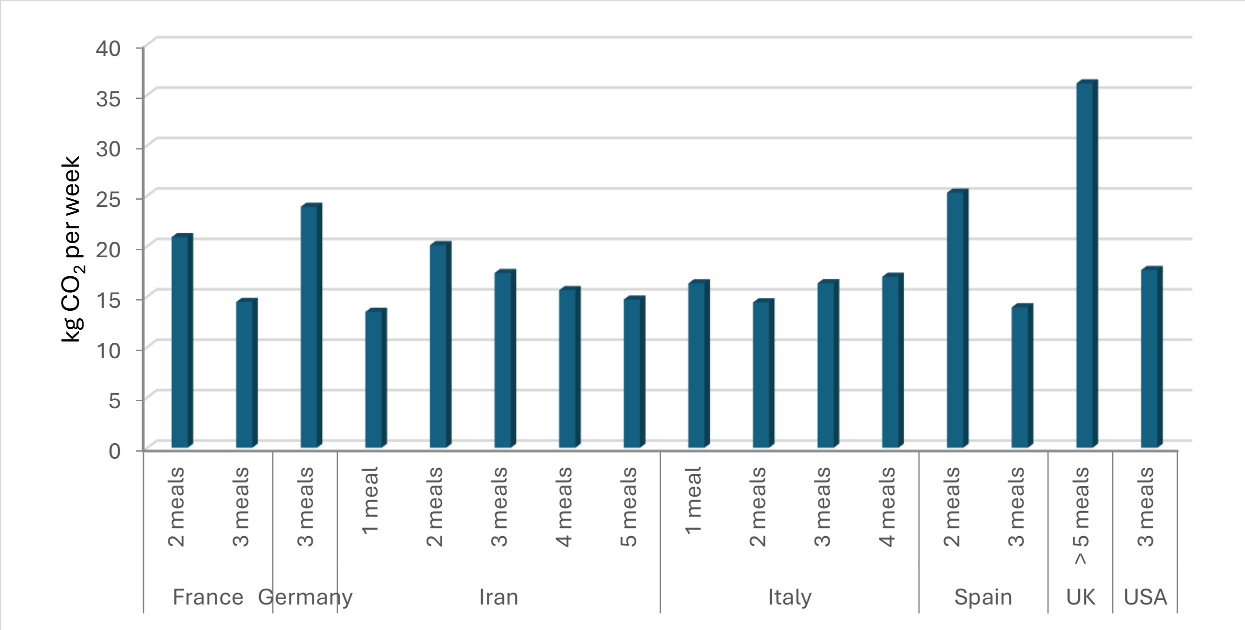
By utilizing tables, we can effectively summarize and analyze CO_2 footprint data for various food products. The table format enables quick comparisons of different food categories, highlighting the environmental impact of each. For example, cereals and vegetables have lower CO_2 footprints compared to meat and dairy products. This information is vital for making well-informed decisions about dietary choices and their environmental consequences.

Additionally, tables assist in identifying trends, such as the high impact of meat and certain beverages like tea and coffee, and in showing outliers, such as organic beef or air-transported pineapples with exceptionally high footprints. Therefore, tables not only organize data but also facilitate a deeper understanding of the presented information.

Carbon footprint in Countries:

Table 4-36 All Countries CO_2 footprint

Countries	Meals	Average of CO_2 per week	Average of Country
France	2 meals	20.89	17.68
	3 meals	14.46	
Germany	3 meals	23.89	23.89
Iran	1 meal	13.48	16.25
	2 meals	20.10	
	3 meals	17.33	
	4 meals	15.63	
	5 meals	14.70	
Italy	1 meal	16.30	16.00
	2 meals	14.42	
	3 meals	16.32	
	4 meals	16.96	
Spain	2 meals	25.30	19.62
	3 meals	13.93	
United Kingdom	> 5 meals	36.14	36.14
United States	3 meals	17.63	17.63
Total		**17.00**	



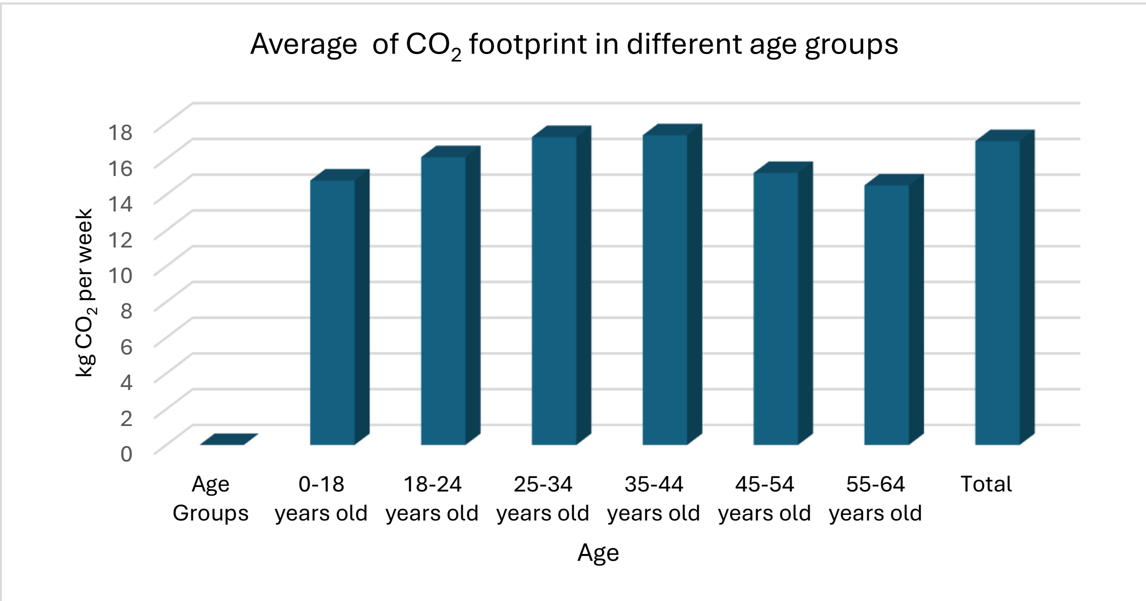
4-16 Average of CO_2 footprint in all countries

The examination of the carbon footprint linked to food consumption in Iran and Italy provides valuable insights into the environmental impact of dietary habits in these nations. In Iran, the total weekly carbon footprint is significantly high at 16.25 kg CO_2, with the majority of emissions originating from the consumption of two daily meals (20.10 kg CO_2). This is followed by three meals (17.33 kg CO_2) and four meal (15.63 kg CO_2). On the other hand, Italy's total weekly carbon footprint is 16.00 kg CO_2, with the highest emissions also arising from four meals per day (16.96 kg CO_2), followed by three meals (16.32 kg CO_2) and one meal (16.30 kg CO_2). These findings are in line with research on the water footprint of food consumption, displaying the substantial contributions of staple crops and high-value agricultural products to both water and carbon footprints. For example, in Iran, the high water footprint of rice and pistachios due to irrigation and agrochemical use is reflected in their significant carbon footprint. Similarly, in Italy, the cultivation of olives, grapes, and wheat, which are major contributors to the water footprint, also has a significant impact on the carbon footprint. These patterns emphasize the necessity for sustainable agricultural practices to alleviate the environmental impact of food production in both countries. The global average carbon footprint of food consumption varies widely based on dietary patterns, with estimates ranging from 2 to 5 kg CO_2 per person per day. The EAT-Lancet Commission recommends a dietary carbon footprint of around 2.5 kg CO_2 per person per day to meet sustainability goals. Iran's total weekly carbon footprint of 6357.43 kg CO_2 translates to approximately 907.63 kg CO_2 per day. Given Iran's population, this significantly exceeds the global average and recommended sustainability targets, indicating the need for more sustainable dietary practices and agricultural methods. Both Iran and Italy surpass the recommended sustainability targets for carbon footprints from food consumption. Strategies to decrease carbon footprints include promoting plant-based diets, enhancing agricultural efficiency, and reducing food waste.

4-37 Average Of CO_2 footprint in different age groups

Age Groups	Average of CO_2 foot print per week
0-18 years old	14.80
18-24 years old	16.10
25-34 years old	17.23
35-44 years old	17.33
45-54 years old	15.22
55-64 years old	14.53
Total	17.00

The table 4-37 illustrates clear trends in carbon footprints across different age groups, revealing notable variations shaped by life style and consumption behaviors. Young adults aged 18-34 demonstrate the highest carbon footprints, ranging from 16.10 to 17.33 kg CO_2 per week, driven by active social lives, frequent travel, and higher energy usage.



4-17 Average of CO_2 footprint in different age groups

As individuals transition into middle age (35-54 years), their carbon footprints remain elevated, spanning from 17.33 to 15.22 kg CO_2 per week, reflecting increased

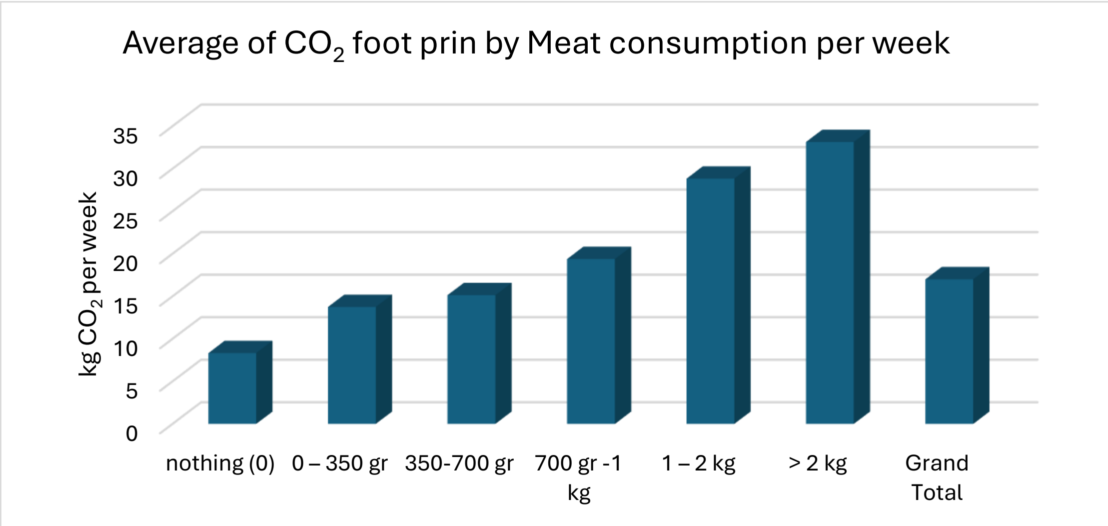
household energy demands and professional commitments. In contrast, older adults aged 55-64 exhibits a significant decline in carbon footprint to 14.53 kg CO_2 per week, indicative of reduced consumption and travel patterns as they approach retirement (figure 4-17).
The average total carbon footprint across all age groups stands at 17.00 kg CO_2 per week, emphasizing how age-related choices in lifestyle and economic activities collectively influence environmental impact. These findings underscore the necessity for age-specific approaches in environmental policies and individual behavioral changes. Initiatives can target younger adults with programs promoting sustainable transportation and energy-efficient practices, while aiding middle-aged adults in adopting renewable energy solutions and reducing household emissions. For older adults, strategies can focus on encouraging sustainable living practices that further diminish carbon footprints during retirement years. Addressing these age-specific dynamics is crucial for society's efforts to curtail overall carbon emissions and mitigate the impacts of climate change.

The table 4-38 presents a comprehensive overview of the carbon footprint linked to varying levels of weekly meat consumption, highlighting substantial environmental impacts. Consumption exceeding 2 kg per week results in the highest carbon footprint of 33.14 kg, indicating intensive resource use in production, transportation, and processing. Conversely, consuming no meat (0 kg) shows the lowest carbon footprint at 8.33 units, underscoring significant emissions reduction potential through dietary choices. Moderate consumption levels (0 – 350 gr, 350-700 gr, 700 gr - 1 kg) demonstrate carbon footprints ranging from 13.74 to 19.38 kg CO_2 per week, indicating notable environmental impacts even at lower consumption levels.

4-38 Average CO_2 footprint per week in meat consumption

Consumption	**Average of Co_2 footprint per week**
nothing (0)	8.33
0 – 350 gr	13.74
350-700 gr	15.13
700 gr -1 kg	19.38
1 – 2 kg	28.84
> 2 kg	33.14
Total	**17.00**

Overall, the average carbon footprint for meat consumption across all categories reaches a total of 17.00 kg CO_2 per week (figure 4-18). This highlights the environmental importance of dietary decisions and underscores the potential for climate change mitigation by transitioning towards diets with reduced meat intake. Implementing strategies to encourage lower meat consumption and promote plant-based alternatives can significantly contribute to lowering overall carbon emissions associated with food production and consumption. By fostering awareness and adopting policies that support sustainable dietary practices, societies can work towards a more environmentally conscious food system aligned with global climate objectives.



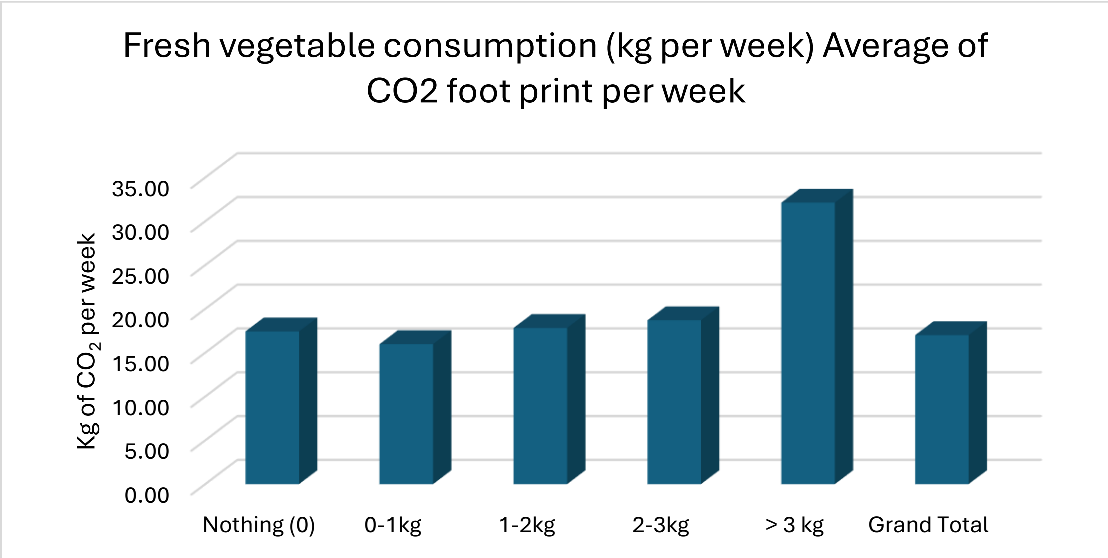
4-18 Average CO_2 footprint per week in meat consumtion

The table 4-39 demonstrates CO_2 footprint associated with fresh vegetable consumption varies significantly depending on the quantity consumed per week. According to the data provided, consuming over 3 kg of fresh vegetables per week results in a CO_2 footprint of 32.12 kg. In contrast, consuming between 0 to 1 kg per week leads to a significantly lower footprint of 15.97 kg CO_2. This disparity underscores the environmental impact of dietary choices, where higher consumption correlates with increased carbon emissions (figure 4-19).

4-39 Average of CO_2 foot print per week in Vegetables

Vegetables	Average of CO_2 footprint per week (kg)
Nothing (0)	17.43
0-1kg	15.97
1-2kg	17.82
2-3kg	18.70
> 3 kg	32.12
Grand Total	17.00

Moreover, the variability in carbon footprints across different consumption levels highlights the importance of individual dietary decisions in mitigating environmental impact. Choosing to consume less or opting for locally grown, seasonal vegetables can substantially reduce one's carbon footprint. This data underscores the potential for dietary choices to contribute positively to sustainability goals. Educating consumers about these impacts and promoting awareness can empower individuals to make more informed choices that align with environmental sustainability.



4-19 Average of CO2 foot print per week in Vegetables

While fresh vegetables are generally considered a healthier dietary option, their carbon footprint varies significantly depending on consumption levels. The understanding and actively managing human dietary choices could collectively reduce the environmental impact associated with food consumption, contributing to broader sustainability efforts.

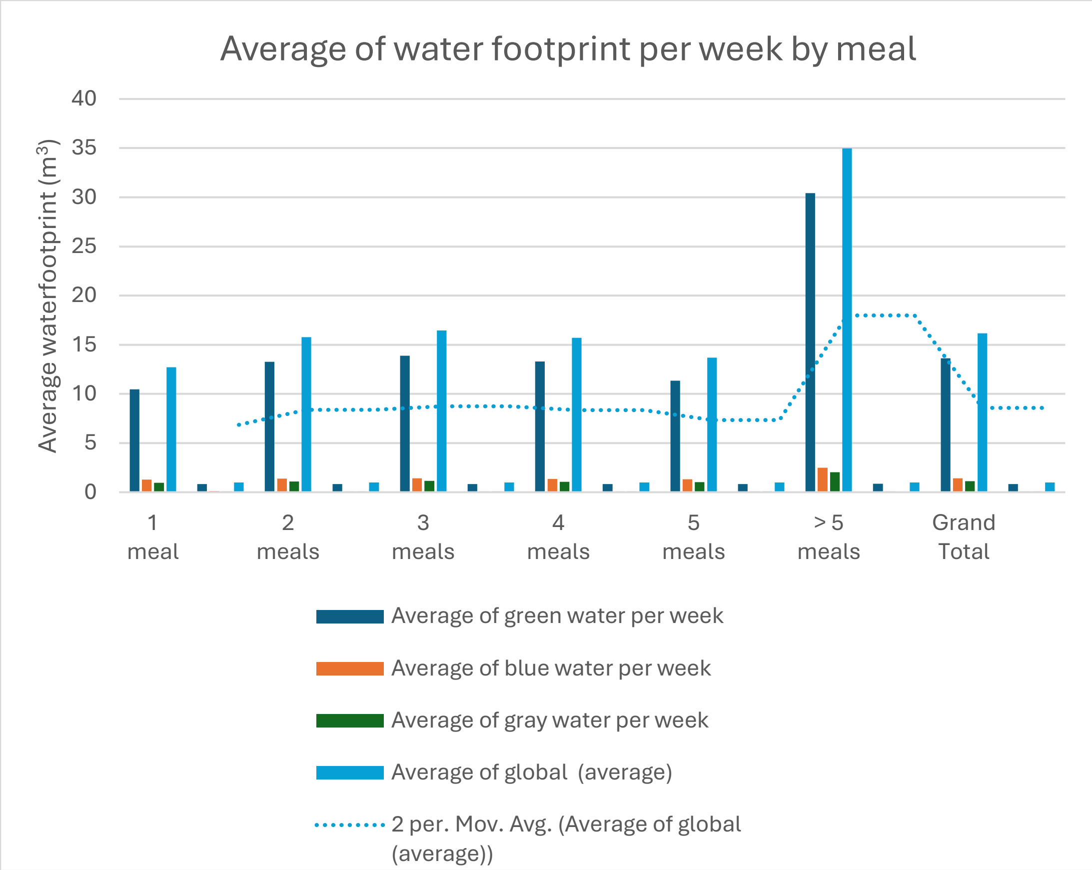
Water Footprint in all Countries:

The overall water footprint per meal varies among different countries, with the mean water footprint per meal being 16.16 liters per capita globally.

Table 4-40 Average of water footprint in m^3 per week and meal (Volume and percentage in terms of green/blue/gray water)

Meals	Average of green water per week	Average of blue water per week	Average of gray water per week	Average of global (average)
1 meal	10.47	1.29	0.96	12.72
	82.29%	10.16%	7.54%	100.00%
2 meals	13.28	1.40	1.09	15.76
	84.21%	8.89%	6.90%	100.00%
3 meals	13.89	1.43	1.15	16.46
	84.38%	8.66%	6.96%	100.00%
4 meals	13.30	1.34	1.07	15.71
	84.67%	8.55%	6.78%	100.00%
5 meals	11.36	1.32	1.01	13.69
	82.98%	9.63%	7.39%	100.00%
> 5 meals	30.44	2.49	2.04	34.97
	87.04%	7.11%	5.85%	100.00%
Grand Total	13.63	1.41	1.12	16.16
	84.33%	8.74%	6.93%	100.00%

4-20 Average of water footprint in m^3 per week meal

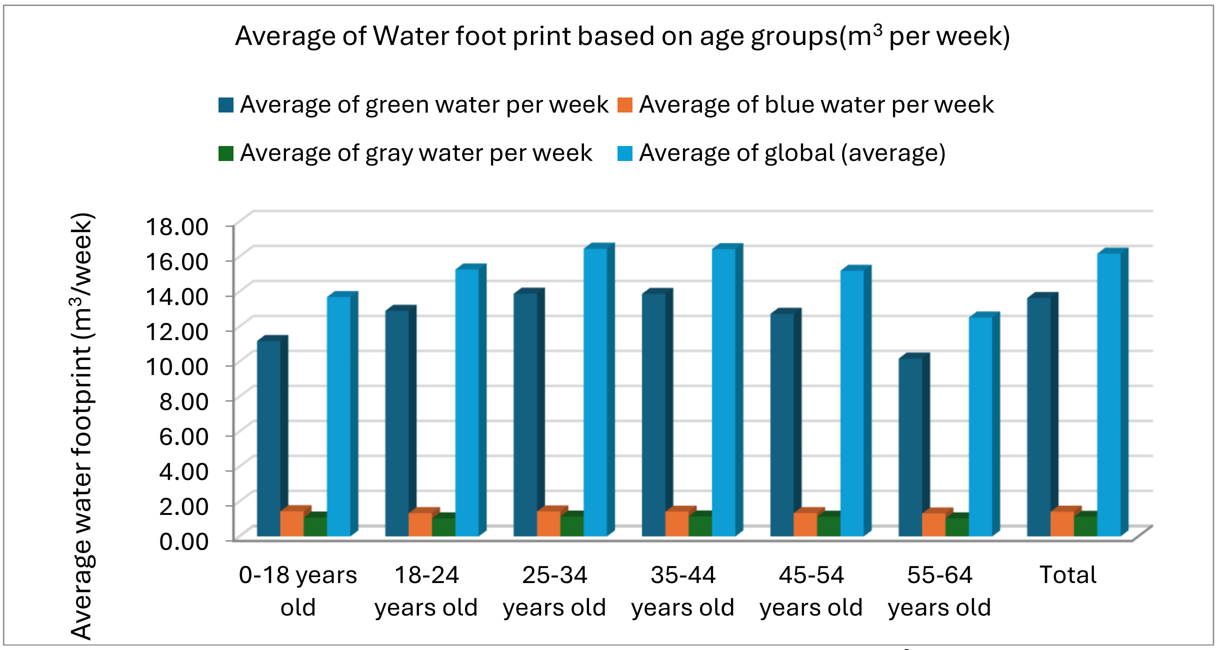


4-21 Average of water footprint per week by meal

4-41 Average of water footprint (m^3) base on age groups

Age	Average of green water per week	Average of blue water per week	Average of gray water per week	Average global
0-18 years old	**11.17**	**1.44**	**1.08**	**13.68**
18-24 years old	**12.89**	**1.33**	**1.03**	**15.26**
25-34 years old	**13.88**	**1.43**	**1.14**	**16.44**
35-44 years old	**13.86**	**1.42**	**1.14**	**16.42**
45-54 years old	**12.72**	**1.34**	**1.12**	**15.18**
55-64 years old	**10.16**	**1.31**	**1.03**	**12.51**
Total	**13.63**	**1.41**	**1.12**	**16.16**

The table 4-41 presents the average weekly water consumption in three categories (green, blue, and gray water) and their global average across different age groups. The data shows notable variations in water usage among different age groups. Young adults aged 25-34 have the highest overall water consumption, especially in green water, averaging 13.88 m^3 kg^{-1} per week. This group also records the highest global average water usage at 16.44 m^3 kg^{-1} per week, likely due to their related food needs. Conversely, the 0-18 year old group has the highest blue water consumption at 1.44 units per week, indicative of their different food consumption.



4-22 Average of Water foot print based on age groups(m^3 per week)

These findings highlight the necessity for focused water conservation measures. Educational initiatives to encourage efficient water use could be aimed at young adults, while infrastructure improvements could address the unique requirements of each age group. Recognizing these consumption trends is essential for crafting effective water management strategies and promoting sustainable use across various demographics. Demographic insights are crucial for addressing water consumption and enhancing conservation efforts effectively (figure 4-21).

Water Footprint in all countries, Italy and Iran:

Water footprints per meal differ between Italy and Iran, reflecting regional differences in water usage related to food production and consumption.

4-42 Water footprint (m^3) in all countries

Countries-Meals	Average of green water per week	Average of gray water per week	Average of blue water per week	Average of global (average)
1 meal	10.47	0.96	1.29	12.72
Iran	10.20	0.98	1.32	12.49
Italy	11.81	0.88	1.18	13.87
2 meals	13.28	1.09	1.40	15.76
France	16.47	1.39	1.58	19.44
Iran	15.52	1.47	1.90	18.89
Italy	11.62	0.89	1.16	13.67
Spain	20.91	1.25	1.63	23.79
3 meals	13.89	1.15	1.43	16.46
France	10.94	1.05	1.19	13.18
Germany	20.10	1.59	1.95	23.65
Iran	13.85	1.15	1.44	16.44
Italy	13.53	1.06	1.32	15.92
Spain	11.92	0.89	1.10	13.91
United States	12.62	1.13	1.30	15.04
4 meals	13.30	1.07	1.34	15.71
Iran	13.14	0.94	1.15	15.23
Italy	13.50	1.21	1.57	16.27
5 meals	11.36	1.01	1.32	13.69
Iran	11.36	1.01	1.32	13.69
Total	13.63	1.12	1.41	16.16

Table 4-43 Water footprint (m^3) in Italy (Volume and percentage of the 3 components)

Meals	Average of green water per week	Average of blue water per week	Average of gray water per week	Average of global (average)
1 meal	11.81	1.18	0.88	13.87
	85.17%	8.51%	6.32%	100.00%
2 meals	11.62	1.16	0.89	13.67
	85.01%	8.48%	6.51%	100.00%
3 meals	13.53	1.32	1.06	15.92
	85.02%	8.31%	6.67%	100.00%
4 meals	13.50	1.57	1.21	16.27
	82.935	9.63%	7.445	100.005
Total	12.57	1.28	1.00	14.86
	84.62%	8.64%	6.74%	100.00%

Table 4-44 Water footprint (m^3) in Iran (Volume and percentage of the 3 components)

Meals	Average of green water per week	Average of blue water per week	Average of gray water per week	Average of global (average)
1 meal	10.20	1.32	0.98	12.49
	81.66%	10.53%	7.82%	100.00%
2 meals	15.52	1.90	1.47	18.89
	82.15%	10.05%	7.80%	100.00%
3 meals	13.85	1.44	1.15	16.44
	84.24%	8.75%	7.00%	100.00%
4 meals	13.14	1.15	0.94	15.23
	86.25%	7.58%	6.17%	100.00%
5 meals	11.36	1.32	1.01	13.69
	82.98%	9.63%	7.39%	100.00%
Total	**13.65**	**1.44**	**1.15**	**16.24**
	84.04%	**8.89%**	**7.06%**	**100.00%**

4.3.1.1 Analysis and discussion

The analysis of water footprints reveals significant differences across various food categories and consumption habits. Cereals, vegetables, and fruits have lower water footprints compared to meat and dairy products. Notably, beef has the highest water footprint, underscoring the significant environmental impact of meat production. This information is crucial for guiding sustainable food consumption and production practices aimed at reducing the overall water footprint and promoting resource-efficient food systems.

The data tables illustrate the considerable variability in water footprints among different food types. For instance, beef has an exceptionally high water footprint compared to other meats, emphasizing the extensive water resources needed for its production. Cereals such as wheat and rice also have high water footprints, primarily due to intensive irrigation practices.

Dairy products such as butter and cheese have moderate water footprints, influenced by the water used for animal feed and processing. In contrast, vegetables have lower water footprints than meat and dairy, making them a more water-efficient food option.

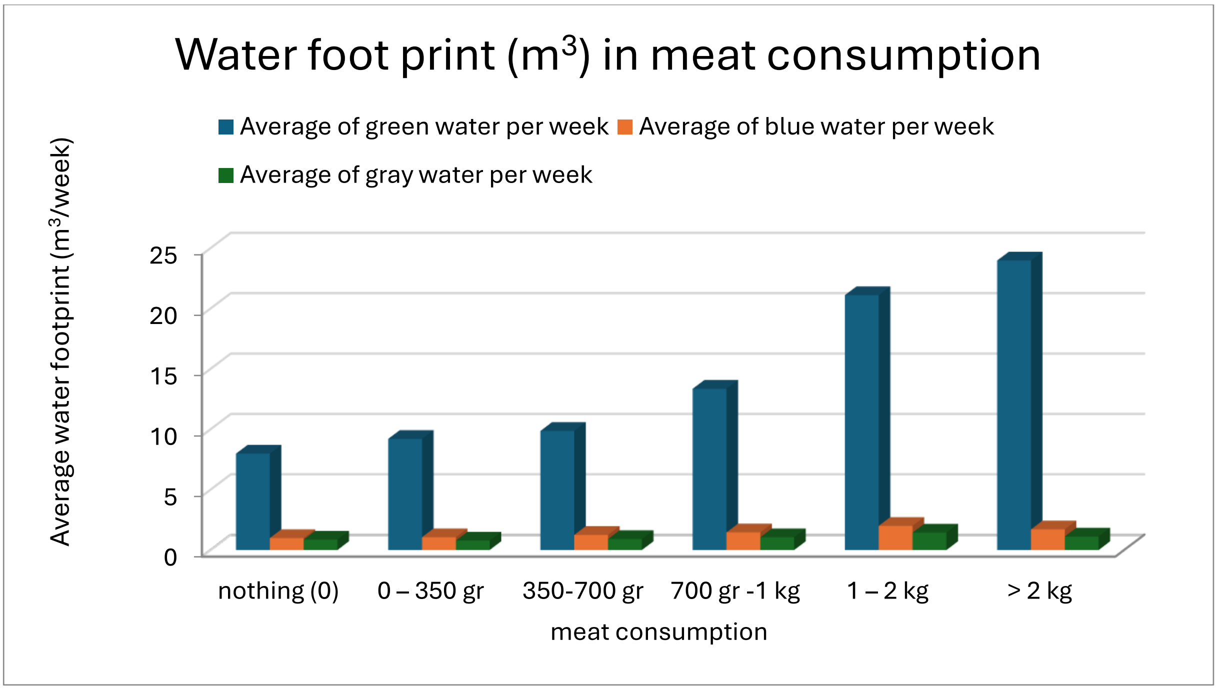
Understanding these differences is crucial for policymakers, farmers, and consumers aiming to promote sustainable water use. Strategies such as improving irrigation efficiency, adopting water-saving technologies, and shifting dietary preferences toward less water-intensive foods can significantly reduce the overall water footprint.

As previously stated, animal-based products have the highest water footprint. In tables 4-27 the water footprint related to meat, and in tables 4-28 and 4-29 the water footprint related to milk and dairy products result higher than plant-based products. Other researchers have also reported this issue (Mekonnen, 2012; Mirzaie *et al*., 2020). Thus, increasing animal-based food groups such as red meat and dairy products in the diet has the greatest effect on increasing the water footprint. Furthermore, consuming less of these materials and replacing them with plant-based dishes such as vegetables, cereals, and pulses can be effective in reducing the water footprint (Jalava *et al*., 2014; Donati *et a*l., 2016; Davis *et al*., 2016; Mirzaie *et al*., 2020). However, this position may not be acceptable to consumers and producers.

4-45 Water footprint (m^3) in meat consumption

Meat consumption	Average of green water per week	Average of blue water per week	Average of gray water per week	Global (average)
nothing (0)	7.98	0.99	0.86	9.83
0 – 350 gr	9.20	1.06	0.78	11.04
350-700 gr	9.86	1.25	0.91	12.02
700 gr -1 kg	13.35	1.46	1.06	15.87
1 – 2 kg	21.10	2.00	1.44	24.53
> 2 kg	23.97	1.71	1.12	26.80
Total	**11.57**	**1.31**	**0.95**	**13.83**

The table 4-45 and figure 4-22 offers a comprehensive view of the environmental impact associated with varying levels of meat consumption, measured in kilograms per week per person and categorized by different types of water usage: green, blue, and gray.



4-23 Water footprint in meat consumption

Analysis reveals that higher levels of meat consumption, such as over 2 kg per week, result in significantly higher water footprints across all categories. This includes substantial amounts of green water used for animal feed production, blue water for livestock drinking and feed crop irrigation, and gray water from meat processing. Conversely, lower consumption levels, like 0 – 350 grams per week, show minimal water footprints, reflecting lighter environmental burdens.

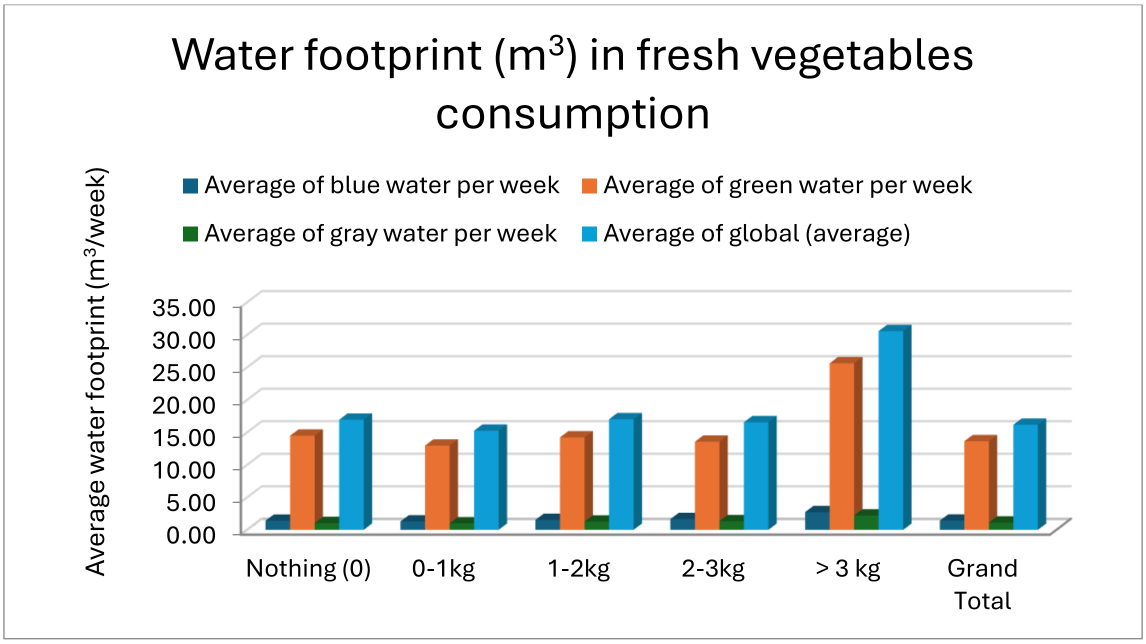
The global average figures provide a benchmark, demonstrating the typical environmental impact per person per week from meat consumption. This data underscores the urgency for sustainable practices in agriculture and consumption habits to mitigate water scarcity and pollution. It highlights the potential benefits of dietary shifts towards less resource-intensive foods, encouraging individuals and policymakers like to consider the environmental consequences of dietary choices (Mekonnen, 2012; Mirzaie *et al*., 2020).

Moving forward, this information serves as a critical tool for informed decision-making and policy formulation. It emphasizes the need for integrated approaches that promote sustainable agriculture, efficient water use, and consumer awareness. By adopting these measures, it would be possible collectively work towards reducing the environmental footprint of meat consumption while safe guarding water resources for future generations. Continued innovation in agriculture and technology will also play a pivotal role in achieving these sustainability goals on a global scale.

4-46 Water footprint (m^3) in fresh vegetables consumption

Vegetables consumption	Average of green water per week	Average of blue water per week	Average of gray water per week	Global (average)
Nothing (0)	**1.41**	**14.48**	**1.04**	**16.93**
0-1kg	**1.29**	**12.96**	**1.00**	**15.25**
1-2kg	**1.53**	**14.21**	**1.27**	**17.01**
2-3kg	**1.66**	**13.55**	**1.33**	**16.54**
> 3 kg	**2.73**	**25.62**	**2.21**	**30.56**
Total	**1.41**	**13.63**	**1.12**	**16.16**

The table 4-46 and figure 4-23 show a comprehensive analysis of the water footprint linked to different levels of weekly fresh vegetable consumption. It categorizes water usage into green, blue, and gray water, thereby illustrating the environmental impact across various dietary patterns. Consumption levels surpassing 3 kg per week display the highest water footprints, reflecting substantial irrigation demands (green water) and potentially intensive agricultural methods (blue water). Gray water, arising from processing and washing, further contributes to the overall environmental load. In contrast, consumption levels below 1 kg per week exhibits lower water footprints, indicating more efficient water management in vegetable farming and processing.



4-24 Average of water footprint by vegetables consumption

In comparison, global average data provides a standardized perspective on the weekly environmental impact per person from fresh vegetable consumption. These averages underscore the typical water footprint associated with vegetable production, emphasizing variations influenced by dietary preferences and regional farming practices. Understanding these intricacies is crucial for developing sustainable food systems that harmonize nutritional requirements with environmental stewardship.

From a broader viewpoint, the discussion underscores the imperative of promoting sustainable agriculture and optimizing water management techniques. Strategies to reduce water footprints in vegetable cultivation include advancing irrigation technologies, embracing organic farming approaches, and enhancing consumer awareness regarding the environmental consequences of dietary choices. Policy makers are important in enacting regulations that support sustainable agricultural practices, while consumers can contribute through informed decisions that prioritize environmental sustainability in their dietary habits. Addressing these challenges greatly contributes to build a future where vegetable consumption not only meets dietary needs but also minimize its ecological impact on global water resources (Taylor *et al*., 2013; Godfray *et al*., 2018).

The results in the water footprint tables of all countries, Italy and Iran - tables 4-42, 4-43 and 4-44 - show that green water plays a prominent role in the production of agricultural products in the world. These results are consistent with the previous findings of other researchers (Rockstrom *et al*., 2009; Mekonnen & Hoekstra, 2011). Mekonnen and Hoekstra (2012). determined the average water footprint pro capita in the world as 1400 $m^3 y^{-1}$ based on the data collected from 1999 to 2005. In this research, Iran (about 1800 m^3y^{-1}) and Italy (around 2200 $m^3 y^{-1}$) have had a larger water footprint than the global average.

Most of Iran's land is arid and semi-arid, and therefore most of its agricultural land is rainfed. According to the water footprint tables, in Iran, the number of blue waters is more than in Italy and other countries. Rockstrom *et al*. (2003) showed that there is a good opportunity to improve water efficiency. To this goal the development of a precision irrigation (e.g., drip irrigation) represents a valid solution. According to researchers, if groundwater is not used, grain production will be significantly lower (Hoff *et al*., 2010; Rost *et al*., 2009; Siebert & Doll, 2010). This is a good opportunity to increase food production from rainfed agriculture by increasing water productivity without the need for additional hydrological resources (Rockstrom & Baron, 2007; Rockstrom *et al*., 2003, 2007a, b). However, the marginal benefit of additional irrigation water in semi-arid and arid regions in terms of increased productivity is very high (Mekonnen & Hoekstra, 2011). In other words, most countries have the potential to be self-sufficient based on green water in theory and may be able to produce their food needs locally.

The available evidence suggests that, on average, European and Oceanian dietary patterns have the highest green water footprints (WFs) per capita (median: 2999 L/day and 2924 L/day, respectively), whereas Asian dietary patterns have the highest blue WFs (median: 382 L/day per capita). Foods of animal origin are major contributors to the green WFs of diets, whereas cereals, fruits, nuts, and oils are major contributors to the blue WF of diets (Harris *et al*., 2019).

However, reducing animal source foods (ASF) content of diets does not always correspond to lower water use, especially if ASFs) items are replaced with foods such as fruits and pulses that can be more dependent on irrigation (Springmann *et al*., 2018).

At any case considerable heterogeneity exists in the total water use of diets and in the relative proportions of green and blue WFs to total WFs (Harris *et al*., 2019; Godfray *et al*., 2018).

To understand the full impact of consumers on water resources, water use must be linked to local water availability, particularly in areas where water demand is growing and climate change threatens supply. Some studies are now using a water scarcity–

weighted footprint metric for this purpose (Hess *et al*., 2015; Goldstein *et al*., 2016), but such studies remain relatively rare.

Table 4-47 and Fig.4-24 summarize our data on the WFs by grouping the number of meals and the countries (Iran and Italy). Iran has higher total average across all categories (green, blue, gray, and global average) compared to Italy.

The total average of green, blue, gray, and global average increases with the number of meals, reaching its peak at 2 meals.

The global average is highest for 2 meals, indicating a possible trend where 2 meals might be the most common or significant in the dataset.

The analysis indicates that Iran consistently contributes more to the overall average in all categories compared to Italy. There is a distinct pattern where the average increase with the number of meals up to three and then decrease. Further examination of the data demonstrates that Iran's contributions are consistently higher in all categories (green, blue, gray, and global average) than those of Italy. This suggests that Iran's impact on the overall dataset is more significant. Additionally, the data shows that the total average for green, blue, gray, and global average increase with the number of meals

In summary, the analysis underscores the substantial contributions of Iran and the observed pattern of increasing average with the number of meals up to three, followed by a decrease. This insight offers a deeper understanding of the meal distribution and its impact on the dataset.

The carbon and water footprints of food consumption in Iran and Italy highlight the need for targeted strategies to achieve sustainability. Iran's high carbon and water footprints indicate a pressing need for more efficient agricultural practices and dietary changes. Italy, while performing better, still has room for improvement to meet global sustainability targets. Both countries can benefit from adopting best practices in sustainable agriculture, promoting dietary shifts towards lower-impact foods, and implementing policies to reduce food waste and improve resource use efficiency.

Table 4-47 IRAN and ITALY's water footprint (m^3)

Row Labels	Average of green water per week	Average of blue water per week	Average of gray water per week	Average of global (average)
Iran	12.90	1.38	1.03	15.31
1 meal	9.68	1.27	0.89	11.84
2 meals	14.63	1.82	1.33	17.78
3 meals	13.07	1.37	1.03	15.47
4 meals	12.62	1.11	0.86	14.59
5 meals	10.84	1.27	0.93	13.05
Italy	12.04	1.24	0.92	14.20
1 meal	11.30	1.13	0.79	13.22
2 meals	11.17	1.12	0.82	13.10
3 meals	13.02	1.28	0.98	15.27
4 meals	12.72	1.50	1.09	15.31
Grand Total	**12.18**	**1.32**	**0.97**	**14.47**

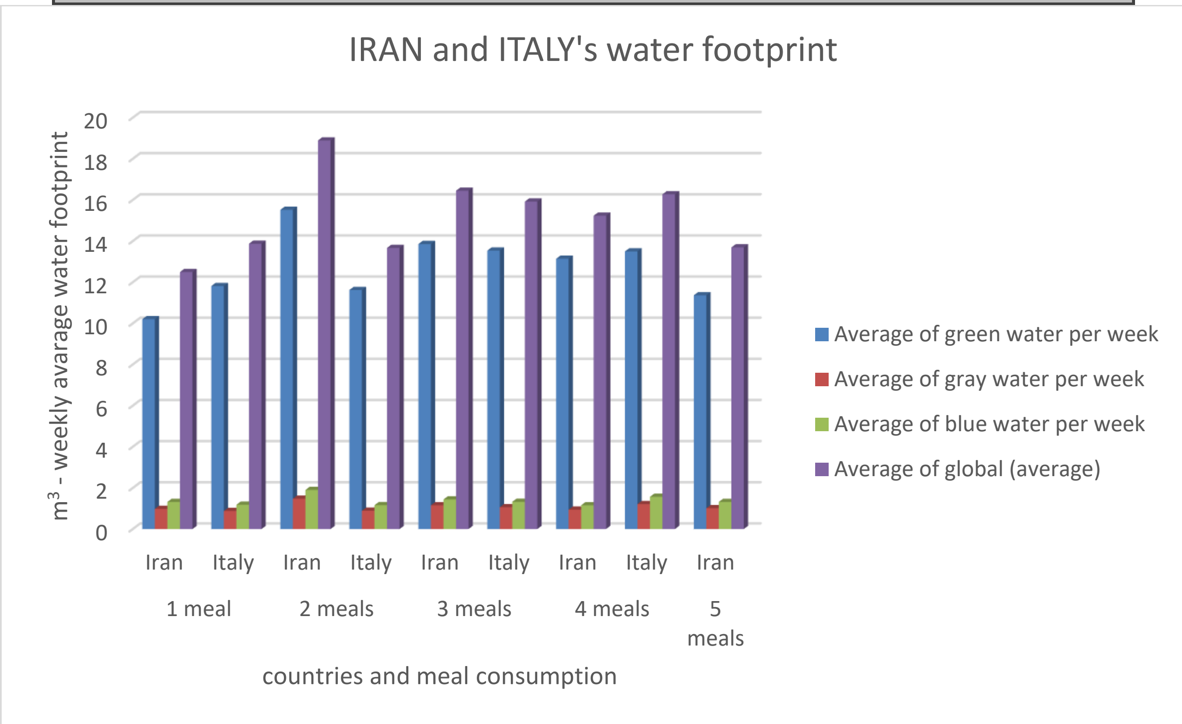


Figure 4-24 IRAN and ITALY's water footprint

5 Chapter 5

5.1 Conclusion

The research underscores the critical importance of food sustainability in addressing the complex challenges at the nexus of agriculture, environmental science, and global socio-economic dynamics. The quantitative analysis carried out through the surveys highlighted the urgent need for transformative changes in our food systems to ensure long-term viability and resilience. For example, we obtained that both Iran and Italy surpass the recommended sustainability targets for carbon footprints from food consumption. Key findings are as follows: the imperative of minimizing waste, optimizing resource utilization, and fostering equitable practices to support both farmers' livelihoods and the well-being of ecosystems.

Moreover, this thesis emphasizes the pivotal role of international initiatives such as the European Green Deal and the 2030 Agenda for Sustainable Development in driving systemic change towards more sustainable food production and consumption patterns. By leveraging innovative strategies like the Farm-to-Fork initiative and adopting holistic approaches such as the One Health framework, stakeholders can forge pathways toward enhanced food security, environmental stewardship, and public health.

The insights gleaned from the examination of carbon and water footprints across diverse food categories underscore the pressing need for concerted efforts to mitigate the environmental impact of dietary choices. Analysis reveals that cereals and vegetables have lower CO_2 footprints compared to meat and dairy, underscoring the significance of plant-based diets for reducing emissions. However, shifting dietary habits presents challenges, necessitating holistic approaches considering both environmental impact and nutritional balance.

The disparities between countries further underscore the importance of tailored interventions to address specific regional challenges while advancing global sustainability objectives. Examination of carbon and water footprints in Iran and Italy demonstrates the urgency of adopting sustainable practices to mitigate emissions and water usage. Strategies such as promoting plant-based diets, enhancing agricultural efficiency, and reducing food waste are crucial for achieving global sustainability targets.

Overall, this research provides a comprehensive roadmap for policymakers, stakeholders, and consumers to jointly work toward a more sustainable, resilient, and equitable food future by emphasizing the nexus of dietary choices and environmental impacts. Addressing these challenges requires collaborative efforts across sectors to promote informed dietary decisions and implement sustainable agricultural practices, ultimately contributing to a more environmentally conscious and resilient food system.

5.2 Future direction

Future research directions for sustainable food systems encompass various crucial aspects. Firstly, understanding the disparity in water footprints across different dietary patterns and regions, considering the impact of trading and food origin, is essential for informing policies on sustainable water management in food production. Secondly, delving deeper into young consumers' perceptions of food sustainability, particularly their preference for local and non-processed foods, can guide the development of strategies promoting sustainable food choices. Thirdly, there is a need to develop integrated metrics considering the cost, environmental impact, and health outcomes of dietary scenarios to design interventions promoting sustainable and healthy dietary patterns. Furthermore, assessing the feasibility of adopting sustainable and healthy diets, understanding the comprehensive environmental impact of diets, exploring the link between environmental impact and dietary sustainability are crucial for developing effective strategies for sustainable food systems.

6 ATTACHMENT 1

The list of questions used as a questionnaire:

1- Country of residence
   United States
   Canada
   United Kingdom
   Australia
   Germany
   France
   Spain
   Italy
   Iran
   China
   Japan
   India
   Saudi Arabia
   United Arab Emirates

2- How old are you?
   0-18 years old
   18-24 years old
   25-34 years old
   35-44 years old
   45-54 years old
   55-64 years old

3- Food consumption
   1 meal
   2 meals
   3 meals
   4 meals
   5 meals
   > 5 meals

4- Cereal products (wheat, rice, maise, pasta etc.) consumption (kg per week)
   Nothing (0)
   0 – 350 gr
   350-700 gr
   700 gr -1 kg
   1 – 2 kg
   > 2 kg

5- Meat products consumption (kg per week)
   Nothing (0)
   0 – 350 gr
   350-700 gr

700 gr -1 kg
1 – 2 kg
> 2 kg

6- Dairy products consumption (kg per week)
Nothing (0)
0 – 350 gr
350-700 gr
700 gr -1 kg
1 – 2 kg
> 2 kg

7- Milk consumption (per week)
Nothing (0)
0 – 350 ml
350-700 ml
700 ml -1 litre
1 – 2 litre
> 2 litre

8- Eggs consumption (number per week)
Nothing (0)
0-7
7-14
14-21
> 21

9- How do you prefer to take your food?
Cooked
Raw(uncooked)
Grilled
Fried
Steamed

10-How is your sugar and sweets consumption?
Nothing (0)
0-200 gr
200-400 gr
400-800 gr
> 800 gr

11-Fresh Vegetables consumption (kg per week)
Nothing (0)
0-1kg
1-2kg
2-3kg
> 3 kg

12-Fresh Fruits consumption (kg per week)
Nothing (0)
0-1kg
1-2kg
2-3kg
> 3 kg

13-Starchy roots (potatoes, cassava) consumption (kg per week)
Nothing (0)
0-1kg
1-2kg
2-3kg
> 3 kg

14-How many cups of coffee do you take per day?
None
1 cup
2 cup
3 cup
4 cup
> 4 cup

15-How many cups of tea do you take per day?
None
1 cup
2 cup
3 cup
4 cup
> 4 cup

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