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Essays on environmental impacts of dietary changes in Brazil

João Augusto Barcellos Lins
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JOÃO AUGUSTO BARCELLOS LINS

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Thesis submitted to the Applied Economics Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Doctor Scientiae*.

Adviser: Alexandre Braganca Coelho

Co-adviser: Guilherme F. Travassos

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ABSTRACT

LINS, João Augusto Barcellos, D.Sc., Universidade Federal de Viçosa, June, 2026. **Essays on environmental impacts of dietary changes in Brazil**. Adviser: Alexandre Braganca Coelho. Co-adviser: Guilherme Fonseca Travassos.

In this thesis, we investigate the environmental impacts of dietary habits and choices in Brazil and explore demand-side strategies for mitigation. We divided our research into two main chapters. The first chapter examines the nutritional and environmental impact of different diet types in Brazil and dietary transitions. We used nationwide dietary intake microdata from the Household Budget Survey (POF) from 2017-2018, in addition to environmental indicators. We estimated the carbon, water, and ecological footprint for eight distinct diet patterns, including vegan, vegetarian, pescatarian, flexitarian, and a Brazilian typical diet. The results demonstrate that strictly plant-based diets achieve the greatest reductions in environmental footprints when compared to animal-based diets. Meanwhile, pescatarian, vegetarian, and ruminant-replaced diets offer a "win/win" balance by providing moderate environmental benefits alongside greater nutritional diversity. The research additionally highlights that even partial dietary transitions, such as changing eating habits for just a single day, can lead to relevant environmental reductions. In the second chapter, we evaluated how a system of environmental food taxes and subsidies could be used to effectively reduce environmental impacts from the agrifood sector in Brazil. Using the most recent microdata from the POF, we estimated elasticities for 16 food groups through a Quadratic Almost Ideal Demand System (QUAIDS) model, and simulated tax-system scenarios including standalone environmental taxes, subsidies for sustainable foods, and a combined approach. Our results show that while standalone taxes on high-emitting foods reduce carbon footprints, they are regressive and may risk exacerbating food insecurity. Conversely, a dual-incentive policy combining taxes with subsidies emerges as the optimal choice, combining a reduction in environmental losses with better social equity. Ultimately, this research provides relevant evidence for policymakers, illustrating that demand-side interventions, such as encouraging dietary shifts and implementing targeted fiscal policies, can serve as an efficient complement to traditional command-and-control environmental strategies in Brazil.

Keywords: dietary change; Life Cycle Assessment; Greenhouse-gas Emissions; environmental taxes; Food Demand System; sustainability;

environmental impact.

RESUMO

LINS, João Augusto Barcellos, D.Sc., Universidade Federal de Viçosa, junho de 2026. **Ensaios sobre o impacto ambiental de mudanças alimentares no Brasil**. Orientador: Alexandre Braganca Coelho. Coorientador: Guilherme Fonseca Travassos.

Nesta tese, investigam-se os impactos ambientais oriundos de hábitos e escolhas alimentares no Brasil, e avalia-se uma estratégia de política pública para reduzir o impacto. A pesquisa foi dividida em dois capítulos principais. No primeiro capítulo, foram examinados os impactos nutricionais e ambientais de diferentes tipos de dietas no Brasil, assim como os efeitos de transições alimentares. Foram utilizados os microdados de consumo alimentar individual, em nível nacional, da Pesquisa de Orçamentos Familiares (POF) de 2017-2018, além de informações sobre indicadores ambientais para alimentos no Brasil. Foram estimadas as pegadas de carbono, de água e ecológica para oito padrões de dieta diferentes. Os resultados demonstram que as dietas à base de plantas alcançam as maiores reduções nas pegadas ambientais em comparação às dietas à base de produtos de origem animal. Por outro lado, dietas pescetarianas, vegetarianas e com substituição de carnes de ruminantes oferecem um equilíbrio, proporcionando benefícios ambientais moderados em conjunto com uma maior diversidade nutricional. Mesmo transições alimentares parciais, como a mudança de hábitos por apenas um único dia, podem levar a reduções ambientais relevantes. No segundo capítulo, avaliou-se como um sistema de impostos e subsídios ambientais sobre alimentos poderia ser utilizado para reduzir os impactos ambientais do setor agroalimentar no Brasil. Utilizando os microdados da POF, foram estimadas elasticidades para 16 diferentes grupos de alimentos utilizando o Quadratic Almost Ideal Demand System (QUAIDS), e foram simulados diferentes cenários de tributação no Brasil. Os resultados mostram que, embora impostos em alimentos com alta emissão reduzam as pegadas de carbono, eles são regressivos e correm o risco de agravar a insegurança alimentar. Em contrapartida, uma política de duplo incentivo, combinando impostos e subsídios, pode ser a escolha ideal, aliando a redução das perdas ambientais a uma melhor equidade social. Por fim, esta pesquisa fornece evidências relevantes para os formuladores de políticas públicas, ilustrando que intervenções pelo lado da demanda podem servir como um complemento eficiente às estratégias ambientais tradicionais de comando e controle no Brasil.

Palavras-chave: transição alimentar; Ciclo da Vida do Produto ; Gases de

Efeito Estufa ; imposto Ambiental; Sistema de Demanda; sustentabilidade; impactos ambientais.

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INTRODUCTION

The agriculture sector has significant environmental impacts. Agricultural activities are responsible for high levels of greenhouse gas (GHG) emissions (25%-33%), water consumption (>70%), and land occupation (40%) (Clark and Tilman, 2017; Forero-Cantor et al., 2020; Säll, 2018). Agriculture also drives deforestation and biodiversity loss. Among agriculture sectors, cattle raising is one of the highest contributors to these impacts (Clark and Tilman, 2017; FAO, 2013; Säll and Gren, 2015).

Different food production systems can damage the environment to different magnitudes. Beef production, specifically, is the highest contributor to the carbon footprint, so beef consumption can be linked to significant environmental impacts (Esteve-Llorens et al., 2019). According to the diet choices of individuals and families, there is more severe damage to the environment, with increased effects of climate change (FAO, 2019; Hartmann and Siegrist, 2017; Tukker and Jansen, 2006; Wang et al., 2021). From this perspective, consumers' preferences for specific foods could represent an important factor concerning environmental food sustainability (Allen and Prosperi, 2016).

The transition from a meat-based to a plant-based diet could reduce environmental damage, as these diets entail a better use of soil and water, improve the quality of local biodiversity, and increase animal welfare (Aiking, 2011; Dernini, 2018; Hartmann and Siegrist, 2017; Yeh and Hartmann, 2021). Beyond the environmental benefits, vegetarian/vegan diets could also provide better health for individuals, reducing the occurrence of strokes, heart attacks, and cancer (Dinu et al., 2017).

Other types of diets also have benefits for both the individual and the environment. Diets that reduce the level of ruminant meat, replacing it with pork, poultry, or fish, show a reduction in GHG emissions and land use (Hallström et al., 2015). In general, the environmental impact level is negatively correlated with animal-based food restriction (Aleksandrowicz et al., 2016). Thus, there is a relevant importance of diet choice, both in terms of environmental and public health, emphasizing the need to encourage reductions in meat and other animal-derived foods.

One way to reduce the environmental impact is through changes in diet patterns, but individuals are unlikely to change their diet preferences easily. However, a small change in population diet habits can already lead to a modest reduction in GHG emissions (Willits-Smith et al., 2020). The consumption reduction or increase of specific foods through demand-side policies is commonly used by policymakers (Barilla, 2013). An example of an instrument is the

Pigouvian taxes, used as a mechanism that penalizes the externalities that some food consumption has, such as health deterioration or environmental impact. The application of taxes is well documented in the literature for unhealthy foods (Leifert and Lucinda, 2015; Maniadakis et al., 2013; Niebylski et al., 2015; Popkin et al., 2021) and for foods that impact the environment (Barilla, 2013; Bonnet et al., 2018; Forero-Cantor et al., 2020; Gren et al., 2021; Säll, 2018). However, policies that aim to increase food taxes could sound unpopular and regressive to policymakers and the population, making them difficult to enforce (García-Muros et al., 2017).

The use of environmental taxes on foods with serious environmental damage has already been analyzed for different countries in Europe, such as Sweden (Säll and Gren, 2015), Denmark (Edjabou and Smed, 2013), France (Bonnet et al., 2018; Caillavet et al., 2019), and Spain (Forero-Cantor et al., 2020). In developing economies, there is a lack of studies that analyzes the impacts of dietary changes on the environment and the application of environmental taxes to reduce them.

However, some studies have already analyzed the carbon, water, and ecological footprints of the main food groups in Brazilian diets (Travassos et al., 2020) and the GHG emissions of the food subgroups for the state capital cities in Brazil (Aguiar et al., 2021). In addition, the environmental impact of ultra-processed[1] and processed foods has already been assessed (da Silva et al., 2021; Garzillo et al., 2022). Finally, Garzillo et al. (2019) established the relationship between environmental footprint (water and carbon) and each type of food consumed in Brazilian households.

Furthermore, the application of a tax could follow several different approaches. The taxation system could follow a structure based on the relevance of the food in the overall environmental impact, weighted GHG emission, or accounting for the food's full life cycle impact (Moberg et al., 2019). Also, tax scenarios could be implemented by changes in the existing Value-Added Tax (VAT) system (ICMS, in Brazil), where it could be lower for environmentally friendly foods or higher for non-friendly foods (Moberg et al., 2021). Other scenarios involve the use of combined systems of subsidies and *ad-valorem* taxes (Abadie et al., 2016) or refunding farmers with agricultural-enhancing ecosystem services (Gren et al., 2021).

[1] According to the NOVA classification, ultra-processed foods are industrial formulations manufactured from substances derived from foods, ready-to-eat, with high concentration of fat, sugar, or salt. (Monteiro et al., 2018).

In this context, the objective of this thesis is to develop two studies. In the first study, we answer the following question: How do diets with fewer animal-based products affect the environment in Brazil? We investigate this question in Chapter 1 by analyzing how different diets (such as vegan, vegetarian, pescatarian, ruminant-replaced, high-meat-based, flexitarian, and the Brazilian typical diet) change the level of GHG emission, land use, and water use in Brazil. In Chapter 2, we estimate whether a tax-subsidy system would be effective in reducing the environmental damage from food in Brazil. We simulate how different tax scenarios combined with subsidies could achieve a better allocation of resources and less environmental damage in Brazil. The database that we used to answer these questions comes from the Brazilian Household Budget Survey (*Pesquisa de Orçamentos Familiares* - POF) 2017-2018, for dietary intake, and from Garzillo *et al.* (2019) for the dietary environmental impact of each food type in the POF.

Our proposal is the first, to the best of our knowledge, to evaluate how specific diets, such as vegetarian, vegan, or ruminant-exclusive, could help to decrease the Brazilian environmental degradation, as well as to analyze an instrument (such as environmental taxes) that helps to mitigate the dietary environmental impact in Brazil. The results in these studies could serve as a pillar for policymakers who want to mitigate the environmental degradation in Brazil, combining them with other traditional strategies, such as the classic command-and-control policies. In addition, the Brazilian government has been working on a new tax system proposal, and one of the items contemplated is the creation of a selective tax, which encompasses an environmental tax. Therefore, this thesis might provide information that helps the government design this new tax and understand its impact on society.

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CHAPTER 1

1. Nutritional and Environmental Tradeoff of Dietary Transitions in Brazil

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Abstract

Our study examines the nutritional and environmental implications of dietary transitions in Brazil using nationwide dietary intake microdata and environmental indicators. We estimate carbon, water, and ecological footprints for eight types of diet patterns and simulate how a dietary transition could influence the environment in Brazil. Our results show that Plant-Based diets yield the largest reductions in carbon, ecological, and water footprints compared to Animal-Based diets. In contrast, Pescatarian, Vegetarian, and Ruminant Replaced diets balance moderate environmental benefits with greater nutritional diversity, highlighted as win/win dietary patterns. Even under scenarios in which the population changes their eating habits by only a single day, relevant reductions are observed, though smaller than in full conversion. These findings underscore dietary change as a promising strategy for sustainability, while also underscoring the cultural, social, and economic challenges that must be addressed through future policies and research.

Keywords: Dietary Change. Environmental Impact. Life Cycle Assessment. Greenhouse-gas Emissions.

1.1 Introduction

Climate change is augmenting environmental degradation and threatening the biodiversity and ecosystems around the globe (Weiskopf et al., 2020). Furthermore, the impacts of climate change are heterogeneous, as the poorest countries tend to be more vulnerable to its consequences and less prepared for higher variations in the climate (Tol, 2018). In this sense, understanding the causes of environmental degradation and their impacts on climate change is important to slow down the effects and achieve sustainability.

Moreover, one of the main sources of environmental degradation is food production. In the past decades, demand for food has grown, which has increased the opportunities for farmers to expand their production. However, specific food production chains are more prejudicial to the environment's quality and increase the effects of climate change (FAO, 2019). Cattle raising, as an example, plays an important role in food security but is responsible for several damages to the environment, as this activity increases greenhouse gas (GHG) emissions, deforestation, and land and water waste (Bustamante et al., 2012; Gerber et al., 2015), making beef food with a high environmental impact. This type of impact represents a challenge in improving the quality of the environment. For example, Brazil is one of the main global producers of beef and dairy, with a highlight of a sharp increase in production over the last decades (Malafaia et al., 2021; McManus et al., 2016). Thereby, Brazil became a major exporter of animal-based products, while also meeting the internal market demand, which expanded and intensified environmental pressure in Brazilian agriculture and food sector (Skidmore et al., 2021; Telles et al., 2024)

Thus, the consumption of specific food groups could be more prejudicial to the environment, which increases the environmental pressure that comes from food production. Moreover, the individual choice and preference for high intake of beef and other cattle-derived food groups could lead to more unsustainable diets. In contrast, many types of diets could help with food security and are less harmful to the environment. Replacing beef with other types of protein, such as pork, poultry, or fish, reduces GHG emissions and land use (Hallström et al., 2015). An option for consumers is to replace beef with vegetable proteins, achieving a healthier and more sustainable diet (Dinu et al., 2017; Hartmann & Siegrist, 2017). Generally, animal-based diets are more harmful to the environment than plant-based ones (Agyemang et al., 2022; Aleksandrowicz et al., 2016; Esteve-Llorens et al., 2019), suggesting that there is a need for diet change to achieve sustainability through food consumption. However, many cultural, social and economic challenges make individuals less likely to engage in a dietary switchover (Willits-Smith et al., 2020).

Even if there are barriers and several difficulties to switch between diets and eating habits, Brazilian families have recently experienced a change in their food patterns with an increase in the consumption of ultra-processed food and a decrease in beef intake, due to higher prices (IBGE, 2020b). Ultra-processed foods harm the environment as well (Garzillo et al., 2022), so the replacement of beef for this type of food may not be effective, since even if it has less impact on the environment (such as carbon and water footprint), those foods impose severe damage to the individual's health (Popkin et al., 2021). This change also highlights the need for analysis of the Brazilian diet patterns and their impact on the environment.

Despite some studies that had already estimated the environmental impact of Brazilian diets (Aguiar et al., 2021; da Silva et al., 2021; Garzillo et al., 2022; Travassos et al., 2020), only few publications underscored the environmental effects of dietary choices and shifts in Brazil (Bakman et al., 2024; Travassos et al., 2025; Verly-Jr et al., 2022). Generally, previous literature aimed to measure the relationship between food and environmental damage, but did not establish specific types of diets, measuring the single effect for each major food group. Aguiar et al. (2021) investigated the link between food diets and GHG emissions at the individual level in the capital state cities of Brazil, finding evidence that beef and dairy are the main contributors to emissions. On the other hand, Travassos et al. (2020) estimated the relationship between carbon, water, and ecological footprint for different groups of foods, adding different measures of environmental impacts. They found that beef is the main contributor to all footprints. Meanwhile, da Silva et al. (2021) explored the environmental impacts of food consumption in Brazil over the decades, underscoring the increase in GHG emissions alongside with an increase in the consumption of ultra-processed foods. In addition, Garzillo et al. (2022) estimated the environmental impact of ultra-processed foods in Brazil, finding that, despite being less harmful than beef and dairy products, they still have a significant relevance in deteriorating the environment, besides being the unhealthiest food type.

Moreover, Travassos et al. (2025) investigated the effects of choosing a more sustainable meat consumption pattern in Brazil, highlighting the improvements in both environmental and nutritional perspectives. Verly-Jr et al. (2022) access the outcomes to more sustainable diet choices, underscoring that the highest reductions in GHG emissions come alongside reductions in animal-based products and rice, but with an increase in the overall diet cost. Finally, Bakman et al. (2024) explores different dietary shifts in Brazil, assessing the trade-offs and outcomes of shifting from a conventional Brazilian dietary pattern to seven alternatives. They highlight that changing to alternatives with less animal products generates the best environmental outcomes relating to GHG emissions and land use.

Generally, those previous studies in Brazil did not focus on the diet that individuals choose, assessing only the environmental impact of each food group. In developed economies, however, there is plenty of evidence of how vegetarian, vegan, and other semi-vegetarian diets could reduce environmental issues (Agyemang et al., 2022; Aleksandrowicz et al., 2016; Hallström et al., 2015; Soret et al., 2014). This aggregate type of analysis is relevant, as the impact of foods, individually, does not exactly represent the consumer's patterns. Therefore, our main contribution is to provide information to understand how much of the reduction in emissions could be achieved by changes in diet in Brazil, showing how each alternative contributes in terms of reduction. This is important because the traditional approach for governments has been to encourage emission reductions by looking only at the supply side, and it is also important to encourage changes on the demand side of the economy. This is possible only by knowing the impacts of these types of changes.

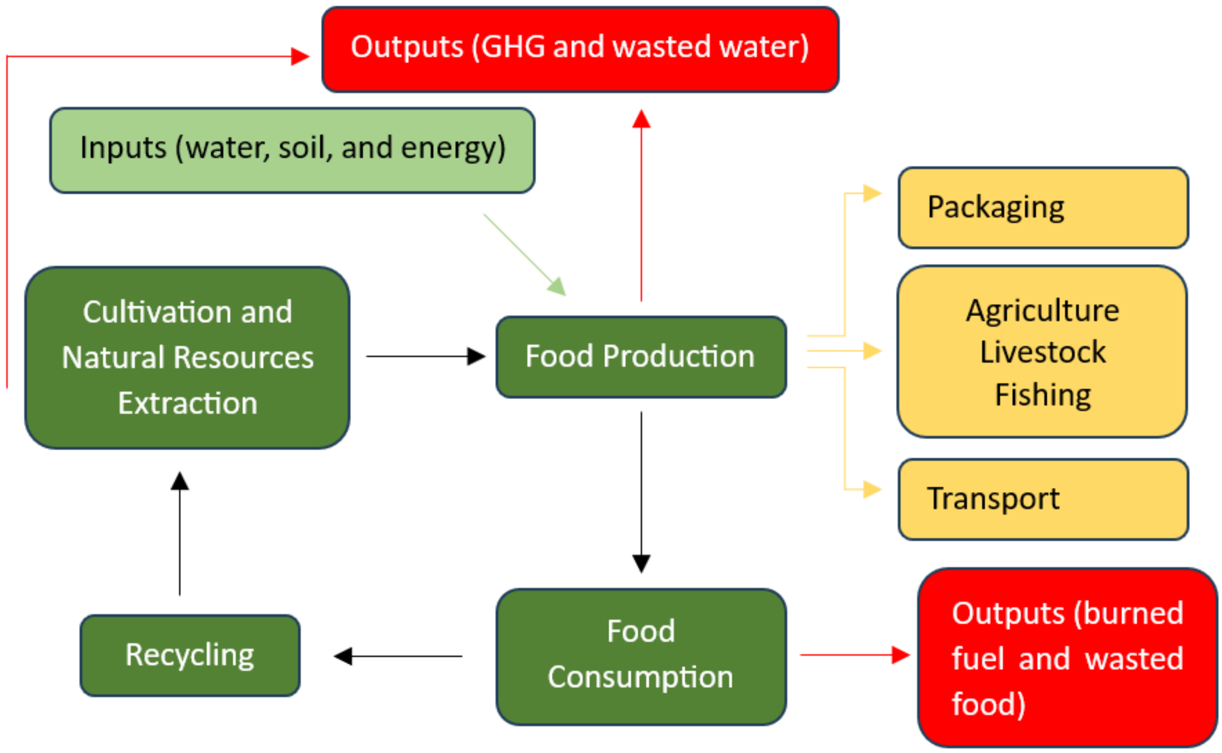
In this context, this study aims to advance the previous analysis from the literature in Brazil, proposing an estimation of the environmental impact for Brazilian diets and to stablish the relationship between different types of diets (such as vegan, vegetarian, ruminant-meat based, pescatarian, flexitarian, Brazilian typical diet, and ruminant meat replaced diet) and their respective damage to the environment. Thus, we identify how dietary choices in Brazil impact the environment and how changes in diets could reduce the environmental damage, advancing further in the literature with important results for a country that has international relevance in the agricultural sector, such as Brazil. This evidence is even important as Brazil is one of the largest producers and consumers of beef and dairy products, so understanding Brazilian diets could be a great step to promote eco-friendly diets and achieve a more sustainable food system. Also, our evidence can expose how much emissions and other environmental degradations could be reduced in Brazil through diet and habit changes. These demand-side strategies could complement the supply-side approaches more frequently used by governments, for example, emissions reductions from the industrial and transportation sectors.

Our results show that Plant-Based diets yield the largest reductions in carbon, ecological, and water footprints. In contrast, Flexitarian and ruminant-replaced diets balance moderate environmental benefits with greater nutritional diversity. Even under partial adoption scenarios, relevant reductions are observed, though smaller than in full conversion. Our study is structured into six sections. After this introduction: Section 2 presents the theoretical framework that supports our analysis; Section 3 describes the methodological approach and data; Section 4 reports the main results; Section 5 discusses the study findings in light of broader literature; Section 6 concludes the study with final remarks and policy implications.

1.2 Theoretical framework

Foods can impact the environment through different aspects. From production until consumption, the environment suffers losses due to different impacts that the food sector creates (BCFN, 2016). In this context, the Product Life Cycle Assessment (LCA) methodology[2] generates indicators accounting for inputs used in production (such as water, soil, and energy) as well as outputs (such as GHG emissions and water waste) generated through the food production chain (Garzillo et al., 2019). The LCA is described in Figure 1.

Figure 1. Life Cycle Assessment steps accounting for Inputs and Outputs in the food production sector.



Source: Adapted from BCFN (2016) and Garzillo *et al.* (2019).

Note: The green boxes represent the life cycle of the food system. In gold, we represent the activities that compose the food production. The red boxes are the outputs that come from the specific activities in the life cycle. Finally, in the light green boxes, there are the inputs used in food production.

[2] The LCA is regulated internationally by the standards ISO 14040:2006 and ISO 14044:2006 (BCFN, 2016).

Considering the food production chains, the main environmental impacts that come from this sector are those related to GHG emissions, the use of water resources, and land use (BCFN, 2016). Also, according to Garzillo *et al.* (2019), the volume of outcomes produced (kilograms of CO_2 and other gases) and inputs used (liters of water) in the processing are not homogeneous among foods, highlighting the individual analysis for each life-cycle production.

The food production life cycle can change the environment through different channels. First, we often observe land use changes as producers, to expand cattle and crop farming, increase deforestation by slashing and burning forests, and consequently, increase the CO_2 level in the atmosphere (Koch et al., 2019). Then, in the production process, there are CH_4 emissions which come mainly from livestock, as a consequence of the fermentation in the gastric system of ruminants, and from rice production (Pittelkow et al., 2014). In addition, the extensive use of fertilizers in agri-food production increases the emissions of N_2O, which heavily impacts the atmosphere (Mosier et al., 2005). Agriculture is also the largest user of water, so food production is directly linked to the scarcity of water and its environmental issues (Mekonnen & Gerbens-Leenes, 2020).

After food production, farmers need to transport their food to the market, which also increases GHG emissions through fuel combustion in civil aviation, road transportation, and railways (Tubiello et al., 2021). In addition, as some foods tend to be perishable, the transport needs a refrigeration system, which also increases GHG emissions, especially in regions with high temperatures (Wu et al., 2013). Furthermore, outside the farm gate, the packaging process has a high energy cost, which contributes to CO_2 emissions in the atmosphere (Tubiello et al., 2021).

Moreover, consumers also play a role in potential environmental degradation. The preparation of certain foods demands cooking procedures, which generate more CO_2, due to the burning of fuel (wood, coal, liquefied petroleum gas – LPG) (Garzillo et al., 2019). Also, during the whole food supply chain, food tends to be lost or wasted; however, it is in the consumption part that food is more wasted (Van Der Werf & Gilliland, 2017). In addition, the later the food is wasted in the food supply chain, the higher its environmental impacts are on society, due to the sum of all the other impacts that the environment suffered previously in production, transport, and packaging (Scherhaufer et al., 2018). Thus, the mass of solid food waste disposed of in landfills is an important issue to the environment and is part of the environmental impact from the food life cycle. In this context, the environmental impact on the food chain could be measured through different environmental indicators that will account for every stage of the life cycle, such as *footprints*, which mark the trail of the potential degradation that the whole activity has.

1.3 Empirical analysis

1.3.1 Environmental Indicators

In our study, to account for each food's environmental degradation, we calculate three footprint indicators that come from the LCA. Therefore, we will be able to measure the food consumption environmental impact as a part of GHG emissions (Carbon Footprint – CF), water use (Water Footprint – WF), and local biodiversity loss (Ecological Footprint – EF). This approach is commonly used in literature when assessing the relationship between food consumption and environmental quality (da Silva et al., 2021; Travassos et al., 2020).

The CF measures the volume of GHG emissions, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other gases that are released directly or indirectly into the atmosphere by an activity of the food life cycle, from production until the culinary preparation (BCFN, 2016). The CF also provides information on energy consumption in the production system, analyzing the amount of fossil fuel intake. The values of the GHG emissions calculated for the CF are expressed in mass of CO_2 or equivalent value for each food intake (gCO_{2eq} per 100g).

On the other hand, WF measures the volume of water resources used and polluted during the production life cycle, accounting for the use of water and the hydrological system (BCFN, 2016; Novoa et al., 2019). The WF is split into three main components (Mekonnen & Hoekstra, 2011): green water (rainwater consumed), blue water (surface and groundwater consumed), and grey water (volume of freshwater required to return polluted water to its natural standards and quality). For impacts related to water use (WF), we quantify the amount of freshwater used (blue and green water) and the output of polluted water (grey water) in the overall life cycle for each consumed food (liters of water per 100g). Furthermore, we consider the WF as the sum of the three components (blue, green, and grey water) to its total value.

Finally, the EF measures the last aspect of environmental degradation, accounting for changes in the biodiversity of the planet with an aggregate index that assesses the combined environmental impacts (Banerjee et al., 2020). The EF represents the environmental impact of the production process, quantifying the regenerative capacity of the biosphere to provide natural resources to human activity (food supply chain), maintaining ecosystem sustainability (BCFN, 2016). The EF also considers the direct and indirect demand for natural resources, comparing it with the biological assets on the planet (Garzillo et al., 2019). Even though it is an aggregate index that considers different aspects of environmental degradation that are presented in other indicators (such as water use or energy intake), it excludes certain relevant and important environmental pressures that come from human activities[3], underestimating the human impact on the biosphere (BCFN, 2016). In our analysis, we consider the land area used for the consumed food as the EF (g-m^2 per 100g). Thus, to understand the environmental impact of foods, the best option is to use the indicators together, so they can account for all issues. However, we needed to be careful when interpreting each finding, as the footprint proxies' values are not an exact measure, just the best possible environmental impact estimation (Garzillo et al., 2019).

1.3.2 Empirical Strategy

Our design study is divided into a five-step procedure. Initially, we extract the microdata from the National Intake Data (INA), which is part of the Brazilian Household Budget Survey (POF) from 2018-2019 (IBGE, 2020b). Then we build up the diet groups that individuals in Brazil have, with a total of eight possible diet groups, which enable us to analyze nutritional and health aspects of each diet. Then we use the converter created by Garzillo *et al*. (2019) to assess each gram of consumed food to its environmental impact, and with this information, we estimate the environmental impact (*footprints*) individually, for our specific categories of diets. Then we perform a Kruskal-Wallis statistical test (Kruskal & Wallis, 1952; Mann & Whitney, 1947) to evaluate overall differences across diet groups and their environmental footprints. Subsequently, we conduct pairwise comparisons using the Mann-Whitney test (Mann & Whitney, 1947) for each combination of diets.

1.3.2.1 Diet Classification

In our study, our diet groups do not necessarily ensure that they are nutritionally adequate, but these are possible and reliable choices that Brazilian households could face when choosing their diet. The diet group creation and specification were made following Aleksandrowicz et al. (2016) and adjusted for Brazilian food choices. We set up eight different diets for individuals: Vegan, Vegetarian, Pescatarian, Replaced-Ruminant Eater, High-Ruminant Eater, Flexitarian, Brazilian Typical Diet, and other diets.

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[3] Examples of human activities that are not accounted in the EF are water pollution, emission of toxic substances (heavy metals), noise pollution, depletion of the ozone layer and acid rain.

1.3.2.1.1 Vegan

Vegans primarily consume vegetables, fruits, pasta, and substitute sources of protein, such as soy and other plant-based products (Agyemang et al., 2022; Craig & Mangels, 2009). For this type of diet, we consider only individuals who do not consume any animal-source food, such as meat, fish, poultry, eggs, honey, or dairy products, being the most restrictive diet in our analysis. In this context, we selected vegans as individuals who have zero cholesterol diets, since their food consumption excludes all animal-derived products.

1.3.2.1.2 Vegetarian

The vegetarian diet is similar to the vegan diet but with fewer restrictions. For this group, we consider vegetarians who do not consume animal meat such as beef, fish, seafood, poultry, pork, or lamb, but consume dairy products and eggs. Generally, vegans could be considered vegetarians, as the concept of plant-based diets varies widely (Storz, 2022). In order to separate these groups, we consider vegetarians only individuals that do not consume meat but have dairy products or eggs in their diet patterns.

1.3.2.1.3 Pescatarian

The pescatarian diet could be seen as a branch of the vegetarian diet. The difference in this diet is the fact that individuals also eat fish and seafood. The pescatarian diet is defined as a healthy dietary pattern (Kim et al., 2021; Vanham et al., 2018), with high consumption of vegetables, legumes, nuts, and fishes, but avoiding all other meats (beef, lamb, poultry, goat, etc.). For the pescatarian group, we consider individuals who eat fish and seafood, in addition to other animal source foods, such as eggs and dairy products, that are within the premises of the pescatarian diet (Agyemang et al., 2022).

1.3.2.1.4 Ruminant-Meat Replaced

For this diet, we consider the substitution of Ruminant-Meat for other types of meat, such as those from monogastric animals (poultry and pork, mainly). However, this diet does not have the best health indicators, as pointed out by Scarborough et al. (2012), but can drastically reduce GHG emissions and land use. For our analysis, we will consider individuals who have a Replaced Ruminant-Meat as those who do not consume red meat (beef and lamb) but have consumption of white meat (poultry and pork).

1.3.2.1.5 High-Ruminant Eater

This diet focuses on the consumption of beef as one of the main sources of calories. This group represents individuals who have, on average, the intake of beef two times higher than the average population (Mogensen et al., 2020). In this group, we will consider individuals who consume vegetables and other non-animal source foods in addition to beef. In our analysis, individuals that are classified as having a "High Ruminant Eater" diet must have eaten at least a one-third share of total grams of foods consumed from beef or other ruminant meat.

1.3.2.1.6 Flexitarian

This group follows a vegetarian diet but is less strict with a major consumption of plant-based foods, and an occasional consumption of meat or fish (Derbyshire, 2017; Grasso & Jaworska, 2020). The Flexitarian diet is a sustainable dietary pattern, also pointed out as a diet with health and environmental benefits, and a rising trend in the world. In our analysis, we will consider as flexitarians individuals who have animal products and meat in their diets but do not consume more than 15% percent of their total grams of foods consumed from meat, poultry, fish, and pork.

1.3.2.1.7 Brazilian Typical Diet

For our seventh diet group, the Brazilian Typical Diet, we chose to analyze the most common pattern of food consumption in Brazil. Brazilian food patterns are based on the consumption of rice, beans, and beef in the main meals (lunch and dinner), juice, coffee, and bread in other meals such as breakfast and afternoon snacks (IBGE, 2020b). As beef is a main protein source in Brazilian eating patterns, we chose to assign individuals to this dietary pattern are those whose diets necessarily include beef, but in moderate proportions. Specifically, beef must account for at least 15% and no more than one-third of the total grams of food consumed in the diet. This criterion allows us to distinguish this group from both Flexitarians and High-Ruminant Eaters, whose diets also contain patterns of beef consumption.

1.3.2.1.8 Other Diets

The last group, which we label as "Other Diets", comprises individuals whose dietary patterns could not be clearly assigned to any of the seven previously defined categories. This group includes heterogeneous consumption behaviors that do not exhibit a specific pattern or characteristic that shapes an eating habit. Although residual, this group is relevant for revealing the diversity of dietary and eating patterns that fall outside the dominant dietary composition in the Brazilian population.

1.3.2.2 Diet Environmental Impact

To assess the environmental impact of each dietary pattern in Brazil and its distribution among the population, first, we use the estimated dietary footprints. Afterwards, we construct an Environmental Diet Footprint Index (EDFI), designed to integrate multiple dimensions of environmental performance and provide a composite measure of how environmentally sustainable a diet could be. The index follows a multi-indicator framework, similar to the Food Sustainability Index (Economist Impact & BCFN, 2021), but focuses exclusively on three key dimensions of environmental performance. The three dimensions used are the CF, WF, and EF, which together capture and reflect the main environmental pressures associated with food consumption patterns (Crippa et al., 2021a; Poore & Nemecek, 2018; Ran et al., 2024; Willett et al., 2019). All indicators were normalized per 1,000kcal to ensure comparability among diets differing in energy density.

The EDFI was built by standardizing each environmental indicator on a 10-point scale, according to specific thresholds representing best-case scenarios of environmental performance[4]. For each metric, we settled a target value (best-scenario) and an upper limit (worst-scenario), with the score decreasing linearly according to the distance from these thresholds. For the CF score, a maximum score (10 points) was assigned to diets with emissions below 0.8kgCO_2eq per 1,000kcal, and a minimum score (0 points) exceeding 2.0kgCO_2eq (Heller & Keoleian, 2015; Rosi et al., 2017). For the WF, diets below 1,000L per 1,000kcal received 10 points, while those above 2,000L received 0 points (Tompa et al., 2020; Vanham et al., 2013, 2018). Finally, for the EF, the highest score (10 points) was designed to diets below 5g-m^2 per 1,000kcal, and the lowest (0 points) for those above 12g-m^2 per 1,000kcal (Collins & Fairchild, 2007; Galli et al., 2023).

Once each component was standardized, we aggregated into a single metric using an impact-weight approach, assigning the weights for each indicator of 3:2:1 to CF, WF e EF, respectively. This weighted scheme reflects the priority and hierarchical contribution of each environmental dimension to natural resources pressures, mainly in Brazil (Chaudhary et al., 2018; Gerten et al., 2020). In this approach, we set a priority to GHG emissions, due to their global and systemic influence on climate change, while water and land use and waste are weighted proportionately lower, due to their local relevance instead of global influence like GHG emissions (Poore & Nemecek, 2018; Steffen et al., 2015; Willett et al., 2019). The

[4] To estimate the scores thresholds, we considered values for an average daily reference of 2,000kcal, estimating this value for the 1,000kcal reference and adapting it for our proposed index.

resulting composite index was rescaled to range from 0 to 1, where higher EDFI values indicate better environmental performance while lower scores indicate diets with stronger environmental impacts.

In addition, we tried to measure and understand how changing eating habits could impact on the environment. To achieve this goal, we simulated three scenarios (Table 1) and estimated how changes from an animal-based diet to a plant-based diet or replacing beef with other animal-source foods with lower environmental degradation potential would reduce the environmental impacts in Brazil. To simulate the environmental impacts, we considered diet switchover using the sample size, to observe the aggregate shift in the environmental indicators, and per capita, to account for the potential reduction of each eating habit.

Table 1. Description of the three main simulated scenarios for a diet switchover.

Scenario	Diet Switchover	Days of change
(1)	Transition from a diet with any intake of meat to a plant-based diet (Vegan or Vegetarian)	5 Days (71.42%); 3 Days (42.85%); 1 Day (14.28%)
(2)	Transition from a high beef intake diet to a more sustainable diet (Flexitarian, Pescatarian, or Ruminant Meat Replaced)	5 Days (71.42%); 3 Days (42.85%); 1 Day (14.28%)
(3)	Transition from the Brazilian Typical diet to a more sustainable diet (Pescatarian, Ruminant Replaced, and Vegetarian)	5 Days (71.42%); 3 Days (42.85%); 1 Day (14.28%)

Source: Own elaboration.

In the first scenario, we considered that individuals who consume any type of meat will change to a plant-based diet (vegan or vegetarian). For our analysis, we considered that individuals will partially change their eating habits, shifting their diets only a few days per week. There were three partial weekly adoption rates: 1 day (14.28% of total), 3 days (42.85% of total), and 5 days per week (71.42% of total). In the second scenario, we considered individuals with a high meat intake who will change to a more environmentally friendly diet, such as a flexitarian, pescatarian, or ruminant meat-replaced diet. The switchover rates were the same as in the first scenario. Finally, in our last scenario, we investigated the transition from the Brazilian typical diet to more sustainable alternatives, such as a Pescatarian, Ruminant Replaced, and Vegetarian. The switchover rates follow the same pattern as the two previous scenarios.

To estimate the total impact of a diet switchover, first, we calculate the overall footprint value:

$$OF_k = \sum Footprint_{ki} * n_i \quad (1)$$

where OF_k is the overall footprint for the k indicator; $Footprint$ is the value of footprint for the *i-th* diet; and n_i is the population of the *i-th* diet. Then we calculate the weighted footprint for those who are eligible for a diet switchover, which is signaled by $i - p$, where p is the groups of diets not eligible.

$$Footprint_{kw} = \frac{\sum Footprint_{k(i-p)} * n_{i-p}}{\sum n_{i-p}} \quad (2)$$

Now we calculate the amount of change that comes from the specific dietary transition:

$$Diet\ Footprint\ Switchover\ (DFS_k) = Footprint_{kw} - Footprint_{kg} \quad (3)$$

where $Footprint_{kg}$ is the footprint value of the newly adopted diet *g*. In sequence, we calculate the magnitude of the footprint change:

$$Footprint\ Change\ (FC_k) = (DFS_k * [(n_{total} - n_g) * CR] \quad (4)$$

where n_{total} is the total number of individuals eligible for the dietary transition; n_g is the number of individuals that already are on the diet *g* and CR is the conversion rate standardized by the scenario proposed. Finally, we calculate the footprint reduction:

$$Footprint\ Reduction = FC_k / OF_k \quad (5)$$

Furthermore, to account for the per capita change, we calculate the average overall weekly footprint of each diet ($F_{k,i}^{w}$):

$$F_{k,i}^{w} = 7 * Footprint_{ki} \quad (6)$$

then we calculate the new average footprint accounting for the switchover days:

$$F_{k,t,i}^{w} = (7 - d)F_i + dF_t \quad (7)$$

where F_i is the baseline *i-th* diet; F_t is the new target diet; and *d* are the days of diet switchover. Now we calculate the percentual change by:

$$\Delta_i = \frac{F^{w}_{k,i} - F^{w}_{k,t,i}}{F^{w}_{k,i}} * 100 \quad (8)$$

1.3.2.3 Nutritional and Health Outcomes

In addition to the environmental impacts, we also evaluate nutritional indicators, such as the number of calories and macronutrients, to shed light on aspects beyond the environmental characteristics of each diet. To account for the health and nutritional aspects of the evaluated diets, we chose to analyze a specific group of relevant macronutrients (protein, carbs, lipids, and fibers) in addition to energy intake (calories) and five micronutrients (calcium, sodium, cholesterol, iron, and zinc), due to their relevance for appropriate nutritional and health assessment (Afshin et al., 2019; Galchenko et al., 2021; Souza et al., 2025; Tapsell et al., 2016; Wawrzyniak & Suliburska, 2021).

In addition, we propose and estimate a Nutritional Healthy Index (NHI) to establish a specific metric to compare healthy and nutritional aspects among diet groups. Our index follows the main energy-density guidelines in the Healthy Eating Index (HEI) proposed by Kennedy et al.(1995), and the Nutrient Rich Food Index (NRF) proposed by Drewnowski (2009), with a focus on the macro and micronutrient composition of each diet. The nutritional intake targets that we used were based on international dietary guidelines (EFSA, 2010; FAO, 2010; Institute of Medicine, 2005; WHO, 2012; WHO & FAO, 2004). This type of approach allows us to assess diet quality using only nutrient composition data (Fernandes et al., 2018; Waijers et al., 2007) but we are aware that for a precise evaluation of nutritional quality and efficiency of diets, more information is needed (Arvaniti & Panagiotakos, 2008).

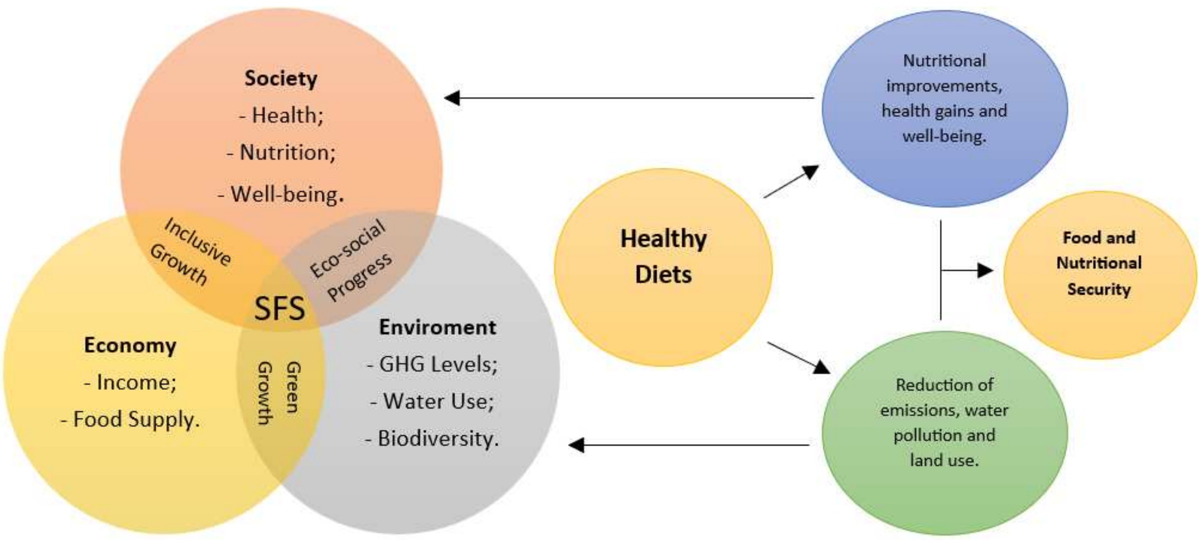
To estimate our NHI, we followed three main metrics: the first one is the Macronutrients Energy Density (MED), which focuses on the percentage of each macronutrient (proteins, carbohydrates and lipids) over the total energy; the second is the Benefic Nutrients Target (BNT), which accounts for the target intake of calcium and fibers by the amount of calories; and the third and last one, is the Harmful Nutrients Target (HNT), which account for a threshold for sodium and cholesterol intake by the amount of calories.

To determine the MED, first, we standardized the macronutrients evaluated to an energy-adjusted ratio per 1,000kcal. The macronutrient distribution was expressed as the percentage of total energy derived from proteins, carbohydrates, and lipids, using the Atwater conversion factors of 4, 4, and 9 kcal/g, respectively (FAO, 2003). Thus, we established a metric of 10 points for each macronutrient, respecting the threshold of its density over the overall energy intake (EFSA, 2010; FAO, 2010; Fernandes et al., 2018; Institute of Medicine, 2005).

Protein received 10 points when ranging from 10% to 35% of total energy (declining linearly to 0 below 5% or above 45%), carbohydrates were scored 10 points when within 45–65% (0 below 30% or above 75%), and lipids were scored 10 points between 15–30% (0 below 10% or above 40%). BNT components included dietary fiber and calcium densities, with 10 points awarded for achieving at least 14 g and 500 mg per 1,000 kcal, respectively, with a total of 20 points (EFSA, 2010; Institute of Medicine, 2005; WHO, 2012) Finally, for the last metric, HNT, each nutrient (sodium and cholesterol) received a maximum of 10 points when intake did not exceed 1,000 mg and 100 mg per 1,000 kcal, respectively, decreasing linearly to 0 points at 2,000 mg and 300 mg per 1,000 kcal (Fernandes et al., 2018; Lichtenstein et al., 2006; WHO, 2012). Each of the seven components contributed equally, resulting in a total raw score from 0 to 70, subsequently rescaled to a 0–1 range for interpretation. Higher NHI values indicate better adherence to nutritional recommendations and a more balanced nutrient profile, while lower scores reflect deviations from optimal nutrient intakes.

While nutritional quality and health outcomes are essential dimensions in the evaluation of dietary patterns, their broader sustainability also depends on the environmental burdens they impose, which promote sustainable food systems (Gibbs & Cappuccio, 2022; Meybeck & Gitz, 2017). Consequently, understanding the carbon, water, and ecological footprints associated with nutritional and health indicators of these diets is critical and essential for integrating health, environment, and well-being, enabling more comprehensive assessments of diet sustainability (Figure 2).

Figure 2. Scheme of the relationship between healthy diets and sustainable food systems (SFS).



Source: own elaboration based on FAO (2018); Gibbs and Cappuccio (2022); and Meybeck and Gitz (2017).

1.3.2.4 Data

For our analysis, we used data from the National Intake Data (INA), which is part of the 2017-2018 Brazilian Household Budget Survey (POF) that accounts for individual food intake (IBGE, 2020b). Personal food was collected for all residents "10-year-old or above" in the households that participated in the survey between July 11, 2017, and July 11 of 2018, for a total of 46,164 individuals from 20,112 households. In addition, the survey follows individuals up to two non-consecutive days, so we have a total of 83,032 observations to establish the diet types and groups that each observation in our sample will have.

We chose to analyze the observations by individual (considering two days of observation) and by day (treating each day as an independent observation) in our sample. The reason we chose to do this type of analysis is to have less bias and noise in our study, as diets could be considered habits and preferences. Daily observations would not consider the complete individual preferences for food, as they do not account for the intake from the second day evaluated, which could express different patterns of choice. On the other hand, as we consider specific diet consumption, observation by the day could lead to understanding the food's impact with more precision. After that, we used data on environmental footprints (CF, WF, and EF) for each food intake, which the POF investigates to assess the environmental indicators of each food consumed in Brazil. The data comes from the converter of consumed grams of each food that Garzillo *et al.* (2019) developed[5], accounting for the three environmental *footprints* that we will use.

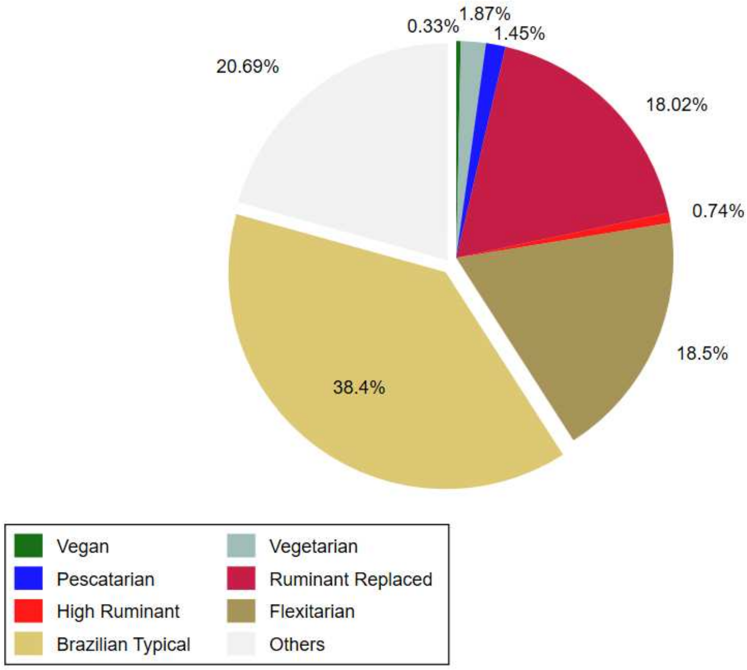
1.4 Results

1.4.1 Descriptive Statistics

We analyzed approximately 2,300 different foods that were consumed by individuals in Brazil. These foods were classified into different groups, following their type and origin, to enable us to create the diet groups and not be misled into putting an animal product in a vegan diet, for example. To avoid outliers, we dropped the top 1% of observations regarding the environmental footprints. In our sample, the major diet pattern is the Brazilian Typical Diet, with 38.4% of the total (Figure 3).

[5] More information could be found in https://osf.io/gs4cy/

Figure 3. Diet patterns among the sample population.



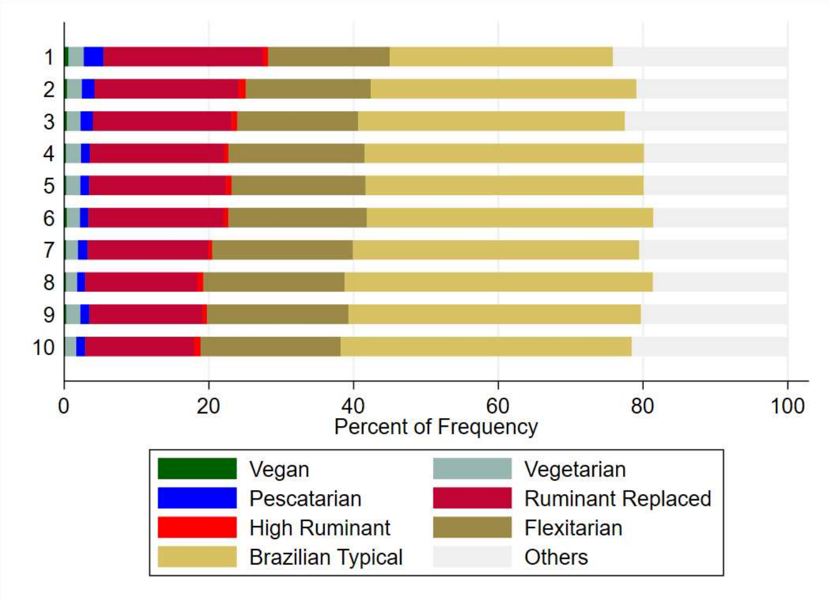
Source: Own elaboration.

Note: This analysis was made using individual values, not daily.

The second major diet is the Flexitarian (18.5%), followed by Ruminant Replaced (18.02%), both with very similar shares. Vegan and vegetarian diets make up a small part of the sample, nearly 2% of the total. In addition, Pescatarians represent only 1.45%, and High Ruminant Eaters are the second smallest fraction of the sample (0.74%). Other diets make up one-fifth of the total (20.69%).

Previous studies highlight income as one of the primary drivers of food group preferences and intake across different countries (Manyanga et al., 2017; Muhammad et al., 2017). Due to this issue, we examined how dietary patterns are distributed across income levels by estimating their distribution among per capita income percentiles (Figure 4). Overall, our results indicate that dietary composition remains relatively stable across income groups, suggesting limited differentiation by socioeconomic status. However, Ruminant-Replaced and Pescatarian diets exhibit higher frequencies within the lowest income decile, followed by a gradual decline as income increases. This downward trend may reflect the substitution of fish and other animal protein sources for higher-priced meat products, such as beef, as income rises.

Figure 4. Dietary percentage frequency among income distribution.



Source: Own elaboration.

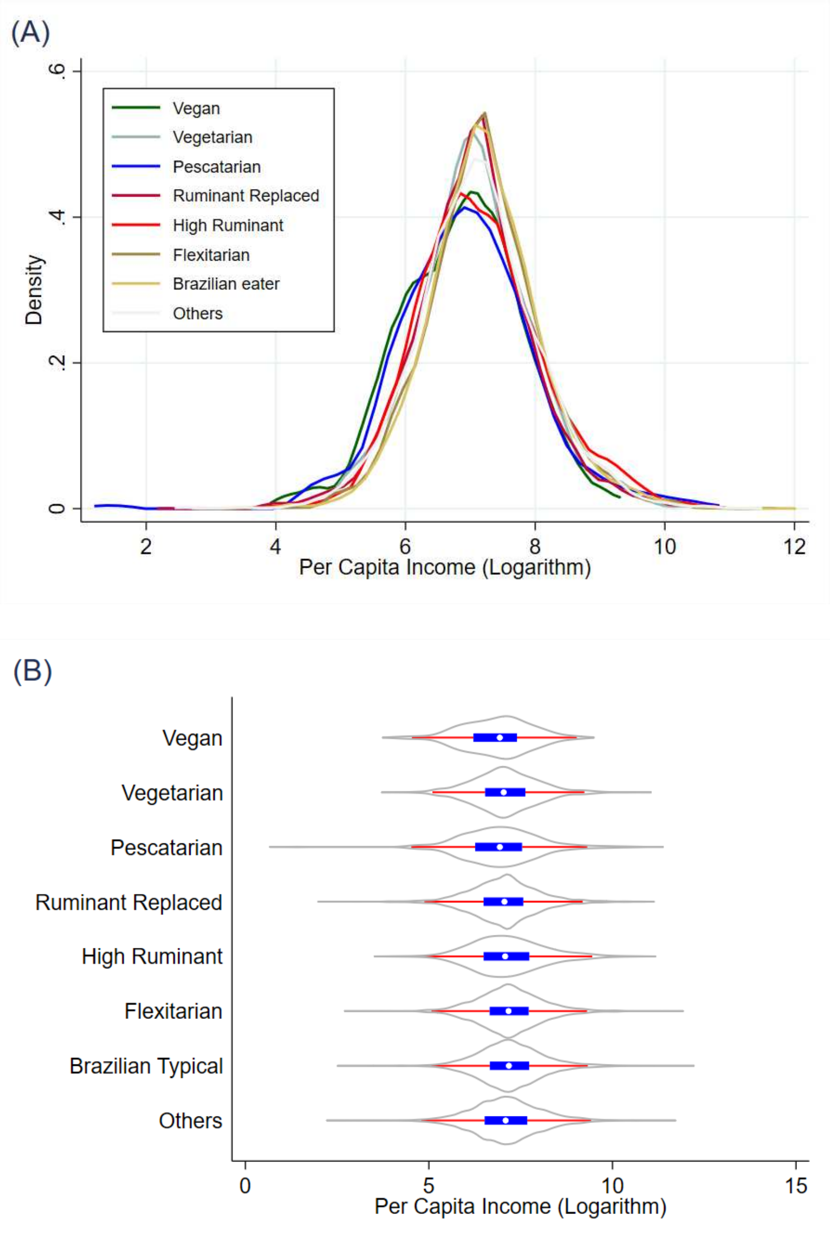
Note: The 1st decile is the lowest income group, while the 10th decile is the highest income group.

In addition, we used a log transformation function to understand the distribution of each diet pattern through per capita income (Figure 5). Our results show a clean pattern, as every diet follows the same distributional shape and closely matches the mean and median income values. In panel (A) of Figure 5, the kernel density estimate demonstrates overlapping income across diet types, suggesting that income differences do not substantially explain dietary segmentation within our sample.

Moreover, at panel (B), we estimate a violin plot for each diet group, which further confirms the convergence in central income tendencies among dietary choices. Although median income levels appear remarkably consistent, indicating that dietary choices are not strongly segmented by economic status within the sample, the variation in the width and form of distributions indicates differences in the degree of income heterogeneity across diets. We highlight Vegan and Pescatarian diets, which have a flatter and longer distribution, indicating higher variance and dispersion in individuals' incomes associated with these eating habits. In contrast, Flexitarian and Brazilian Typical diets display a more concentrated and narrower shape, reflecting a more homogeneous income structure, with less variability.

These patterns that we presented suggest that while income does not systematically differentiate dietary profiles on average, the variability and heterogeneity of distributions reflect and underline socioeconomic diversity. Probably, Brazilian dietary choices are shaped not only by income capacity but also by cultural, behavioral, and other non-observable characteristics. Consequently, the intersection between diet and socioeconomic status may be more nuanced than income-based explanations alone can capture.

Figure 5. Diet Patterns distribution, by per capita income (logarithm).



Source: Own elaboration.

Note: For Panel (A), we used a kernel distribution, while for Panel (B), we used a violin plot approach, merging the kernel distribution with a boxplot analysis. Individual values.

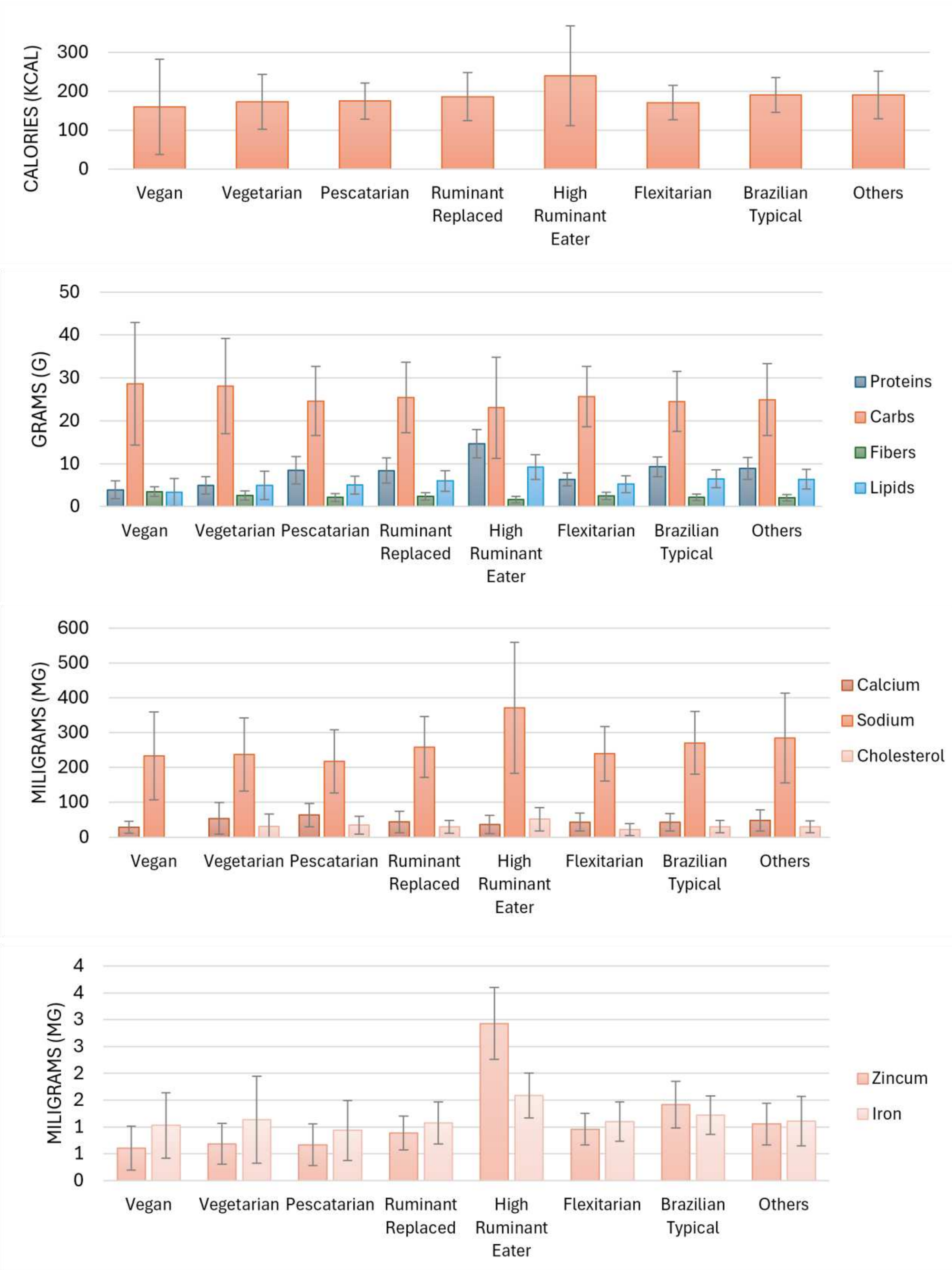
1.4.2 Health and Nutritional Aspects

As we chose to analyze our data both by individual (considering two days of observation) and by day (treating each day as an independent observation), we found that the results for the nutritional indicators were qualitatively similar[6]. However, we clearly observed a slight overall overestimation when using the daily basis. This overestimation likely arises from the phenomenon of *dietary compensation*, in which individuals adjust their subsequent food intake in response to the energy content of previous meals, reducing intake after periods of high consumption, or increasing it following dietary restrictions or as a form of reward (Blundell & Macdiarmid, 1997; Brunstrom & Rogers, 2009; Flynn et al., 2022).

Across the evaluated diets, we observed a clear difference in nutritional outcomes (Figure 6)[7]. Thus, differences in energy, protein, and lipid density per 100g have direct implications for health and nutritional outcomes (Galchenko et al., 2021; Noakes et al., 2005). Diets with higher energy intake, such as the High Ruminant Eater, can increase the risk of positive energy balance and weight gain (Hill et al., 2012; Webber, 2003), particularly in environments with easy access to palatable, calorie-rich foods (Stubbs & Whybrow, 2004). In contrast, diets with a lower energy intake, such as Vegan and Flexitarian, when adequately nutrient-dense, can support satiety with lower caloric intake, aiding in the prevention of chronic diseases and associated metabolic disorders (Derbyshire, 2017; Fraser, 2009; Koutentakis et al., 2023). In addition, Vegan diets seem to have less than half of the amount of lipids per 100g, compared to all other diet groups, and a higher intake of fiber, which also contributes to a healthier diet. However, the low intake of zinc and iron could lower the health benefits of such diets.

[6] Values of the daily analysis are available in the Appendix A.
[7] More detailed data are available as tables in the Appendix A.

Figure 6. Average values of total intake of calories (kcal) and macronutrients, by diet group. Nutritional information per 100g.



Source: Own elaboration.

Furthermore, plant-based diets are the ones with less protein per 100g of consumed food, which is a macronutrient that offers several potential benefits, such as maintaining lean body mass, improving satiety, and enhancing thermogenesis, all of which assist in weight management and metabolic outcomes (Halton & Hu, 2004; Paddon-Jones et al., 2008). Therefore, while the high fiber and low lipid observed in the plant-based diets (Vegan and Vegetarian) are strongly associated with health benefits, the comparatively low protein and zinc density highlight the need for balanced meal composition to optimize both metabolic health and functional outcomes (Ahnen et al., 2019). Strategies that combine diverse plant protein sources could improve with targeted supplementation and mitigate this limitation without compromising the dietary pattern (Ahnen et al., 2019; Hevia-Larraín et al., 2021).

In addition, we highlight the values of the Flexitarian, which, in our analysis, exhibited a lower caloric density, comparable to the vegan pattern, while maintaining a more balanced macronutrient distribution. This balance of the flexitarian pattern is characterized by moderate protein and fat densities alongside adequate carbohydrate and fiber content, suggesting a dietary profile that can support energy regulation without compromising essential nutrient intake (Derbyshire, 2017). However, we must highlight that this analysis considers a comparative intake of 100g per diet[8].

1.4.3 Diet's Environmental Impact

Building on the conceptual framework of sustainable food systems presented before, the following section examines specifically the environmental impacts of the dietary patterns assessed in our study. By quantifying their associated carbon, water, and ecological footprints, we aim to capture the resource demands and environmental pressures embedded in each dietary profile. We expect that this approach will allow for a direct comparison between nutritional quality and environmental performance, highlighting potential tradeoffs and synergies that can inform dietary recommendations aligned with both health promotion and planetary boundaries. Our statistical tests resulted in rejection of the null hypothesis. Therefore, we can conclude that each diet has its own influence over footprints and differs significantly from the other. As discussed before, our two analytical approaches yielded different absolute values, with the daily-based method presenting a higher magnitude[9]. However, the qualitative trends remain

[8] Values for the total intake of macro and micronutrients are available on the Appendix (Table 1A, 3A and 4A), which underscore a higher gap for the intake of proteins, zinc and calcium in plant-based diets. Considering the total intake, we observed that Vegans consumes half the total grams of animal-based diets, which could reinforce the gap for specific nutrients necessity.

[9] Values of the daily analysis and additional information are available in the Appendix A.

consistent across both approaches. Our assumption follows that dietary compensation patterns also reflect the magnitude of environmental impact.

Overall, plant-based diets, such as Vegan and Vegetarian, occupy the lower range for all indicators, while patterns rich in ruminant meat, such as the High Ruminant Eater and the Brazilian Typical, usually rank higher. Our results (Figure 7) show a persistent hierarchical pattern[10], which consists of plant-based diets occupying the lower quartile of environmental degradation, ruminant-based diets occupying the higher quartile, and intermediate diet patterns, like flexitarian, pescatarian, and ruminant replaced with a more moderate footprint, which is widely supported by previous literature (Aleksandrowicz et al., 2016; Biesbroek et al., 2023; Clark et al., 2020; Hallström et al., 2015; Willett et al., 2019).

These differences could largely be explained by the intrinsic characteristics of food groups that majorly compose each dietary pattern. Animal-sourced products, especially from ruminants, are associated with higher GHG emissions (Springmann, Clark, et al., 2018; Willett et al., 2019) and freshwater requirements (Clark et al., 2020; Gibbs & Cappuccio, 2022; Mekonnen & Gerbens-Leenes, 2020). In contrast, plant-based foods usually are more resource-efficient, yielding lower emissions, lower land-use, and less water waste (Aleksandrowicz et al., 2016; Biesbroek et al., 2023; Willett et al., 2019). The predominance of cereals, fruits, legumes, and vegetables in Vegan and Vegetarian diets, therefore, results in robust lower environmental footprints.

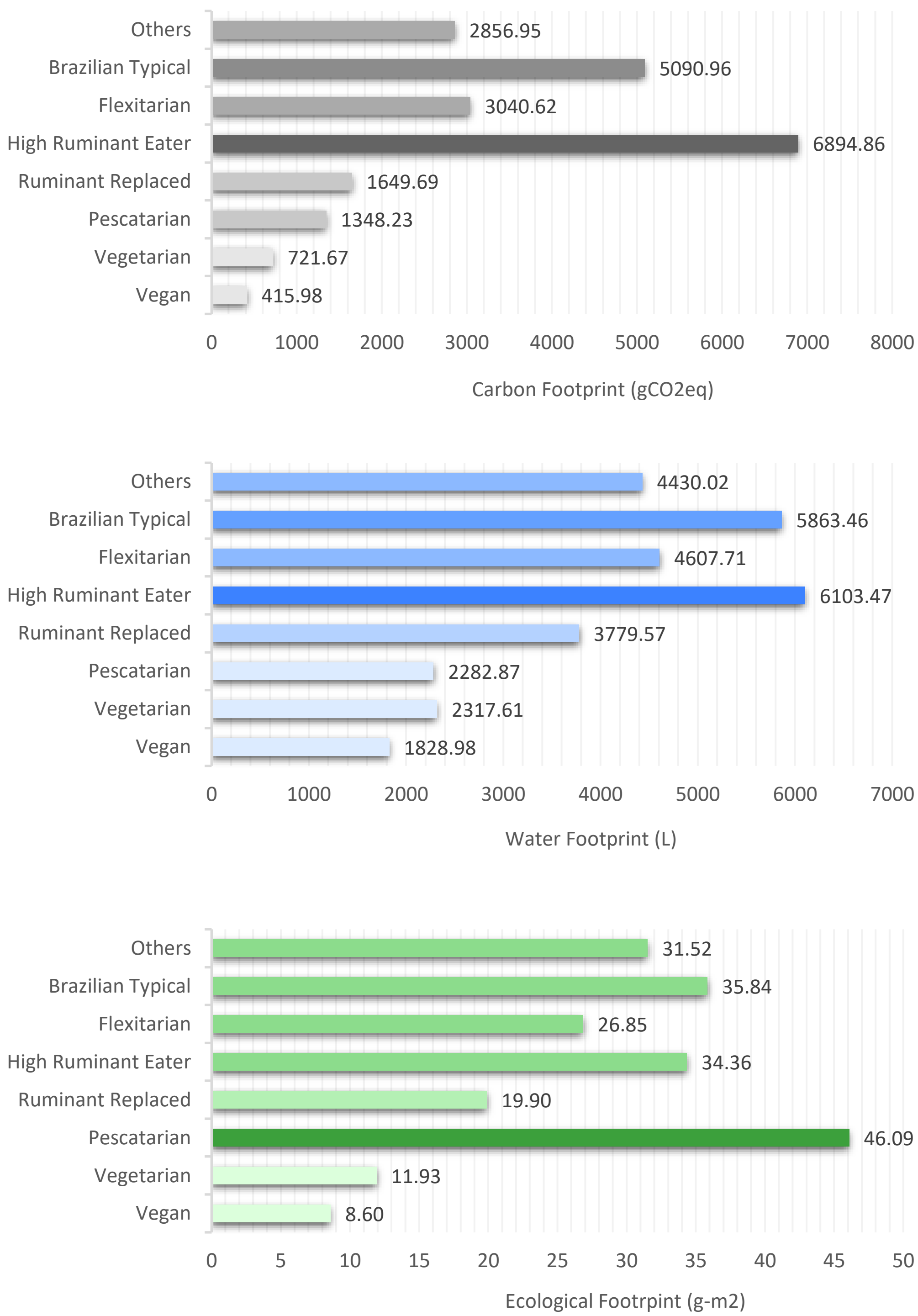
We also highlight Ruminant Replaced and Flexitarian diets, as they stand out for their lower environmental footprints, compared to other animal-based diets, and more dietary flexibility. All these patterns reduce ruminant meat consumption, resulting in a considerable reduction in the carbon footprint, which is more observable at the Ruminant Replaced and Pescatarian patterns, given that flexitarians still consume beef.

A highlight in our results is the water footprint of pescatarians, which is the lowest among all animal-based diets, a result which is explained as wild-caught seafood does not rely on freshwater inputs for production, while animal farming requires large volumes of freshwater (Mekonnen & Gerbens-Leenes, 2020; Pahlow et al., 2015). On the other hand, Pescatarians have the highest ecological footprint among all diets, reflecting the high area resources demanded by aquaculture (Jiang et al., 2022). These differences underscore that reducing

[10] The same dietary pattern is observed, also, by different genders, men and women (Table 8A-9A). However, we observe a slightly higher consumption of food grams by men compared to women, which results in a slightly higher footprint for men.

ruminant meat is an effective first step, but the overall environmental outcome depends on the specific animal-sourced foods used as replacements.

Figure 7. Average values of Carbon Footprint, Water Footprint, and Ecological Footprint, by diet group. Per capita values.



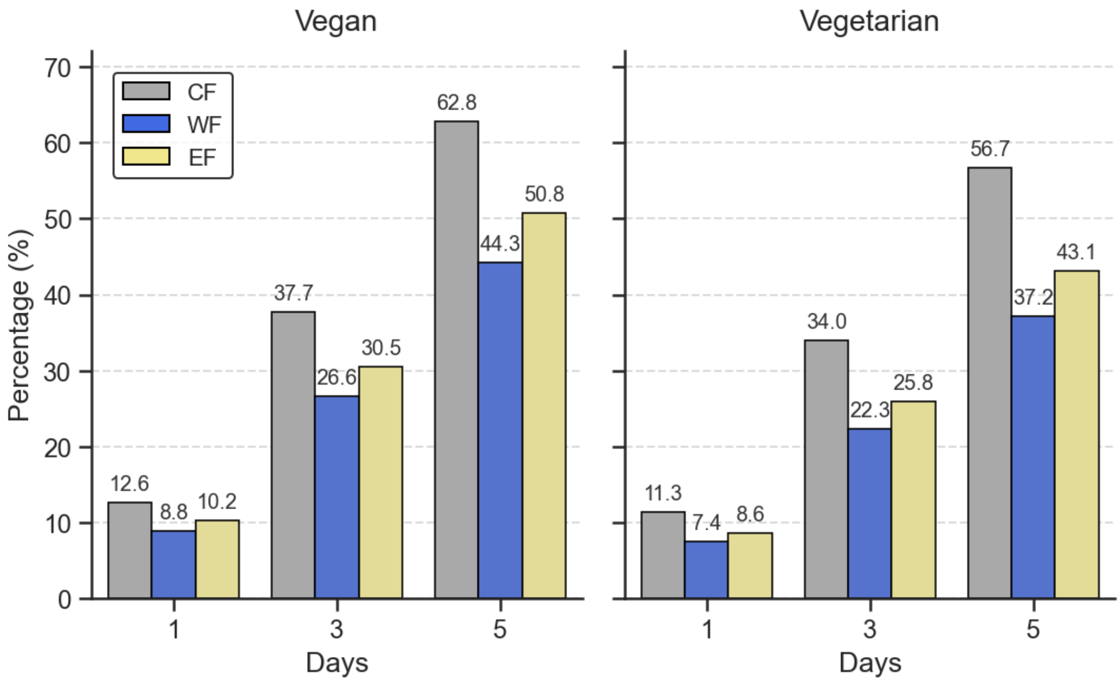
Source: Own elaboration.

1.4.4 Diet Transition and Switchover

After establishing the environmental performance of the eight previous dietary patterns and their respective footprints, we focus on examining how changing eating habits could reshape environmental impacts. Exploring dietary transitions, particularly from an animal-based diet to a plant-based diet, offers a way to assess the potential reductions in environmental degradation through dietary changes in Brazil. For this analysis, as we would like to estimate the effect of a diet switchover, we choose to analyze it individually and not daily, so we can properly see the effect of an eating habit change. In the first scenario (Figure 8), we aim to understand how transitioning from an animal-based diet to a plant-based diet could shift foods' environmental impact from consumption.

As expected, dietary shifts toward a Vegan pattern have produced larger reductions in environmental footprints, compared to a Vegetarian shift. We must emphasize that in this scenario, many individuals would be eligible to change their diets (approximately 97.9% of the sample), which expresses the highly aggregate effect. In the optimistic scenario, where individuals would not eat any type of meat for 5 days, we estimate a reduction in CF of approximately 57-63% (88.9 and 98.5 tonCO_2eq, respectively). EF shows the second largest decrease, ranging from 43% to 51% (58.1 and 68.5 g-ha), while WF decreases by 37-44% (80.8 and 96.2 million liters). A more plausible scenario, in which the population would abdicate eating meat for only 1 day, suggests reductions in CF of about 11-13% (17.7 and 19.7 tonCO_2eq, respectively). EF decreases by approximately 8-10% (11.6 and 13.7 g-ha), and WF by 7-9% (16.1 and 19.2 million liters). In a midterm scenario, in which individuals choose to shift their dietary habits for 3 days, we estimate reductions in the CF of about 34-38% (53.3 and 59.1 tonCO_2eq, respectively). EF decreases by approximately 26-31% (34.6 and 42.1 g-ha), and WF by 22-26% (48.3 and 57.6 million liters).

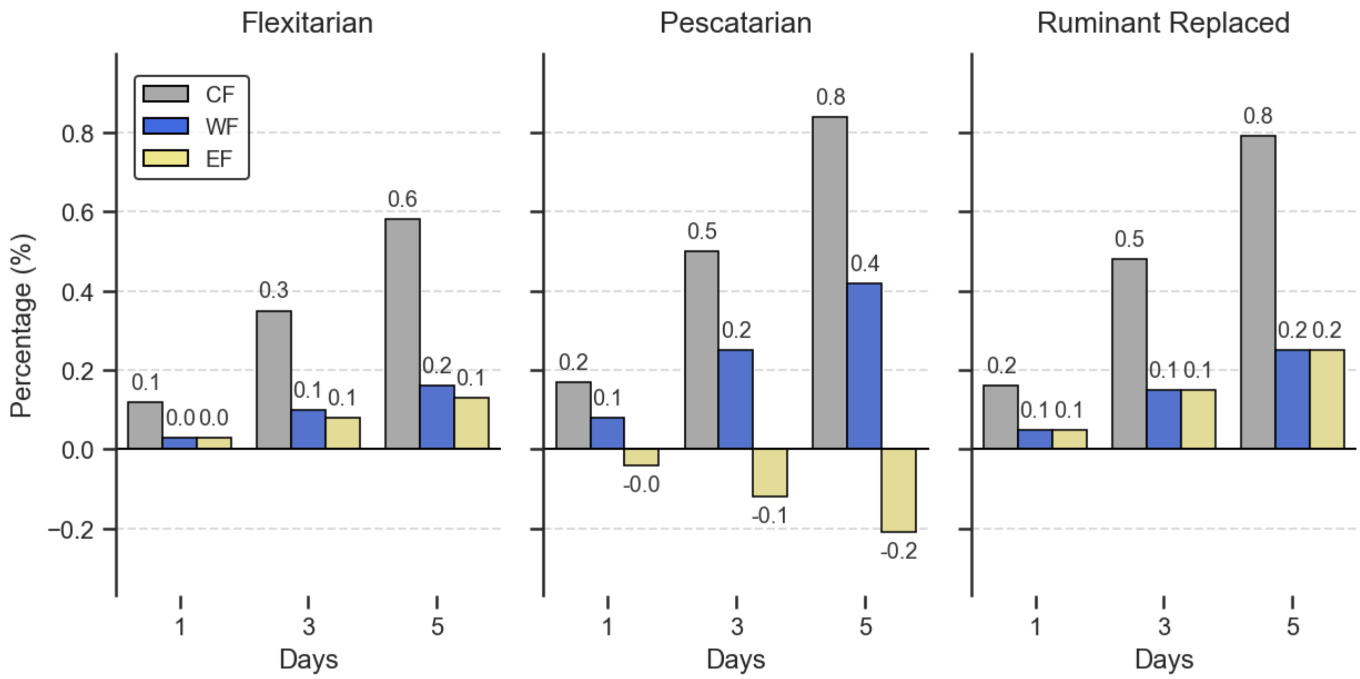
Figure 8. Reduction in the total amount of CF, WF, and EF from diets with any intake of meat to a plant-based diet (Vegan or Vegetarian), n=43,974.



Source: Own elaboration.

In the second scenario (Figure 9), we considered that only individuals with a High Ruminant diet would change their eating habits. Furthermore, we aimed to assess the aggregate effect of switchovers from a High Ruminant Eater diet to more sustainable ones (Flexitarian, Pescatarian, and Ruminant Replaced). In this scenario, the population eligible for dietary transition is small, close to 0.8% of the total population, which provides a small aggregate effect. Considering the optimistic scenario, where high-ruminant meat eaters would change their eating habits 5 days a week, we observe a decrease in CF of 0.6-0.84% (0.9 and 1.3 tonCO_2eq); WF shows the second largest decrease, ranging from 0.18-0.42% (0.38 and 0.9 million liters), where both reductions come from the switchover to a Pescatarian diet. However, we observed that this switchover from a High Ruminant Eater diet to a Pescatarian diet increases the total amount of EF, close to 0.21% (0.27 g-ha). The lower effect of this scenario mainly comes due to the small number of individuals that have this diet pattern, which decreases the aggregate effect of switchovers in this group. In addition, the effect of a single day eating habit change in this group shows a close to zero aggregate effect.

Figure 9. Reduction in the total amount of CF, WF, and EF from High Ruminant Eaters to more sustainable diets (Flexitarian, Pescatarian, and Ruminant Replaced), n=333.



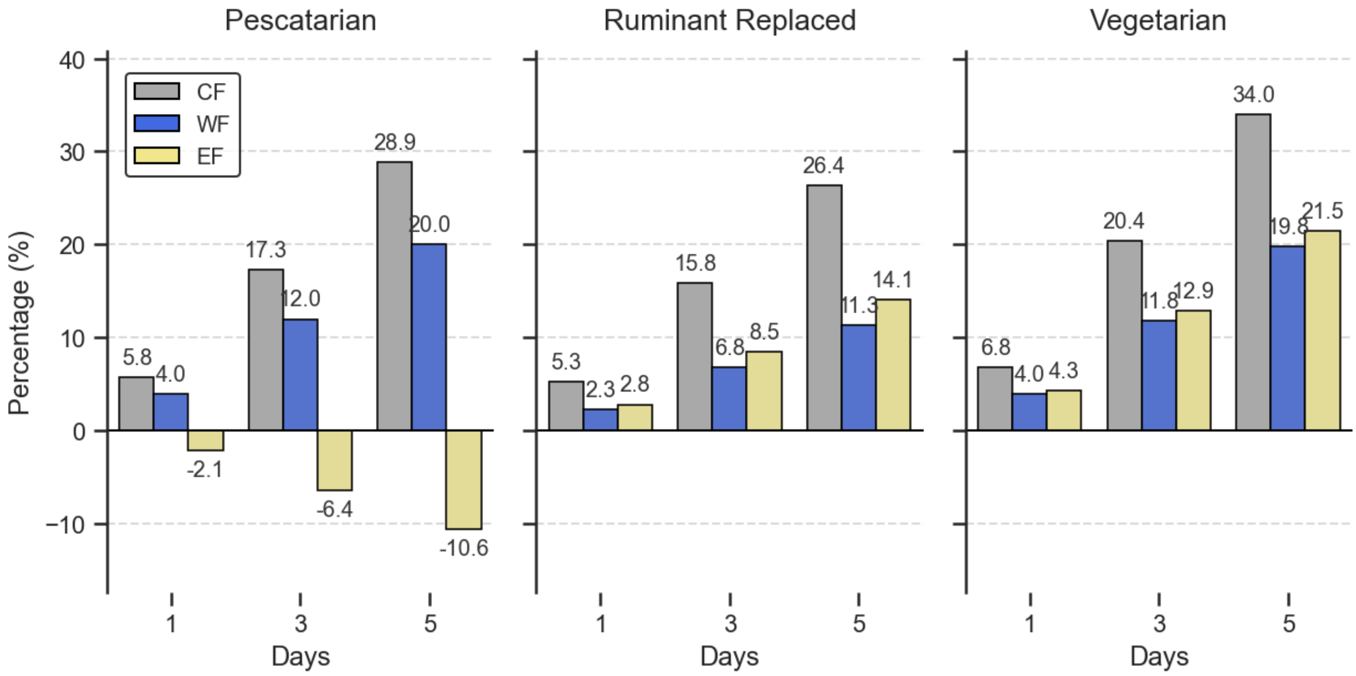
Source: Own elaboration.

In the third and final scenario (Figure 10), we propose an alternative to the more common diet in out sample, which is the Brazilian Typical, to more sustainable patterns (Pescatarian, Ruminant Replaced, and Vegetarian). In this scenario, the share of the population eligible for transition is relatively large, close to 38% of the total. Assuming a 5-day switchover among Brazilian typical eaters, we observe substantial reductions in CF of 26-34% (39.8 and 51.3 tonCO_2eq). WF shows the second largest decrease, ranging from 11-20% (24.2 and 42.1 million liters). However, the switchover from a Brazilian Typical Diet to a Pescatarian one increases the EF approximately by 11% (13.8 g-ha), while for the other diets, the reduction ranges from 14-22% (18.4 and 28.1 g-ha).

On the other hand, as we consider the single day switchover, CF decreases by 5-7% (7.9 and 10.2 tonCO_2eq), and WF by 2-4% (4.8 and 8.5 million liters). The increase of EF for pescatarians is about 2% (2.7 g-ha), while for the other two diets, it reduces EF by 3-4% (3.6-5.6 g-ha). The largest reductions are mainly associated with switchovers that aim to a Plant-Based diet (Vegetarian), although transitions to other patterns of more sustainable diets, such as Ruminant Replaced, also present a positive relevant impact over the environment. The midterm scenario, which individuals choose to shift their dietary habits for 3 days, also shows significant aggregate reductions. We estimate that CF would reduce by about 16-20% (23.9 and

30.8 tonCO_2eq, respectively). WF decreases by approximately 7-12% (14.5 and 25.6 million liters), while EF increases by 6% (8.3 g-ha) for pescatarians ones and decreases by 9-13% (11.1 and 16.8 g-ha) for the other groups.

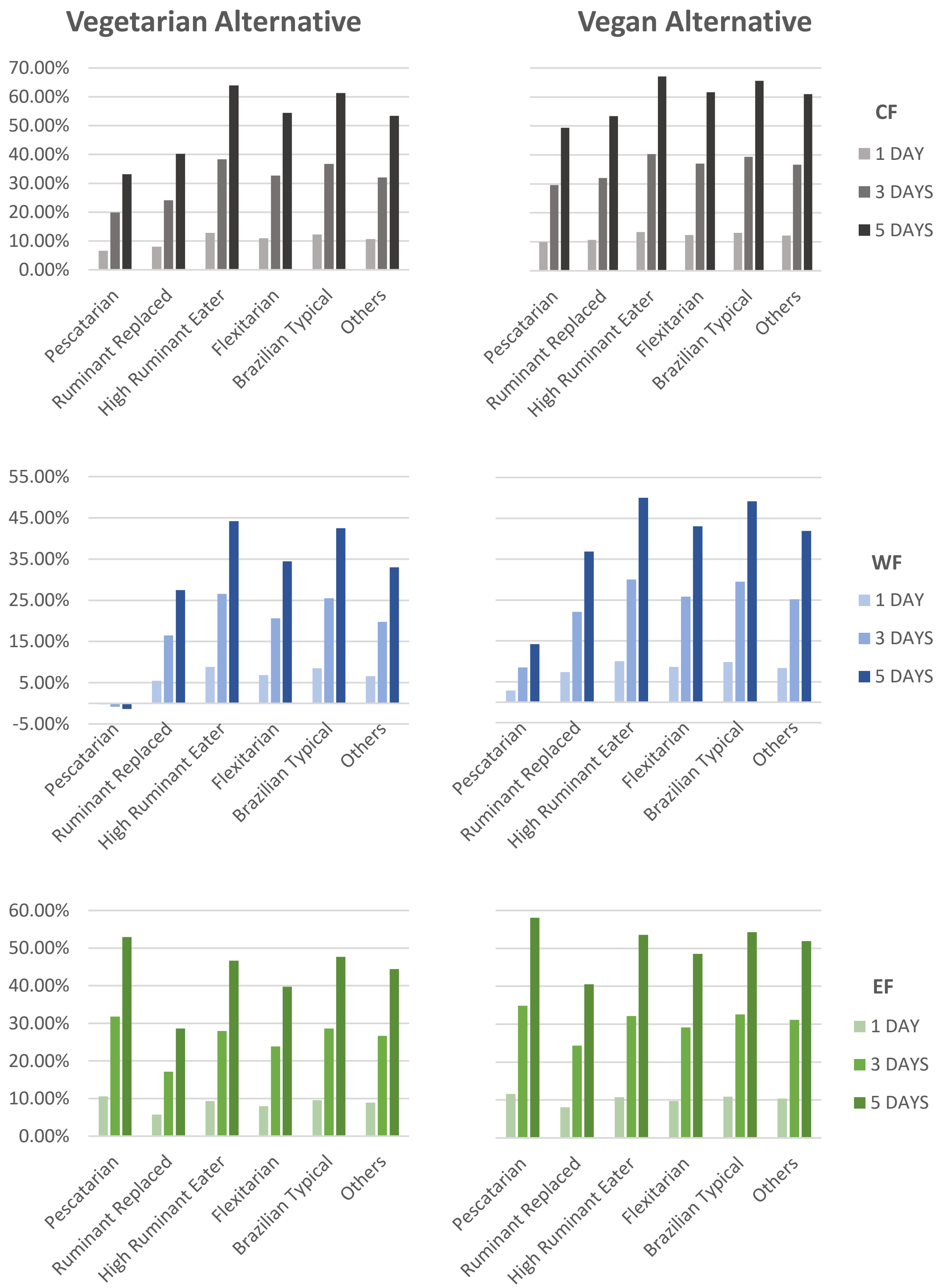
Figure 10. Reduction in the total amount of CF, WF, and EF from Brazilian Typical eaters to more sustainable diets (Pescatarian, Ruminant Replaced, and Vegetarian), n=20,845.



Source: Own elaboration.

Furthermore, we evaluated the effect of a per capita switchover from animal-based diet to plant-based alternatives (Vegan or Vegetarian), with the alternative switchover rates (Figure 11). As expected, the largest reductions across almost every environmental indicator arise from switching from a High-Ruminant diet, followed by the Brazilian Typical pattern. Both transitions could lead to individual CF reductions of approximately 13% for a one-day switchover, reaching 64% for the five-day alternative. A similar pattern is observed for the WF, with potential reductions ranging from 8% to 44%, depending on the number of days of dietary change. Conversely, the greatest reduction in the EF is observed among pescatarian individuals, whose footprint could decrease by 10-60% under a one- to five-day switchover scenario.

Figure 11. Reduction in the per capita amount of CF, WF, and EF from each animal-based diet to plant-based alternatives.

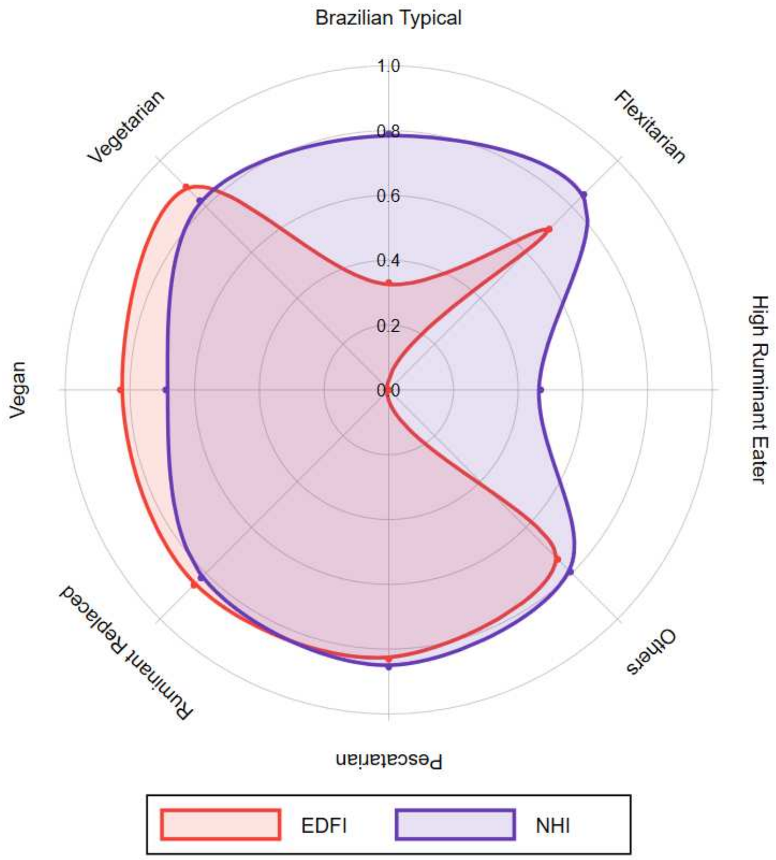


Source: Own elaboration.

1.4.5 Nutritional and Environmental Index Scores

Our final result concerns both the Nutritional Healthy Index (NHI) and the Environmental Diet Footprint Index (EDFI), which together highlight how the analyzed dietary patterns perform from environmental and nutritional perspectives (Figure 12). Regarding the NHI, we observe that High Ruminant Eaters exhibit the worst nutritional adherence (0.469 out of 1.0), reflecting a less balanced and nutritionally poorer profile. On the other hand, Pescatarians and Flexitarians achieved the highest scores (0.855 and 0.852, respectively), followed by Vegetarians (0.825) and Ruminant-Replaced diets (0.820). Brazilian Typical Eaters had an intermediate score of approximately 0.789, while others' diets scored 0.799. Vegans presented a lower score, of approximately 0.689, mainly due to their higher energy density derived from carbohydrates, in addition to a lower score for calcium and sodium.

Figure 12. NHI and EDFI results for all eight diet groups evaluated.



Source: Own elaboration.

Considering the EDFI, a similar pattern was observed for some diet types. High-Ruminant Diets had the worst environmental performance, scoring 0 out of 1.0. Conversely, Vegetarian diets performed best, with a score of 0.885, followed by the Ruminant Replaced diets (0.851). Other diets which are commonly considered environmentally sustainable, such as the Vegan and Pescatarian, also showed a good performance, with an EDFI of 0.829 and 0.831, respectively. The Brazilian Typical Diet exhibited a very low score, of 0.331, highlighting the elevated environmental pressure associated with common Brazilian food consumption patterns. Flexitarian diets, which are also considered to be an environmentally good diet, had a moderate performance, with a score of 0.701, close to the Others diets, which scored 0.739.

When considering both indicators, a win/win scenario emerges for individuals adopting Vegetarian, Pescatarian or Ruminant Replaced dietary patterns. In these three cases, both nutritional and environmental indicators score highly, with Pescatarian diets achieving a higher NHI than the EDFI, while Vegetarian diets present the opposite pattern. Ruminant Replaced could be considered as an intermediate case between the two diets. Flexitarian patterns represent a win/lose scenario, combining a strong nutritional profile with a weaker environmental one, while Vegan diets illustrate a lose/win scenario, characterized by lower nutritional scores but favorable environmental performance.

1.5 Discussion

Previous literature highlights the environmental impact of specific food groups, with a major focus on products derived from cattle raising, such as beef and milk (Biesbroek et al., 2023; Willett et al., 2019). In Brazil, this is also observed empirically, as shown by Travassos et al. (2020) and Da Cruz et al. (2024), which underscore that beef and other cattle-derived products have the highest environmental footprints among food groups in the country.

Regarding dietary patterns and eating preferences, previous studies aimed to understand how dietary choices could lead to a more sustainable and healthier lifestyle. In the United States, He et al. (2021) and Willits-Smith et al. (2020) highlighted that shifts toward healthier diets can reduce environmental pressure while improving nutritional quality. On the other hand, findings regarding diet costs and affordability are inconclusive, as some evidence suggests the healthier dietary pattern costs may either reduce or increase overall diet cost. In addition, Guo et al. (2022) demonstrated that diets with lower consumption of dairy and beef can improve health outcomes and benefit the environment in China. Meanwhile, in Brazil, Travassos et al. (2025) highlight the relevance of a more sustainable meat consumption within better environmental outcomes. Moreover, Bakman et al. (2024) underscore how transitioning from a conventional Brazilian diet to diets with less animal-based products can lead to a lower environmental burden. On a global scale, past evidence suggests that more sustainable dietary patterns could reduce environmental resources demand in high and low-income countries (Springmann et al., 2021, 2025).

These findings are consistent with our results, which underscore the positive environmental effects of transitions toward dietary patterns with fewer animal-based protein sources. Our results expand on previous literature by showing that, even in middle-income contexts like Brazil, relevant environmental gains can be achieved through modest shifts in eating habits. To contextualize the magnitude of dietary emissions, Brazilian per capita GHG emissions were approximately 11.9 tCO_2eq per year in 2019 (considering land use change) and 5.9 tCO_2eq (without land use change), considerably higher than that observed in the European Union and South America countries (Crippa et al., 2025; Jones et al., 2023). Our results indicate that individuals following a Brazilian Typical Diet generate an average annual dietary carbon footprint of 1.86 tCO_2eq, representing roughly 15.6% of total per capita emissions (considering land use change). This highlights the substantial contribution of food consumption to the overall environmental pressure. Thus, promoting dietary transitions at the population level, especially among groups with intake of ruminant meat, could generate environmental benefits even higher than those reported in high-income countries.

Our finding underscores dietary transition as a key strategy for reducing environmental degradation in Brazil. Even in scenarios where individuals choose to change their eating habits once a week (such as the Meatless Monday movement) the environmental effect can be relevant to the environment, with potential reductions of 8-11% in emissions, 5-7.5% in water use and waste, and 5-8% in land use. It is important to highlight that the aggregate efficiency of a dietary transition depends on the population group that adopts it. We observed that individuals with a high intake of beef (such as those following a High Ruminant diet) exhibit the largest footprints among all dietary groups. However, since they represent a relatively small share of the population, their dietary shift has less expressive aggregate outcome. On the other hand, groups such as the Brazilian Typical hold great relevance, reinforcing the hypothesis that food policies aiming to reduce environmental impacts should primarily target this segment rather than other groups of less relevance.

Furthermore, a plausible concern could be related to cultural habits, and the cost of transitioning to more sustainable dietary patterns. Evidence shown by Deng et al. (2025), suggests that adopting more sustainable and healthier diets could largely improve health (through dietary quality) and the environment (reducing water use and waste). However, they highlight that this transition could, in the short run, decrease food affordability and worsen water use in developing economies due to the increase in food demand of specific groups. However, in the Brazilian context, Caldeira et al. (2024) examined the relationship between the cost-effectiveness of current Brazilian diets and their environmental performance, underscoring that alternative dietary guidelines can achieve lower environmental impacts while maintaining or even improving cost-efficiency compared to the current Brazilian diet. Moreover, Verly-Jr et al. (2022) also explored the cost-effectiveness of dietary shift in Brazil, indicating that moving toward healthy diets would lead to higher costs, although it can be mitigated when considering local food habits and aiming for a sustainable diet, in addition to an overall GHG emissions and cost reduction.

Nevertheless, previous literature identifies substantial barriers for consumers to change their food preferences and eating habits, particularly when related to the acceptance of plant-based diets (Fehér et al., 2020; Gibbs & Cappuccio, 2022). Among the main obstacles, behavioral factors and palatability stand out as the most relevant aspects, as consumers often report a strong attachment to the sensory qualities of meat (like flavor and texture) and express reluctance to remove it from their diets, constituting one of the most persistent barriers to large-scale dietary transitions (Gibbs & Cappuccio, 2022; Pohjolainen et al., 2015).

Another important barrier concerns misinformation about plant-based diets. Although evidence consistently demonstrates that plant-based diets are better for health (Biesbroek et al., 2023; Dinu et al., 2017; Drewnowski et al., 2020; Mertens et al., 2018), individuals usually think that those diets are nutritionally inadequate. This perception often relates to lower amounts of nutrients, particularly protein and calcium, presented in plant-based diets, despite evidence showing that well-planned plant-based diets can provide adequate levels (Fehér et al., 2020; Viroli et al., 2023). In addition, plant-based diets could have higher prices in some medium and low-income countries, compared to more traditional diets, which also contributes to a lower popular acceptance of plant-based diets (Springmann et al., 2021).

Although the challenges and barriers to adopting plant-based diets, there are strategies that could mitigate and even surpass those barriers. Regarding the preference for the sensory aspects of beef, incentives and innovations in the food industries for plant-based meals that shape beef could make plant-based diets more attractive to consumers which values these characteristics (Szenderák et al., 2022). In addition, even though those products suffer from the industrial process in their manufacture, being classified as ultra-processed food, previous literature shows that those foods do not present harm to health (Bohrer, 2019).

To overcome the misinformation about plant-based diets, one potential strategy could be the application of labels on some plant-based products that emphasize their health benefits and lower environmental footprint. Food labelling is an effective policy, with well-documented evidence of its effectiveness, mainly focused on health (Aitken et al., 2020; Cecchini & Warin, 2016; Oliveira et al., 2018; Temple, 2020). Brazil already has an ongoing labeling policy, ruled by the RDC 429/2020[11] from the Brazilian Health Regulatory Agency (ANVISA), which highlights foods with high percentages of fats, sugars, and sodium. This strategy could be expanded to include labels with environmental footprint information to warn consumers and clarify the environmental impact of specific food groups. Informative labels could highlight the plant-based diets' low environmental impact, nudging consumers toward more sustainable food choices (Gressier et al., 2020).

Even if we consider that plant-based diets could have higher prices, this is also a transposable barrier, mainly through fiscal policies. Financial incentives, such as credit, to agricultural producers that produce healthier and more sustainable foods could reduce production costs and market prices (Pancrazi et al., 2022; Springmann, Mason-D'Croz, et al., 2018). In addition, the tax and subsidies system that lowers sustainable food prices (fruits, vegetables, and grains) and increases the cost of high-impact foods (beef) can also effectively nudge consumers (Moberg et al., 2021; Pancrazi et al., 2022). In summary, policies, consumer education, and food system interventions that facilitate dietary shift could play a crucial role in aligning nutritional goals with planetary boundaries.

1.6 Final Remarks

Our study highlights the relevance that discussing diets and food consumption has on environmental topics, mainly associated with the promotion of sustainable food systems. Dietary transitions are an effective pathway to simultaneously reduce environmental impact and could also promote better nutritional adequacy. Our evidence shows a clear pattern of Plant-Based diets, especially Vegan and Vegetarian, as the main driver to achieve the largest reductions in GHG emissions, water waste, and biodiversity preservation. In addition, Flexitarian and Ruminant Replaced diets emerge as more balanced options that combine

[11] The RDC No. 429 from 2020 stablishes a new food labelling policy in Brazil aimed to improve the comprehension of nutritional information in packaged products. This regulation introduced front warning stamps with the phrase "HIGH IN …" to indicate products containing elevated amounts of sugar, saturated fat and sodium (BRASIL, 2023).

environmental gains and nutritional diversity. Our findings reinforce the role of dietary choices as key drivers of sustainability agendas.

However, we must emphasize that the efficiency of dietary transitions presents some heterogeneous effects. In more realistic scenarios, we observed a null effect among High-Ruminant eaters, which can be explained by their smaller representation in our sample. This contrasts with the results for typical Brazilian Typical eaters and the aggregated group of meat consumers. This finding is particularly relevant for policymakers seeking to reduce environmental pressure in Brazil through demand-side strategies or by promoting dietary shifts, as interventions should focus on the most relevant groups, such as the Brazilian Typical eaters. Moreover, individual choices toward more sustainable eating patterns should be encouraged, as meat eaters can substantially reduce their own environmental footprint through such behavioral changes.

On the other hand, we also discuss how performing a dietary transition is not trivial, with several barriers and challenges to the population. Moreover, food preferences, cultural attachments, affordability, and accessibility of sustainable food are among the many barriers that difficult the adoption of more sustainable diets. In this sense, public policies, educational initiatives, and market incentives become more essential to foster gradual and inclusive transitions, surpassing the main barriers discussed in our study. Strategies that encourage a gradual and light transition, such as the adoption of Flexitarian, Ruminant Meat Replaced, or Pescatarian diets, can serve as entry points for broader transformations, reducing reluctance and resistance to dietary changes. Ultimately, aligning nutritional health and environmental sustainability in food systems is not only a technical challenge but also a social one.

Nevertheless, we must acknowledge important limitations in our study. The estimations presented by us rely on dietary data and environmental indicators that, although robust, cannot fully capture the complexity of individual behavior, food preferences, food supply chains, and regional variety in agricultural practices. In addition, as discussed before, dietary transitions are deeply influenced by cultural, social, and economic constraints. We suggest that future research should explore strategies to overcome heterogeneity in food consumption. In addition, these studies could also explore the effectiveness of policies that reduce and mitigate the dietary transition barriers.

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APPENDIX A

Table 1A. Total values of calories, grams, macronutrients and micronutrients, daily, by diet group.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Calories (kcal)	964.73	1298.01	1541.74	1737.11	1539.54	1751.97	1771.02	1793.02
	(556.53)	(616.60)	(670.49)	(773.60)	(725.28)	(758.20)	(740.71)	(783.63)
Total Grams (g)	664.76	809.46	913.03	961.05	677.00	1054.26	949.23	977.34
	(372.36)	(405.27)	(409.90)	(434.49)	(318.41)	(460.61)	(399.34)	(436.78)
Proteins (g)	24.11	38.25	73.75	81.13	97.71	64.48	88.24	86.16
	(13.36)	(21.30)	(33.09)	(46.90)	(46.07)	(28.72)	(38.86)	(43.27)
Carbs (g)	177.00	210.84	218.30	233.36	145.39	264.69	225.16	229.86
	(96.54)	(102.95)	(111.22)	(110.23)	(70.83)	(119.20)	(102.96)	(109.62)
Fibers (g)	23.90	21.23	19.92	22.55	11.04	26.70	21.14	19.81
	(16.08)	(14.87)	(14.21)	(14.69)	(7.96)	(16.21)	(12.60)	(12.81)
Lipids (g)	18.90	37.44	45.15	57.22	62.63	53.58	60.70	60.86
	(15.54)	(25.16)	(26.04)	(34.20)	(38.26)	(30.18)	(30.68)	(32.74)
Calcium (mg)	167.29	397.96	536.45	400.21	223.95	439.21	374.93	444.17
	(105.25)	(356.99)	(325.11)	(337.29)	(175.17)	(328.56)	(296.17)	(346.27)
Sodium (mg)	1444.96	1805.91	1949.68	2406.29	2502.76	2454.04	2481.87	2763.98
	(849.94)	(1037.52)	(1128.37)	(1239.31)	(2172.45)	(1211.01)	(1246.11)	(1789.35)
Cholesterol (mg)	0.00	249.61	271.07	274.05	344.58	212.74	274.13	275.74
	(0.00)	(274.58)	(207.03)	(217.44)	(343.71)	(203.95)	(213.19)	(195.04)
Zinc (mg)	4.05	5.34	5.82	8.54	19.70	10.52	14.96	11.10
	(3.57)	(3.58)	(3.61)	(5.09)	(9.82)	(5.19)	(6.76)	(6.72)
Iron (mg)	6.23	8.51	8.56	9.97	10.74	11.54	11.97	10.64
	(3.72)	(5.28)	(7.57)	(5.34)	(5.67)	(5.68)	(5.56)	(5.83)
Observations	740	4114	2,921	25917	1343	13718	19147	15125

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 2A. Average values of calories, grams, macronutrients and micronutrients, daily, by diet group. Nutritional information per 100g.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Calories (kcal)	175.68	177.30	177.11	188.96	237.79	173.00	193.41	195.05
	(252.37)	(80.90)	(62.09)	(60.02)	(93.13)	(49.56)	(52.11)	(79.81)
Proteins (g)	3.91	5.07	8.56	8.66	14.77	6.29	9.55	9.08
	(2.01)	(2.14)	(3.08)	(3.24)	(3.38)	(1.64)	(2.39)	(2.96)
Carbs (g)	29.81	28.56	24.83	25.46	22.85	26.15	24.65	25.11
	(15.80)	(12.89)	(9.02)	(8.75)	(9.97)	(8.18)	(8.11)	(10.56)
Fibers (g)	3.51	2.58	2.12	2.29	1.58	2.51	2.20	2.01
	(1.18)	(1.10)	(0.92)	(0.93)	(0.78)	(0.94)	(0.85)	(0.85)
Lipids (g)	3.35	5.14	5.15	6.18	9.36	5.29	6.60	6.56
	(3.23)	(3.27)	(2.29)	(2.68)	(3.35)	(2.33)	(2.37)	(2.76)
Calcium (mg)	27.91	54.33	62.53	43.83	35.32	43.17	40.78	48.48
	(19.36)	(46.53)	(34.41)	(33.66)	(26.37)	(28.76)	(28.13)	(35.69)
Sodium (mg)	240.30	238.19	221.87	262.03	364.14	242.68	271.17	304.74
	(127.02)	(105.47)	(100.91)	(100.41)	(200.51)	(87.23)	(98.42)	(178.89)
Cholesterol (mg)	0.00	35.08	31.59	29.88	49.97	21.22	30.02	29.62
	(0.00)	(39.84)	(22.52)	(21.41)	(33.98)	(20.52)	(21.67)	(19.50)
Zinc (mg)	0.61	0.69	0.65	0.91	2.96	1.02	1.63	1.16
	(0.36)	(0.36)	(0.28)	(0.36)	(0.77)	(0.33)	(0.50)	(0.48)
Iron (mg)	1.03	1.13	0.97	1.07	1.62	1.14	1.30	1.13
	(0.61)	(0.68)	(0.82)	(0.42)	(0.46)	(0.41)	(0.40)	(0.48)
Observations	740	4114	2,921	25917	1343	13718	19147	15125

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 3A. Total values of calories, grams, macronutrients and micronutrients, individually (two-days), by diet group.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Calories (kcal)	1307.55	1865.14	2265.72	2887.02	2402.05	3174.92	3388.73	3265.77
	(800.14)	(1104.86)	(1084.12)	(1415.97)	(1386.48)	(1392.88)	(1383.78)	(1428.25)
Total Grams (g)	976.97	1190.81	1355.37	1620.56	1067.64	1920.38	1828.36	1783.96
	(659.42)	(717.75)	(673.03)	(817.05)	(635.19)	(855.96)	(756.69)	(791.91)
Proteins (g)	34.68	54.56	107.21	131.58	151.76	119.01	165.36	154.77
	(22.89)	(36.59)	(51.93)	(77.30)	(84.90)	(54.19)	(71.56)	(75.18)
Carbs (g)	249.18	307.83	325.20	395.05	226.51	477.12	435.64	427.36
	(161.39)	(182.11)	(180.22)	(203.40)	(132.18)	(215.42)	(193.03)	(200.31)
Fibers (g)	35.64	32.19	29.86	39.17	17.58	48.75	40.38	37.56
	(27.90)	(4.67)	(20.62)	(26.08)	(13.80)	(28.67)	(23.05)	(23.04)
Lipids (g)	25.26	52.31	64.40	93.56	97.73	97.15	115.33	109.11
	(21.73)	(41.34)	(37.01)	(56.59)	(69.74)	(51.88)	(55.11)	(56.67)
Calcium (mg)	250.11	590.31	804.25	668.56	353.15	811.55	754.02	821.36
	(194.41)	(649.95)	(495.65)	(518.01)	(250.33)	(565.54)	(522.88)	(579.19)
Sodium (mg)	2038.36	2641.65	2776.90	4026.17	4104.74	4448.73	4810.94	4809.99
	(1507.32)	(1776.91)	(1491.76)	(2140.62)	(4005.58)	(2205.54)	(2330.63)	(2670.63)
Cholesterol (mg)	0.00	310.99	425.59	459.95	563.18	407.14	531.26	513.19
	(0.00)	(370.36)	(320.15)	(358.59)	(524.14)	(330.61)	(341.55)	(332.67)
Zinc (mg)	5.83	7.83	8.81	14.13	30.64	17.95	24.94	18.54
	(5.82)	(6.28)	(6.19)	(8.70)	(17.96)	(8.99)	(11.29)	(10.60)
Iron (mg)	8.79	12.55	12.34	16.88	16.28	20.50	21.73	19.12
	(6.10)	(9.85)	(8.94)	(9.46)	(9.39)	(10.20)	(9.83)	(10.04)
Observations	149	841	652	8,104	333	8,320	17,264	9,301

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 4A. Total values of calories, grams, macronutrients and micronutrients, individually (one-day), by diet group.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Calories (kcal)	653.77	932.57	1132.86	1443.51	1201.02	1587.46	1694.36	1632.88
	(400.07)	(552.43)	(542.06)	(707.99)	(693.24)	(696.44)	(691.89)	(714.12)
Total Grams (g)	488.49	595.41	677.69	810.28	533.82	960.19	914.18	891.98
	(329.71)	(358.88)	(336.51)	(408.53)	(317.59)	(427.98)	(378.34)	(395.96)
Proteins (g)	17.34	27.28	53.61	65.79	75.88	59.51	82.68	77.38
	(11.44)	(18.30)	(25.96)	(38.65)	(42.45)	(27.10)	(35.78)	(37.59)
Carbs (g)	124.59	153.92	162.60	197.52	113.26	238.56	217.82	213.68
	(80.70)	(91.06)	(90.11)	(101.70)	(66.09)	(107.71)	(96.52)	(100.15)
Fibers (g)	17.82	16.10	14.93	19.58	8.79	24.38	20.19	18.78
	(13.95)	(12.33)	(10.31)	(13.04)	(6.90)	(14.33)	(11.52)	(11.52)
Lipids (g)	12.63	26.15	32.20	46.78	48.86	48.57	57.67	54.55
	(10.86)	(20.67)	(18.51)	(28.29)	(34.87)	(25.94)	(27.56)	(28.34)
Calcium (mg)	125.06	295.16	402.12	334.28	176.58	405.77	377.01	410.68
	(97.20)	(324.97)	(247.82)	(259.01)	(125.17)	(282.77)	(261.44)	(289.59)
Sodium (mg)	1019.18	1320.83	1388.45	2013.09	2052.37	2224.36	2405.47	2404.99
	(753.66)	(888.46)	(745.88)	(1070.31)	(2002.79)	(1102.77)	(1165.31)	(1335.31)
Cholesterol (mg)	0.00	155.49	212.79	229.97	281.59	203.57	265.63	256.59
	(0.00)	(185.18)	(160.07)	(179.29)	(262.07)	(165.30)	(170.77)	(166.34)
Zinc (mg)	2.91	3.92	4.41	7.06	15.32	8.98	12.47	9.27
	(2.91)	(3.14)	(3.09)	(4.35)	(8.98)	(4.50)	(5.65)	(5.30)
Iron (mg)	4.39	6.28	6.17	8.44	8.14	10.25	10.87	9.56
	(3.05)	(4.93)	(4.47)	(4.73)	(4.69)	(5.10)	(4.91)	(5.02)
Observations	149	841	652	8,104	333	8,320	17,264	9,301

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 5A. Average values of Carbon Footprint, Water Footprint, and Ecological Footprint, daily, by diet group. Per capita values.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Carbon Footprint	612.13	1054.42	1766.48	2057.44	9332.31	3905.80	6600.13	3557.68
	(669.77)	(836.87)	(1267.01)	(1870.83)	(4982.01)	(2371.33)	(3499.29)	(3152.75)
Water Footprint	2463.34	3262.02	2964.88	4485.84	8132.16	5322.84	6854.89	5079.60
	(2242.66)	(2468.14)	(2141.34)	(2845.36)	(3944.84)	(2846.95)	(3245.87)	(3237.56)
Ecological Footprint	11.70	17.21	61.33	23.77	46.48	30.81	41.09	33.89
	(10.32)	(12.31)	(44.03)	(14.21)	(22.83)	(16.89)	(20.73)	(27.29)
Observations	740	4114	2,921	25917	1343	13718	19147	15125

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 6A. Average values of Carbon Footprint, Water Footprint, and Ecological Footprint, individually (one-day), by diet group. Per capita values.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Carbon Footprint	415.98	721.67	1348.23	1649.69	6894.86	3040.62	5090.96	2856.95
	(315.50)	(559.49)	(946.98)	(1333.51)	(4019.61)	(1851.97)	(2792.62)	(2238.87)
Water Footprint	1828.98	2317.61	2282.87	3779.57	6103.47	4607.71	5863.46	4430.02
	(1951.31)	(2006.08)	(1801.16)	(2465.43)	(3306.85)	(2529.53)	(2814.53)	(2661.56)
Ecological Footprint	8.60	11.93	46.09	19.90	34.36	26.85	35.84	31.52
	(8.50)	(9.86)	(33.51)	(12.16)	(18.95)	(14.59)	(18.85)	(23.49)
Observations	149	841	652	8,104	333	8,320	17,264	9,301

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 7A. Average values of Carbon Footprint, Water Footprint, and Ecological Footprint, individually (two-day), by diet group. Per capita values.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Carbon Footprint	831.96	1443.34	2696.46	3299.37	13789.73	6081.24	10181.92	5713.90
	(630.99)	(1118.97)	(1893.95)	(2667.03)	(8039.21)	(3703.93)	(5585.24)	(4477.73)
Water Footprint	3657.96	4635.22	4565.74	7559.14	12206.93	9215.41	11726.93	8860.05
	(3902.61)	(4012.16)	(3602.32)	(4930.86)	(6613.71)	(5059.06)	(5629.05)	(5323.12)
Ecological Footprint	17.20	23.85	92.18	39.80	68.73	53.70	71.69	63.04
	(17.01)	(19.73)	(67.03)	(24.31)	(37.89)	(29.18)	(37.70)	(46.98)
Observations	149	841	652	8,104	333	8,320	17,264	9,301

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 8A. Average values of Carbon Footprint, Water Footprint, and Ecological Footprint, individually (one-day), by diet group and gender. Per capita values.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
MEN (obs)	58	332	253	3565	167	3663	8393	4215
Carbon Footprint	467.86	782.04	1460.00	1851.10	7613.55	3426.95	5629.14	3201.53
	(286.62)	(613.05)	(1035.81)	(1471.40)	(4281.04)	(2056.73)	(2963.21)	(2453.09)
Water Footprint	2269.33	2453.80	2295.85	4131.23	6416.51	5021.66	6375.77	4786.59
	(2213.77)	(1933.13)	(1843.08)	(2639.79)	(3429.98)	(2661.78)	(2947.62)	(2815.42)
Ecological Footprint	10.34	12.65	49.42	21.75	36.98	29.53	38.88	34.38
	(9.69)	(10.16)	(35.29)	(13.02)	(19.84)	(15.66)	(19.79)	(25.54)
WOMEN (obs)	91	509	399	4539	166	4657	8871	5086
Carbon Footprint	382.91	682.29	1277.36	1491.50	6171.84	2736.75	4581.77	2571.38
	(329.87)	(518.45)	(880.07)	(1190.80)	(3608.77)	(1609.73)	(2517.40)	(2000.14)
Water Footprint	1548.32	2228.78	2274.64	3503.37	5788.54	4282.10	5378.76	4134.52
	(1718.42)	(2049.26)	(1776.35)	(2281.92)	(3157.23)	(2370.46)	(2591.06)	(2488.82)
Ecological Footprint	7.49	11.45	43.98	18.44	31.73	24.74	32.97	29.15
	(7.50)	(9.65)	(32.20)	(11.22)	(17.68)	(13.32)	(17.44)	(21.36)
TOTAL (obs)	149	841	652	8,104	333	8,320	17,264	9,301

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 9A. Average values of Carbon Footprint, Water Footprint, and Ecological Footprint, individually (one-day), by diet group and gender. Environmental information per 100g.

Diet Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
MEN (obs)	58	332	253	3565	167	3663	8393	4215
Carbon Footprint	44.14	65.30	107.64	107.83	749.11	167.32	300.97	180.80
	(30.82)	(51.71)	(76.44)	(90.38)	(348.94)	(82.09)	(150.32)	(184.33)
Water Footprint	196.66	213.43	161.88	245.65	620.51	252.15	340.90	265.39
	(188.89)	(179.13)	(108.83)	(149.75)	(241.50)	(131.74)	(153.06)	(164.07)
Ecological Footprint	0.97	1.09	3.74	1.30	3.65	1.47	2.07	1.90
	(1.10)	(0.82)	(2.66)	(0.76)	(1.53)	(0.71)	(0.98)	(1.47)
WOMEN (obs)	91	509	399	4539	166	4657	8871	5086
Carbon Footprint	66.70	65.52	107.36	106.08	706.28	162.68	291.78	166.55
	(165.12)	(38.43)	(68.00)	(94.93)	(296.05)	(79.69)	(146.66)	(135.03)
Water Footprint	214.45	257.40	191.47	256.21	667.29	261.87	344.78	269.74
	(235.09)	(342.67)	(154.62)	(163.78)	(301.21)	(147.09)	(161.87)	(171.20)
Ecological Footprint	1.12	1.28	3.87	1.35	3.60	1.49	2.09	29.15
	(1.26)	(1.50)	(2.98)	(0.84)	(1.62)	(0.73)	(1.01)	(21.36)
TOTAL (obs)	149	841	652	8,104	333	8,320	17,264	9,301

Source: Own elaboration.

Note: Standard deviation between parentheses.

Table 10A. Average total grams of food groups consumed by each diet type.

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Vegetables	153.35	143.05	120.54	120.73	79.77	135.19	111.11	104.56
	(131.27)	(118.43)	(108.27)	(123.83)	(53.84)	(159.24)	(107.14)	(110.28)
Tubers	484.41	221.12	247.20	230.76	223.86	259.96	207.45	219.14
	(522.13)	(257.36)	(228.33)	(249.09)	(184.67)	(286.86)	(199.62)	(224.84)
Fruits	321.63	297.91	304.32	304.11	145.71	383.21	276.87	290.83
	(256.96)	(249.91)	(280.02)	(286.62)	(124.60)	(373.20)	(239.59)	(276.81)
Flours and Pasta	261.46	226.81	159.82	197.94	121.97	206.51	182.91	187.44
	(427.64)	(210.96)	(147.65)	(191.18)	(114.31)	(190.76)	(158.25)	(175.59)
Pasta with Meat*	0.00	0.00	0.00	0.00	83.33	292.23	243.74	272.44
	(0.00)	(0.00)	(0.00)	(0.00)	(28.87)	(206.74)	(193.26)	(179.94)
Coconuts and Nuts	25.00	62.08	80.68	67.98	15.00	56.47	81.29	74.82
	(21.21)	(104.43)	(126.61)	(102.41)	(0.00)	(79.72)	(127.17)	(100.24)
Cereals and Legumes	679.44	551.72	456.22	595.57	329.09	707.88	585.12	496.82
	(501.56)	(423.16)	(351.40)	(472.17)	(233.98)	(551.25)	(411.81)	(384.66)
Salt and Condiments	0.00	49.28	77.48	40.04	18.81	35.17	41.38	41.64
	(0.00)	(87.29)	(125.68)	(49.43)	(22.42)	(44.30)	(43.78)	(44.26)
Sugars	64.86	87.93	93.64	109.66	64.63	132.83	110.78	113.06
	(101.56)	(133.29)	(130.63)	(161.32)	(92.59)	(180.10)	(138.25)	(143.88)
Beef	0.00	0.00	0.00	0.00	425.46	118.40	178.91	114.12
	(0.00)	(0.00)	(0.00)	(0.00)	(247.83)	(77.06)	(123.62)	(105.79)
Swine	0.00	0.00	0.00	227.93	51.06	80.63	174.70	187.52
	(0.00)	(0.00)	(0.00)	(240.06)	(37.90)	(71.17)	(185.95)	(206.16)
Other Ruminants	0.00	0.00	0.00	0.00	236.00	155.67	205.79	265.86
	(0.00)	(0.00)	(0.00)	(0.00)	(110.14)	(82.86)	(131.28)	(183.74)
Other Meats	0.00	0.00	0.00	135.45	0.00	95.00	121.90	155.15
	(0.00)	(0.00)	(0.00)	(63.26)	(0.00)	(46.50)	(68.75)	(128.50)
Fish and Seafood	0.00	0.00	329.88	0.00	216.15	125.81	243.17	261.22
	(0.00)	(0.00)	(239.42)	(0.00)	(136.59)	(73.55)	(178.65)	(185.87)
Chicken	0.00	0.00	0.00	233.36	143.87	117.57	194.02	207.04
	(0.00)	(0.00)	(0.00)	(186.17)	(109.88)	(67.20)	(150.05)	(159.16)
Eggs	0.00	112.71	105.83	98.38	91.82	95.90	89.50	90.96
	(0.00)	(77.51)	(60.36)	(78.10)	(57.54)	(65.06)	(54.42)	(58.83)

Table 10A. (continued)

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Canned Vegetables	96.00	50.17	17.38	128.54	60.50	181.43	159.60	119.67
	(0.00)	(45.42)	(7.04)	(127.41)	(21.92)	(179.63)	(165.56)	(114.77)
Canned Meat*	0.00	0.00	0.00	276.52	220.00	85.87	276.93	301.74
	(0.00)	(0.00)	(0.00)	(242.00)	(0.00)	(57.74)	(232.51)	(253.65)
Baked Goods	93.92	140.54	130.21	169.51	105.95	198.26	172.53	170.09
	(61.12)	(119.88)	(107.36)	(134.27)	(81.53)	(154.28)	(125.86)	(135.24)
Vegan Dairy	0.00	206.67	0.00	284.46	0.00	354.91	261.19	354.29
	(0.00)	(168.87)	(0.00)	(225.20)	(0.00)	(317.97)	(107.04)	(169.20)
Dairy**	18.83	178.09	115.84	141.68	49.10	197.16	127.00	132.98
	(9.29)	(264.12)	(179.36)	(214.64)	(96.44)	(259.40)	(185.70)	(193.71)
Oils	21.15	32.55	27.18	25.90	15.21	30.32	27.22	25.40
	(15.34)	(28.77)	(21.88)	(24.88)	(10.58)	(31.49)	(24.14)	(24.01)
Beverage w/o Milk	2278.39	2128.45	2306.57	2733.37	2480.78	3000.60	3175.19	2972.94
	(2237.80)	(1675.80)	(1585.70)	(1833.69)	(2032.89)	(1974.72)	(2031.69)	(1967.03)
Beverage w/ Milk*	420.00	345.95	282.09	343.58	257.63	376.78	343.95	328.38
	(216.79)	(345.05)	(226.23)	(290.83)	(209.47)	(307.14)	(284.02)	(279.52)
Alcoholic Beverage	1417.50	963.82	980.43	1073.83	1617.34	913.66	1365.98	1410.58
	(1279.49)	(751.59)	(1610.73)	(1318.62)	(1310.86)	(1090.47)	(1533.31)	(1594.76)
Miscellaneous (Beef)*	200.00	0.00	0.00	0.00	118.73	96.21	314.21	335.24
	(141.42)	(0.00)	(0.00)	(0.00)	(137.66)	(69.71)	(295.69)	(311.49)
Miscellaneous (Meat)*	185.00	0.00	0.00	248.49	130.32	102.07	246.27	256.60
	(85.44)	(0.00)	(0.00)	(236.95)	(136.08)	(63.60)	(222.91)	(244.44)
Miscellaneous (Veg)	301.84	326.81	276.69	250.45	158.32	280.97	225.34	229.11
	(234.21)	(341.73)	(298.81)	(256.48)	(156.90)	(278.75)	(211.71)	(221.54)

Source: Own elaboration.

Note: Standard deviation between parentheses.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

** According to the IBGE/POF classification system, margarines were categorized as dairy products despite containing zero cholesterol and being compatible with vegan diets.

Table 11A. Average total calories (kcal) per food group by each diet type.

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Vegetables	45.12	48.20	34.86	35.88	18.17	38.81	29.49	27.88
	(47.29)	(56.99)	(42.56)	(46.60)	(16.39)	(58.17)	(36.08)	(33.74)
Tubers	625.97	267.37	278.15	284.10	263.81	319.54	264.87	274.14
	(556.94)	(376.68)	(281.39)	(328.13)	(225.20)	(398.89)	(310.76)	(299.19)
Fruits	243.40	211.17	203.61	212.98	108.95	250.14	191.33	196.37
	(175.39)	(179.66)	(168.02)	(194.22)	(64.13)	(222.67)	(160.69)	(173.91)
Flours and Pasta	458.60	349.29	407.47	329.65	277.11	324.85	308.90	361.10
	(636.18)	(336.52)	(379.21)	(342.02)	(265.37)	(305.34)	(298.69)	(380.07)
Pasta with Meat*	0.00	0.00	0.00	0.00	102.67	341.15	284.71	321.57
	(0.00)	(0.00)	(0.00)	(0.00)	(41.19)	(239.97)	(226.28)	(211.24)
Coconuts and Nuts	115.45	273.77	213.97	246.06	87.30	221.10	250.52	195.45
	(76.01)	(443.02)	(285.82)	(378.92)	(0.00)	(305.91)	(379.51)	(303.46)
Cereals and Legumes	699.84	575.61	490.99	632.87	376.55	740.90	634.36	541.18
	(516.01)	(433.17)	(357.71)	(485.41)	(251.36)	(575.12)	(428.94)	(399.63)
Salt and Condiments	0.00	48.10	105.05	69.57	30.50	51.19	73.66	75.47
	(0.00)	(62.75)	(224.39)	(94.57)	(31.48)	(61.50)	(85.39)	(86.22)
Sugars	170.72	225.31	222.51	275.55	167.97	332.16	290.60	293.87
	(179.15)	(258.97)	(237.04)	(301.85)	(167.85)	(346.84)	(281.38)	(295.27)
Beef	0.00	0.00	0.00	0.00	1078.25	294.31	442.78	341.80
	(0.00)	(0.00)	(0.00)	(0.00)	(711.74)	(199.16)	(321.70)	(349.72)
Swine	0.00	0.00	0.00	646.61	131.42	229.43	487.85	520.54
	(0.00)	(0.00)	(0.00)	(690.48)	(94.74)	(214.10)	(530.86)	(582.41)
Other Ruminants	0.00	0.00	0.00	0.00	463.12	343.67	434.35	582.98
	(0.00)	(0.00)	(0.00)	(0.00)	(220.57)	(181.63)	(283.92)	(401.63)
Other Meats	0.00	0.00	0.00	340.14	0.00	299.58	361.11	400.44
	(0.00)	(0.00)	(0.00)	(178.96)	(0.00)	(191.84)	(241.18)	(417.65)
Fish and Seafood	0.00	0.00	482.83	0.00	275.14	202.68	348.03	377.04
	(0.00)	(0.00)	(333.74)	(0.00)	(149.08)	(124.05)	(257.46)	(270.53)
Chicken	0.00	0.00	0.00	480.28	289.55	248.27	394.51	423.11
	(0.00)	(0.00)	(0.00)	(371.00)	(206.92)	(148.34)	(287.08)	(296.88)
Eggs	0.00	222.07	213.95	198.83	174.09	192.28	180.21	181.65
	(0.00)	(157.89)	(136.83)	(153.56)	(128.87)	(132.12)	(111.47)	(119.34)

Table 11A. (continued)

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Canned Vegetables	102.72	51.46	17.31	59.81	47.90	83.16	74.34	66.00
	(0.00)	(51.82)	(15.79)	(67.24)	(39.74)	(95.47)	(89.86)	(84.08)
Canned Meat*	0.00	0.00	0.00	433.63	270.65	171.13	420.07	446.25
	(0.00)	(0.00)	(0.00)	(332.99)	(0.00)	(134.11)	(315.55)	(335.21)
Baked Goods	311.57	476.13	434.12	574.48	365.23	670.29	585.78	578.52
	(194.05)	(430.16)	(354.63)	(464.18)	(280.81)	(535.34)	(440.96)	(461.98)
Vegan Dairy	0.00	125.27	0.00	169.27	0.00	194.50	164.07	188.40
	(0.00)	(86.84)	(0.00)	(108.28)	(0.00)	(128.89)	(80.33)	(102.56)
Dairy**	120.49	252.47	219.16	259.27	138.47	310.98	247.07	252.72
	(59.49)	(251.79)	(213.80)	(228.78)	(124.11)	(268.49)	(208.07)	(223.65)
Oils	190.35	292.97	244.65	233.12	136.93	272.89	245.02	228.63
	(138.02)	(258.92)	(196.88)	(223.91)	(95.20)	(283.42)	(217.30)	(216.06)
Beverage w/o Milk	50.12	101.01	113.89	150.91	139.41	175.62	201.29	193.80
	(93.78)	(125.38)	(139.83)	(157.89)	(164.95)	(174.04)	(193.76)	(191.24)
Beverage w/ Milk*	180.60	153.35	123.76	142.10	107.94	155.92	141.22	136.08
	(93.22)	(201.81)	(121.96)	(143.48)	(112.16)	(144.80)	(139.07)	(133.28)
Alcoholic Beverage	780.30	537.23	594.83	667.52	720.42	555.10	649.70	706.06
	(409.69)	(474.61)	(846.13)	(818.71)	(515.98)	(816.22)	(671.30)	(756.05)
Miscellaneous (Beef)*	546.00	0.00	0.00	0.00	228.08	205.13	439.81	464.57
	(386.08)	(0.00)	(0.00)	(0.00)	(174.01)	(130.97)	(337.90)	(371.20)
Miscellaneous (Meat)*	340.40	0.00	0.00	479.38	276.13	204.45	493.45	501.15
	(157.21)	(0.00)	(0.00)	(474.09)	(293.31)	(141.80)	(467.25)	(486.50)
Miscellaneous (Veg)	284.96	405.99	407.69	345.17	212.46	360.85	315.81	352.81
	(285.27)	(597.10)	(461.38)	(372.63)	(240.21)	(412.92)	(356.68)	(386.90)

Source: Own elaboration.

Note: Standard deviation between parentheses.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

** According to the IBGE/POF classification system, margarines were categorized as dairy products despite containing zero cholesterol and being compatible with vegan diets.

Table 12A. Average total Carbon Footprint (gCO_2eq) per food group by each diet type.

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Vegetables	21.29	19.11	12.31	12.63	0.42	12.08	9.21	7.54
	(61.79)	(47.56)	(45.86)	(35.46)	(2.08)	(36.87)	(27.36)	(23.28)
Tubers	49.88	35.60	27.08	29.83	15.61	30.30	25.62	27.16
	(63.51)	(67.95)	(54.67)	(51.20)	(26.10)	(68.07)	(55.08)	(52.34)
Fruits	204.77	257.42	243.81	249.93	123.47	319.73	242.02	251.84
	(229.00)	(260.35)	(270.12)	(289.70)	(119.49)	(391.32)	(282.59)	(294.63)
Flours and Pasta	217.44	204.35	130.60	163.67	86.24	177.91	146.75	160.41
	(430.11)	(225.51)	(173.64)	(202.24)	(81.65)	(233.47)	(182.41)	(217.96)
Pasta with Meat*	0.00	0.00	0.00	0.00	285.66	1299.87	1081.56	1156.13
	(0.00)	(0.00)	(0.00)	(0.00)	(185.13)	(1035.17)	(940.38)	(914.75)
Coconuts and Nuts	374.05	736.11	565.01	832.80	49.03	706.57	1009.80	776.85
	(479.09)	(1899.87)	(1200.71)	(1507.12)	(0.00)	(1456.70)	(2147.18)	(1510.89)
Cereals and Legumes	440.19	365.97	323.55	408.62	255.82	472.00	415.73	356.95
	(332.10)	(276.17)	(230.67)	(312.15)	(170.01)	(373.12)	(278.95)	(260.28)
Salt and Condiments	0.00	54.60	86.67	54.80	24.72	43.98	55.88	57.58
	(0.00)	(87.49)	(120.72)	(69.51)	(25.00)	(53.23)	(60.10)	(60.92)
Sugars	45.33	82.55	75.42	92.26	47.75	124.57	100.36	109.02
	(111.82)	(165.40)	(127.43)	(157.48)	(73.29)	(219.32)	(177.08)	(195.95)
Beef	0.00	0.00	0.00	0.00	12536.32	4248.84	6470.78	2615.23
	(0.00)	(0.00)	(0.00)	(0.00)	(7745.58)	(3223.40)	(4861.44)	(3572.90)
Swine	0.00	0.00	0.00	1416.97	235.29	484.18	1062.15	1136.22
	(0.00)	(0.00)	(0.00)	(1638.52)	(441.16)	(657.05)	(1287.50)	(1439.97)
Other Ruminants	0.00	0.00	0.00	0.00	244.54	2408.94	2132.81	3463.51
	(0.00)	(0.00)	(0.00)	(0.00)	(546.81)	(2194.12)	(2857.22)	(3714.81)
Other Meats	0.00	0.00	0.00	412.07	0.00	382.21	400.24	448.95
	(0.00)	(0.00)	(0.00)	(340.38)	(0.00)	(317.39)	(414.57)	(772.88)
Fish and Seafood	0.00	0.00	1411.03	0.00	903.45	595.09	1014.86	1168.50
	(0.00)	(0.00)	(1527.95)	(0.00)	(667.05)	(817.57)	(1318.59)	(1646.45)
Chicken	0.00	0.00	0.00	1012.94	573.09	494.10	836.78	908.27
	(0.00)	(0.00)	(0.00)	(900.72)	(575.01)	(351.73)	(732.96)	(780.73)
Eggs	0.00	302.50	307.64	279.27	228.82	267.23	255.47	261.17
	(0.00)	(287.46)	(253.54)	(236.01)	(232.16)	(224.19)	(195.54)	(212.40)

Table 12A. (continued)

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Canned Vegetables	237.32	103.43	33.69	255.43	86.88	353.10	286.72	374.58
	(0.00)	(123.45)	(18.25)	(378.32)	(66.28)	(474.13)	(491.89)	(644.03)
Canned Meat*	0.00	0.00	0.00	5224.66	2537.62	2304.48	5031.61	5298.57
	(0.00)	(0.00)	(0.00)	(3919.63)	(0.00)	(1835.81)	(3741.05)	(3854.14)
Baked Goods	82.57	186.99	141.46	203.43	123.28	240.42	204.32	211.19
	(67.36)	(331.67)	(192.02)	(280.76)	(129.74)	(311.21)	(246.45)	(293.25)
Vegan Dairy	0.00	149.42	0.00	236.36	0.00	301.75	213.09	291.86
	(0.00)	(146.38)	(0.00)	(188.94)	(0.00)	(300.59)	(96.73)	(128.78)
Dairy**	29.56	373.39	277.17	314.28	105.03	410.79	285.35	301.58
	(14.59)	(596.78)	(515.19)	(481.16)	(185.98)	(562.27)	(439.32)	(465.43)
Oils	62.21	95.75	79.96	76.19	44.75	89.19	80.08	74.71
	(45.11)	(84.62)	(64.35)	(73.19)	(31.11)	(92.63)	(71.02)	(70.62)
Beverage w/o Milk	105.65	133.34	143.13	196.66	175.30	217.59	248.03	242.72
	(127.23)	(148.52)	(145.20)	(185.61)	(205.58)	(198.45)	(235.78)	(239.18)
Beverage w/ Milk*	200.63	164.40	131.16	146.27	113.92	160.83	145.57	140.62
	(103.56)	(261.21)	(154.39)	(172.99)	(142.90)	(174.23)	(170.31)	(160.74)
Alcoholic Beverage	2220.41	1614.16	1662.02	1863.36	2125.03	1563.88	1922.54	2045.97
	(1261.58)	(1279.78)	(2416.38)	(2080.43)	(1579.94)	(2005.05)	(1981.09)	(2160.33)
Miscellaneous (Beef)*	720.00	0.00	0.00	0.00	1096.10	921.44	2103.27	2398.06
	(509.12)	(0.00)	(0.00)	(0.00)	(1765.03)	(1619.62)	(3045.02)	(3445.02)
Miscellaneous (Meat)*	622.79	0.00	0.00	1047.24	688.42	271.28	1090.95	1130.00
	(287.63)	(0.00)	(0.00)	(2353.41)	(2017.66)	(572.55)	(2269.27)	(2447.67)
Miscellaneous (Veg)	278.41	400.98	372.35	263.14	132.61	283.44	200.52	244.82
	(499.47)	(663.78)	(598.06)	(462.54)	(217.36)	(488.17)	(335.97)	(399.73)

Source: Own elaboration.

Note: Standard deviation between parentheses.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

** According to the IBGE/POF classification system, margarines were categorized as dairy products despite containing zero cholesterol and being compatible with vegan diets.

Table 13A. Average total Water Footprint (liters) per food group by each diet type.

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Vegetables	39.94	40.26	27.31	27.53	2.00	25.67	20.05	16.00
	(115.85)	(93.10)	(101.48)	(83.60)	(9.93)	(77.06)	(58.41)	(48.32)
Tubers	138.75	80.72	72.10	71.27	37.09	70.86	59.33	62.97
	(193.54)	(144.02)	(144.10)	(121.18)	(63.05)	(152.45)	(120.71)	(118.22)
Fruits	334.75	259.03	290.97	279.26	116.29	326.60	245.96	260.05
	(329.79)	(253.22)	(396.76)	(336.67)	(113.28)	(419.14)	(334.60)	(333.13)
Flours and Pasta	196.56	214.15	232.29	197.60	147.77	200.57	182.34	210.46
	(303.97)	(213.21)	(224.79)	(218.07)	(131.77)	(207.68)	(171.55)	(223.46)
Pasta with Meat*	0.00	0.00	0.00	0.00	191.25	890.98	741.20	789.46
	(0.00)	(0.00)	(0.00)	(0.00)	(135.64)	(719.50)	(652.70)	(638.40)
Coconuts and Nuts	335.48	854.91	430.29	852.28	886.12	765.54	866.35	733.11
	(30.42)	(953.90)	(604.40)	(1014.61)	(0.00)	(878.17)	(1090.47)	(786.02)
Cereals and Legumes	747.94	600.50	473.49	631.73	316.31	765.81	605.18	510.47
	(568.66)	(485.70)	(410.05)	(537.60)	(264.36)	(615.36)	(467.90)	(437.74)
Salt and Condiments	0.00	63.52	141.44	34.79	15.43	34.79	33.13	30.66
	(0.00)	(117.95)	(266.95)	(78.72)	(30.23)	(62.64)	(55.18)	(52.33)
Sugars	63.52	141.04	146.19	165.67	80.00	218.82	187.18	209.02
	(145.59)	(345.01)	(435.45)	(436.38)	(149.05)	(491.91)	(445.02)	(547.03)
Beef	0.00	0.00	0.00	0.00	8601.33	2905.22	4373.49	2397.85
	(0.00)	(0.00)	(0.00)	(0.00)	(5561.87)	(2200.21)	(3343.00)	(3339.47)
Swine	0.00	0.00	0.00	2413.96	277.77	763.69	1767.48	1918.95
	(0.00)	(0.00)	(0.00)	(2841.09)	(493.95)	(932.77)	(2199.00)	(2448.64)
Other Ruminants	0.00	0.00	0.00	0.00	131.66	1297.96	1149.98	1867.79
	(0.00)	(0.00)	(0.00)	(0.00)	(294.40)	(1182.66)	(1541.87)	(2005.28)
Other Meats	0.00	0.00	0.00	1220.48	0.00	1141.91	1186.76	1328.52
	(0.00)	(0.00)	(0.00)	(1007.78)	(0.00)	(940.57)	(1224.76)	(2285.88)
Fish and Seafood	0.00	0.00	168.83	0.00	71.91	175.44	125.02	126.14
	(0.00)	(0.00)	(716.47)	(0.00)	(194.12)	(449.28)	(480.77)	(563.85)
Chicken	0.00	0.00	0.00	1351.91	756.69	656.66	1119.60	1211.71
	(0.00)	(0.00)	(0.00)	(1206.12)	(750.70)	(470.62)	(1025.71)	(1058.97)
Eggs	0.00	284.21	289.11	262.44	215.00	251.16	239.82	245.19
	(0.00)	(269.20)	(238.42)	(221.64)	(218.71)	(210.74)	(183.26)	(199.16)

Table 13A. (continued)

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Canned Vegetables	171.03	182.75	157.23	599.41	175.14	842.24	757.95	646.07
	(0.00)	(194.85)	(164.47)	(679.88)	(111.37)	(951.69)	(885.76)	(644.90)
Canned Meat*	0.00	0.00	0.00	4179.60	2258.83	1625.79	4057.44	4333.90
	(0.00)	(0.00)	(0.00)	(3198.99)	(0.00)	(1215.60)	(3076.19)	(3261.02)
Baked Goods	159.20	251.02	207.19	292.60	178.49	345.98	296.38	289.63
	(125.95)	(282.61)	(215.26)	(268.87)	(159.35)	(316.09)	(253.31)	(285.03)
Vegan Dairy	0.00	274.59	0.00	294.63	0.00	347.09	312.38	458.95
	(0.00)	(289.15)	(0.00)	(380.11)	(0.00)	(273.70)	(197.36)	(334.36)
Dairy**	24.93	321.73	231.03	268.00	95.00	364.40	247.18	262.12
	(12.31)	(503.68)	(379.59)	(390.19)	(172.17)	(468.83)	(355.46)	(380.02)
Oils	155.66	239.58	200.07	190.63	111.98	223.16	200.37	186.95
	(112.87)	(211.74)	(161.00)	(183.12)	(77.85)	(231.78)	(177.70)	(176.70)
Beverage w/o Milk	2657.15	3083.96	3077.02	3716.87	2600.83	4044.54	3714.31	3606.65
	(3591.57)	(3723.90)	(3296.50)	(3775.43)	(2402.19)	(3979.98)	(3513.04)	(3610.78)
Beverage w/ Milk*	637.92	3482.18	2756.32	3429.23	2481.51	3847.95	3455.59	3295.19
	(329.28)	(3561.43)	(2634.13)	(3205.84)	(1729.66)	(3558.04)	(3103.94)	(3112.27)
Alcoholic Beverage	647.15	441.33	446.07	488.25	730.07	416.13	618.39	638.95
	(572.90)	(338.42)	(734.24)	(589.81)	(594.65)	(488.84)	(694.42)	(721.58)
Miscellaneous (Beef)*	346.04	0.00	0.00	0.00	938.95	662.90	1945.22	2149.18
	(244.69)	(0.00)	(0.00)	(0.00)	(1534.84)	(1200.04)	(2403.80)	(2664.22)
Miscellaneous (Meat)*	826.10	0.00	0.00	689.42	474.29	213.23	710.11	729.23
	(381.52)	(0.00)	(0.00)	(1502.44)	(1274.25)	(406.21)	(1464.62)	(1562.86)
Miscellaneous (Veg)	312.18	506.32	372.80	325.23	140.69	366.48	241.28	280.06
	(614.81)	(826.00)	(631.84)	(594.96)	(175.16)	(725.46)	(453.20)	(518.30)

Source: Own elaboration.

Note: Standard deviation between parentheses.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

** According to the IBGE/POF classification system, margarines were categorized as dairy products despite containing zero cholesterol and being compatible with vegan diets.

Table 14A. Average total Ecological Footprint (g-m^2) per food group by each diet type.

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Vegetables	0.09	0.10	0.08	0.07	0.00	0.07	0.05	0.04
	(0.26)	(0.29)	(0.32)	(0.20)	(0.02)	(0.31)	(0.16)	(0.18)
Tubers	0.84	0.45	0.38	0.40	0.20	0.40	0.33	0.36
	(1.24)	(0.82)	(0.74)	(0.73)	(0.36)	(0.88)	(0.71)	(0.72)
Fruits	1.49	1.51	1.62	1.59	0.67	1.99	1.42	1.54
	(1.62)	(1.40)	(1.67)	(1.77)	(0.67)	(2.28)	(1.50)	(1.70)
Flours and Pasta	1.11	1.32	1.28	1.14	0.80	1.17	1.05	1.19
	(1.85)	(1.67)	(1.37)	(1.26)	(0.70)	(1.24)	(0.99)	(1.26)
Pasta with Meat*	0.00	0.00	0.00	0.00	1.77	6.16	5.14	5.75
	(0.00)	(0.00)	(0.00)	(0.00)	(0.63)	(4.35)	(4.07)	(3.79)
Coconuts and Nuts	0.88	1.79	1.27	1.95	0.11	1.80	2.43	1.99
	(1.01)	(4.22)	(2.68)	(3.34)	(0.00)	(3.20)	(4.77)	(3.33)
Cereals and Legumes	3.04	2.51	2.10	2.71	1.56	3.19	2.69	2.29
	(2.23)	(1.95)	(1.56)	(2.11)	(1.06)	(2.48)	(1.84)	(1.72)
Salt and Condiments	0.00	0.73	1.11	0.96	0.47	0.74	1.06	1.12
	(0.00)	(0.97)	(1.14)	(1.10)	(0.42)	(0.81)	(1.11)	(1.18)
Sugars	0.32	0.69	0.62	0.82	0.40	1.16	0.95	1.02
	(0.75)	(1.56)	(1.21)	(1.77)	(0.70)	(2.55)	(2.16)	(2.33)
Beef	0.00	0.00	0.00	0.00	49.38	17.22	26.61	3.88
	(0.00)	(0.00)	(0.00)	(0.00)	(32.57)	(13.42)	(19.87)	(4.37)
Swine	0.00	0.00	0.00	11.28	1.09	3.47	8.24	8.92
	(0.00)	(0.00)	(0.00)	(13.38)	(2.06)	(4.40)	(10.42)	(11.50)
Other Ruminants	0.00	0.00	0.00	0.00	1.32	12.99	11.51	18.69
	(0.00)	(0.00)	(0.00)	(0.00)	(2.94)	(11.84)	(15.43)	(20.07)
Other Meats	0.00	0.00	0.00	9.67	0.00	9.05	9.40	10.52
	(0.00)	(0.00)	(0.00)	(7.98)	(0.00)	(7.46)	(9.71)	(18.10)
Fish and Seafood	0.00	0.00	69.77	0.00	30.25	25.74	47.52	54.13
	(0.00)	(0.00)	(64.83)	(0.00)	(23.09)	(27.19)	(48.43)	(54.98)
Chicken	0.00	0.00	0.00	8.02	4.52	3.90	6.64	7.19
	(0.00)	(0.00)	(0.00)	(7.13)	(4.49)	(2.78)	(5.89)	(6.19)
Eggs	0.00	1.96	1.99	1.81	1.48	1.73	1.65	1.69
	(0.00)	(1.85)	(1.64)	(1.53)	(1.51)	(1.45)	(1.26)	(1.37)

Table 14A. (continued)

Food Groups	Vegan	Veggie	Pescatarian	Ruminant Replaced	High Ruminant	Flex	Brazilian	Others
Canned Vegetables	0.69	0.36	0.11	1.20	0.33	1.65	1.37	1.78
	(0.00)	(0.33)	(0.12)	(1.71)	(0.08)	(2.13)	(2.22)	(2.85)
Canned Meat*	0.00	0.00	0.00	16.04	5.14	9.25	14.88	15.15
	(0.00)	(0.00)	(0.00)	(13.17)	(0.00)	(7.77)	(12.46)	(11.69)
Baked Goods	0.61	1.35	1.06	1.49	0.96	1.77	1.55	1.54
	(0.42)	(2.20)	(1.23)	(1.77)	(1.12)	(2.05)	(1.70)	(1.81)
Vegan Dairy	0.00	7.88	0.00	15.48	0.00	19.81	14.69	20.37
	(0.00)	(13.10)	(0.00)	(13.93)	(0.00)	(18.84)	(6.56)	(9.73)
Dairy**	1.24	4.71	3.63	4.61	1.96	6.07	4.39	4.69
	(0.61)	(9.83)	(6.46)	(7.89)	(4.30)	(9.57)	(7.11)	(7.87)
Oils	1.60	2.45	2.05	1.95	1.15	2.29	2.05	1.92
	(1.16)	(2.17)	(1.65)	(1.88)	(0.80)	(2.37)	(1.82)	(1.81)
Beverage w/o Milk	12.24	13.73	14.07	17.62	12.26	19.06	17.85	17.25
	(15.66)	(15.94)	(14.57)	(17.37)	(11.80)	(18.39)	(16.75)	(16.68)
Beverage w/ Milk*	24.15	15.50	13.00	16.70	12.43	18.14	16.76	15.88
	(12.47)	(15.21)	(11.63)	(14.89)	(10.07)	(15.81)	(14.55)	(14.46)
Alcoholic Beverage	10.49	8.07	8.71	9.83	8.50	8.32	8.33	9.20
	(5.67)	(9.34)	(11.62)	(13.07)	(5.84)	(13.92)	(8.94)	(10.32)
Miscellaneous (Beef)*	2.10	0.00	0.00	0.00	2.65	3.23	8.40	9.37
	(1.48)	(0.00)	(0.00)	(0.00)	(5.95)	(6.48)	(12.04)	(13.52)
Miscellaneous (Meat)*	5.01	0.00	0.00	4.18	2.90	1.23	4.32	4.45
	(2.31)	(0.00)	(0.00)	(9.18)	(7.84)	(2.39)	(8.90)	(9.55)
Miscellaneous (Veg)	1.74	2.94	2.03	1.83	0.82	2.03	1.35	1.54
	(3.67)	(4.86)	(3.38)	(3.23)	(0.99)	(3.57)	(2.12)	(2.38)

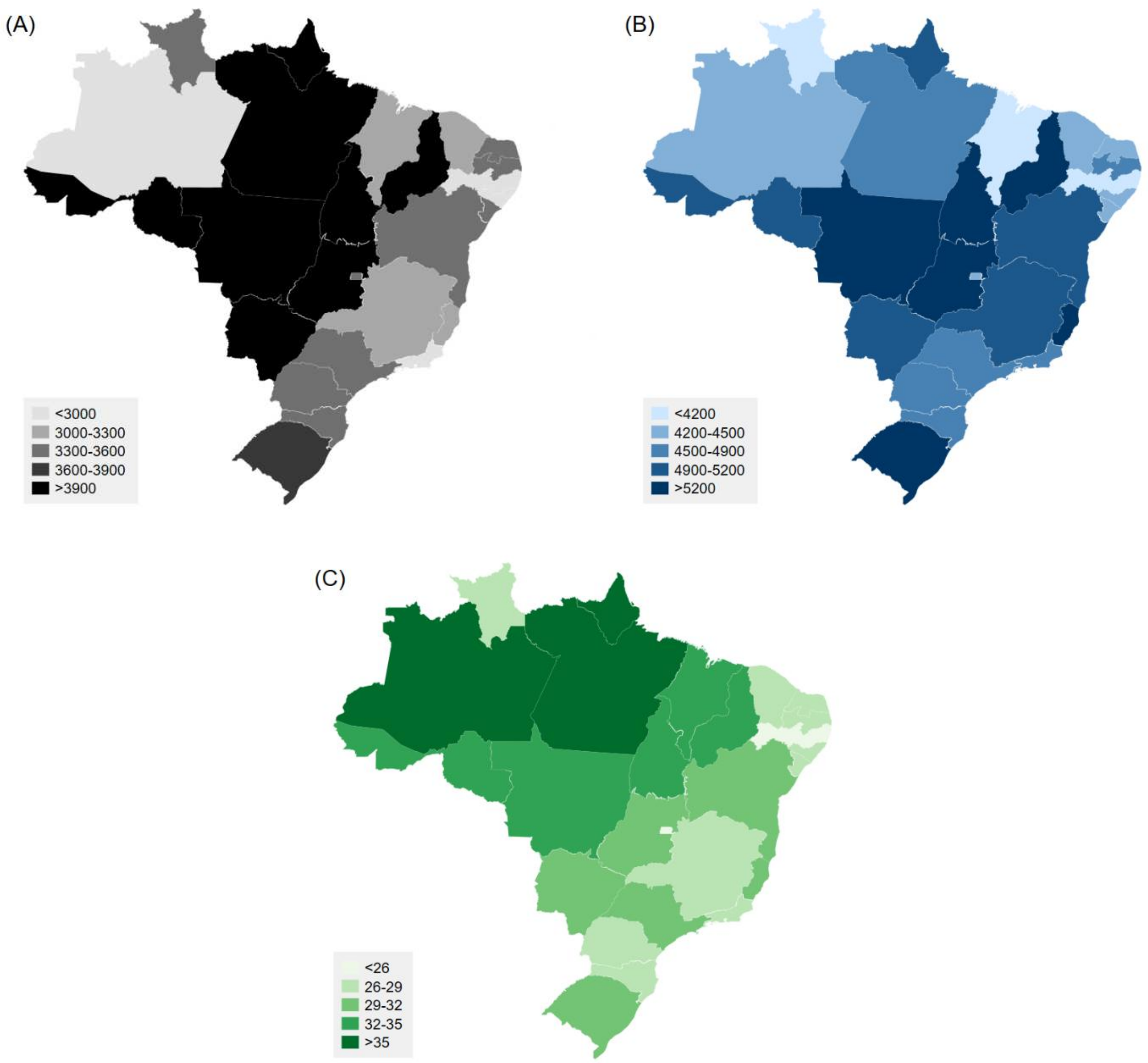
Source: Own elaboration.

Note: Standard deviation between parentheses.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

** According to the IBGE/POF classification system, margarines were categorized as dairy products despite containing zero cholesterol and being compatible with vegan diets.

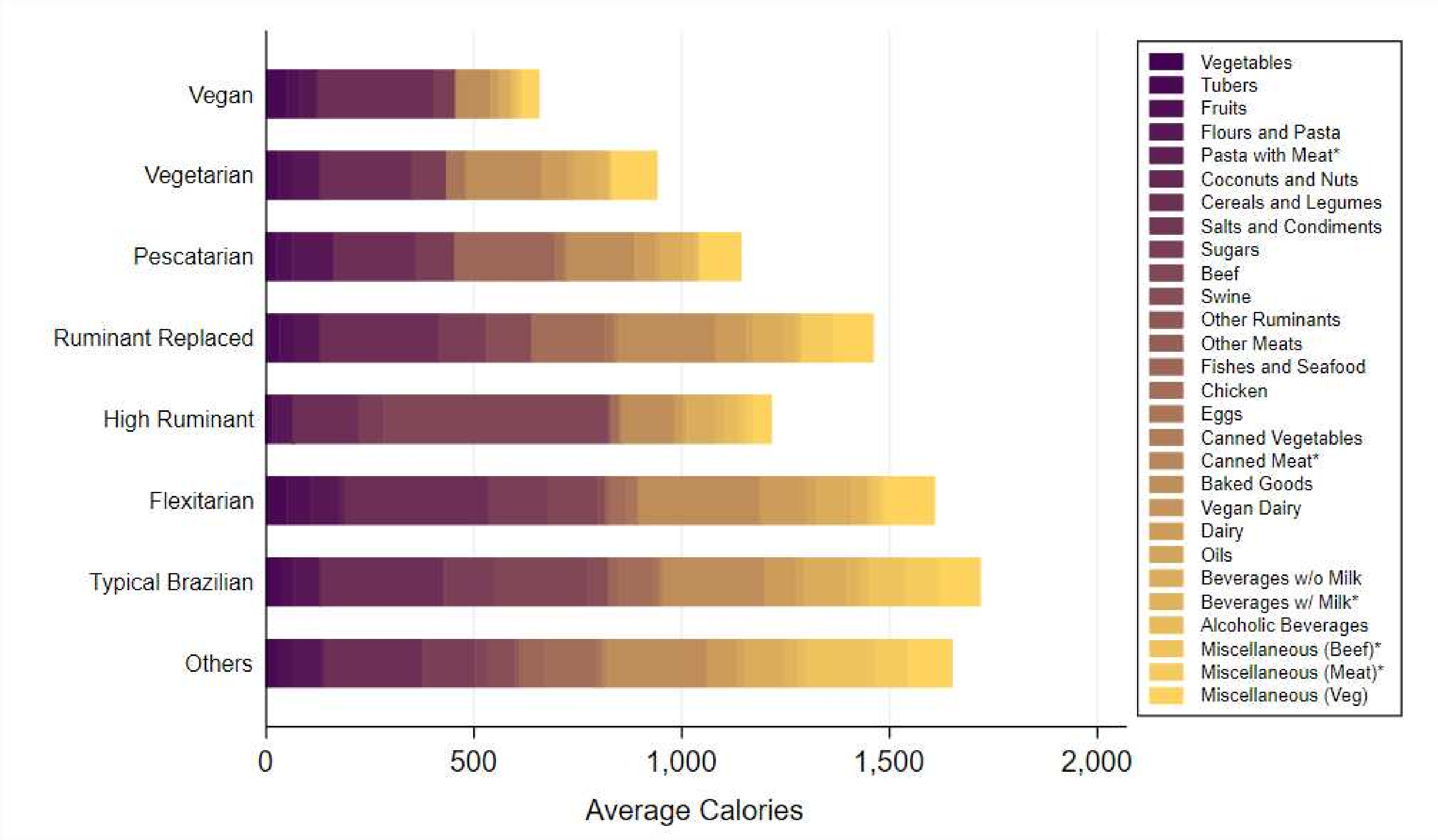
Figure 1A. Average values of Carbon Footprint, Water Footprint, and Ecological Footprint, individually (one-day), by Brazilian Federative Units.



Source: Own elaboration.

Note: Panel (A) related for the Carbon Footprint estimates, while Panel (B) is for Water Footprint, and Panel (C) for Ecological Footprint. Average Per Capita values.

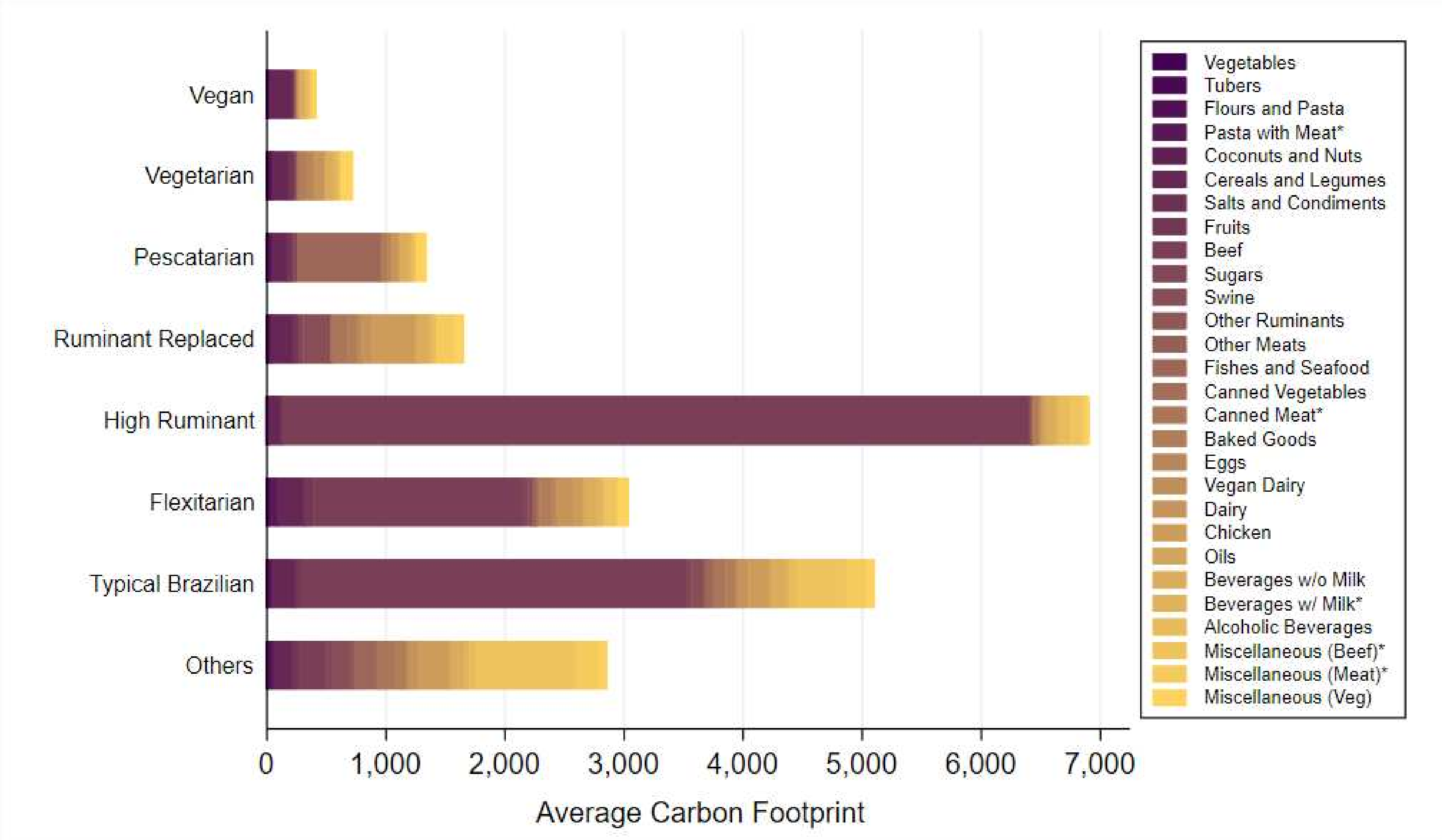
Figure 2A. Average total calories (kcal) contribution per food group, by each diet type.



Source: Own elaboration.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

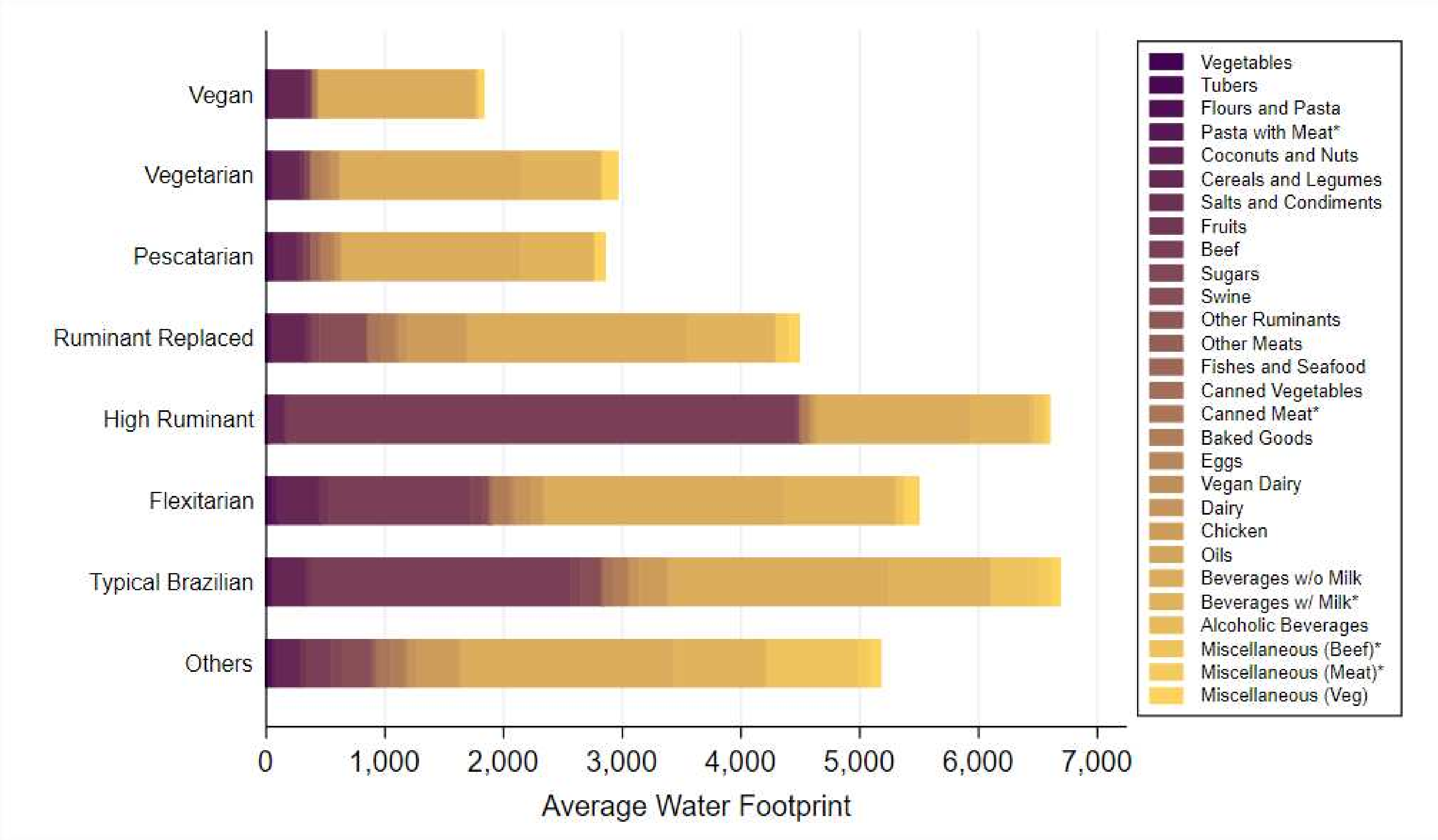
Figure 3A. Average total Carbon Footprint (gCO_2eq) contribution per food group, by each diet type.



Source: Own elaboration.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

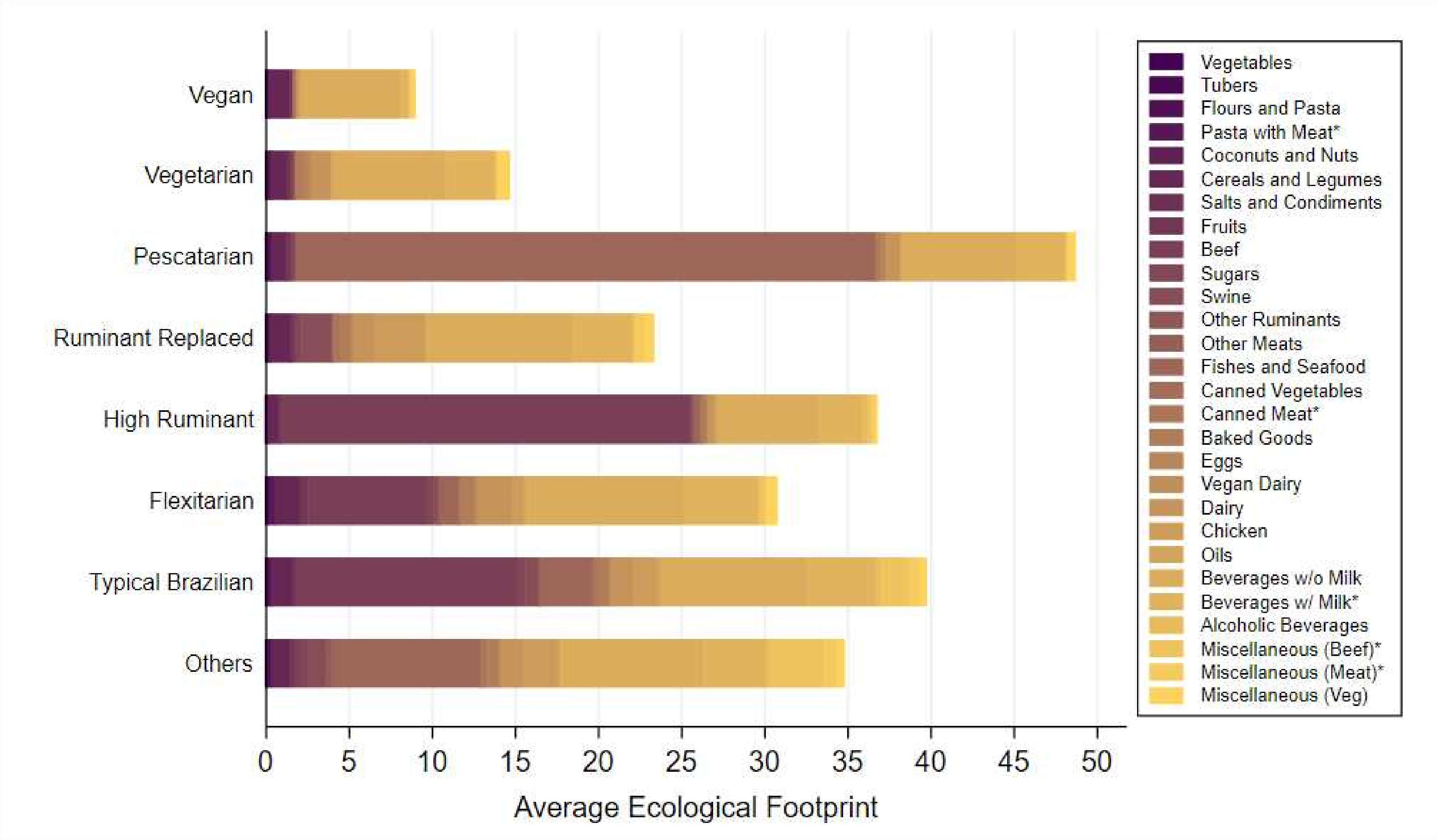
Figure 4A. Average total Water Footprint (liters) contribution per food group, by each diet type.



Source: Own elaboration.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods.

Figure 5A. Average total Ecological Footprint (g-m^2) contribution per food group, by each diet type.



Source: Own elaboration.

* Due to the highly disaggregated level of POF, these groups may, or may, do not, contain animal-based foods

Estimated Footprints Reductions after Diet Transition

$$Total\ Footprint\ (TF) = \sum Footprint_i * n_i$$

$$Footprint_{weighted} = \frac{TF}{\sum n_i}$$

$$Diet\ Footprint\ Switchover\ (DFS) = Footprint_{weighted} - Footprint_{new\ diet}$$

$$Footprint\ Change\ (FC) = (DFS * [\left(n_{total} - n_{without\ change}\right) * Conversion\ Rate]$$

$$Footprint\ Reduction = \frac{FC}{TF}$$

CHAPTER 2

2. Environmental Taxes on Foods: How can they be used to reduce environmental damage in Brazil?

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Abstract

The agrifood sector, particularly cattle raising, is a primary driver of greenhouse gas emissions and environmental degradation. Thus, in this study, we evaluate the environmental and economic impacts of demand-side fiscal policies to nudge consumers toward more sustainable foods. Using the most recent microdata from the Household Budget Survey (POF) from 2017-2018, we estimate elasticities for 16 food groups through a QUAIDS model, and simulated tax-system scenarios including standalone environmental taxes, subsidies for sustainable foods, and a combined approach. Our results show that while standalone taxes on high-emitting foods reduce carbon footprints, they are regressive and may risk exacerbating food insecurity. Conversely, a dual-incentive policy combining taxes with subsidies emerges as the optimal choice, combining a reduction in environmental losses with better social equity.

Keywords: Environmental Taxes. Food Demand System. Sustainability. Environmental Impact.

JEL: D12. H23. Q18.

2.1 Introduction

The food production system is one of the primary drivers of environmental degradation. Agriculture accounts for approximately 30% of all greenhouse gas (GHG) emissions and is a leading cause of land waste, deforestation, and biodiversity loss (Crippa et al., 2021; FAO & WHO, 2019). Specifically, meat and dairy production hold the highest polluting potential due to the extensive deforestation required for cattle feed crops, which substantially increases GHG levels, and their widespread consumption amplifies these impacts by sustaining demand for these supply chains (Crippa et al., 2021; Esteve-Llorens et al., 2019; Lazarus et al., 2021).

In this scenario, individual food preferences play a complementary role in shaping the environment's future (Allen & Prosperi, 2016). Consumers who favor animal-based foods directly contribute to increasing climate change effects and environmental pressure (FAO & WHO, 2019; Hartmann & Siegrist, 2017; Springmann, Auclair, et al., 2025). Conversely, transitioning to a more sustainable, plant-based diet can significantly mitigate GHG emissions, optimize soil and water use, and improve local biodiversity and animal welfare (Aiking, 2011; Deng et al., 2025; Dernini, 2018; Gibbs & Cappuccio, 2022; Hartmann & Siegrist, 2017; Willits-Smith et al., 2020; Yeh & Hartmann, 2021). However, consumers' generally low awareness regarding the negative environmental and health impacts of specific foods, such as beef, often leads to an undervaluation of their true ecological cost (Gibbs & Cappuccio, 2022; Hartmann & Siegrist, 2017).

To address these externalities, environmental taxes and subsidies have emerged as effective policy instruments to reward or penalize consumer choices (Larsson et al., 2026; Saxena et al., 2025; Springmann, Dinivitzer, et al., 2025). The implementation of taxes is well-documented in the literature as a successful method to discourage the consumption of unhealthy foods (Leifert & Lucinda, 2015; Maniadakis et al., 2013; Niebylski et al., 2015; Pereda et al., 2024; Popkin et al., 2021; Roche, 2025; Saxena et al., 2025; Valizadeh & Ng, 2024), tobacco (Gammon et al., 2016; Ringel et al., 2005), and environmentally harmful products (Bonnet et al., 2018; Cleghorn et al., 2022; Ejelöv et al., 2025; Forero-Cantor et al., 2020; Gren et al., 2021; Larsson et al., 2026; Moberg et al., 2021; Säll, 2018). Despite their effectiveness, food taxes can be perceived as unpopular and regressive (García-Muros et al., 2017).

To mitigate public resistance, tax systems aimed at reducing environmental impacts can adopt various structures. The most common approaches include an *ad valorem* tax implemented as a value-added subcharge (VAT), with an arbitrary percentage (Caillavet et al., 2016; Forero-Cantor et al., 2020; Revoredo-Giha et al., 2018; Saxena et al., 2025) or a system weighted by the food's specific GHG emission (Bonnet et al., 2018; Jansson & Säll, 2018; Mardones & Andaur, 2024; Plinke et al., 2026; Säll et al., 2020). Alternatively, neutral-tax systems allocate the collected revenue to subsidize other products, adjusting the current VAT system to balance consumer welfare and environmental goals (Abadie et al., 2016; Blakely et al., 2020; Cleghorn et al., 2022; Larsson et al., 2026; Moberg et al., 2021; Oebel et al., 2024).

While previous literature has predominantly investigated the effects of environmental food taxes in developed economies (Abadie et al., 2016; Bonnet et al., 2018; Caillavet et al., 2019; Ejelöv et al., 2025; Forde et al., 2025; Plinke et al., 2026; Säll, 2018; Springmann, Dinivitzer, et al., 2025), there is a notable lack of similar studies focusing on developing countries. This gap is particularly concerning for emerging economies characterized by extensive agricultural production, such as Brazil. Accounting for an estimated 7.4% (1.3 Gt CO_2e) of global food sector emissions, surpassing the European Union, and ranking among the largest consumers of beef, Brazil exhibits an immense pollution potential (Crippa et al., 2021; FAO, 2022). Moreover, Brazilian deforestation is mainly driven by domestic demand (Haddad et al., 2024), so that the absence of strategies aiming to decrease the environmental damage of Brazilian food consumption requires immediate attention.

To address this research gap, this study investigates a demand-side strategy designed to reduce the environmental potential damage of the Brazilian agri-food sector. We propose a tax system as a policy instrument to effectively reduce the consumption of environmentally intensive foods in Brazil. Building on this analysis, we investigated how different tax designs could enhance the policy's overall efficiency. Our results show that taxing beef while subsidizing other food groups, aiming to avoid tax regressivity and food insecurity, could reduce emissions by 0.301 tCO_2eq per household in a year, almost 8% of the total domiciliary emissions or 0.9% of the overall emissions in Brazil.

Our study is structured into six sections. After this introduction, Section 2 presents the theoretical framework that supports our analysis; Section 3 describes the methodological approach and data; Section 4 reports the main results; Section 5 discusses the study findings in light of broader literature; Section 6 concludes the study with final remarks and policy implications.

2.2 Environmental Taxes

The scale of global ecological challenges demands a shift toward more robust policy instruments capable of properly addressing environmental issues. Consequently, environmental taxation emerges as a fundamental mechanism for sustainability, internalizing environmental burdens associated with specific food consumption (Larsson et al., 2026). The implementation of carbon pricing in the food sector has already been highlighted as an effective strategy to reduce the agrifood system's environmental impacts (Plinke et al., 2026; Springmann, Dinivitzer, et al., 2025).

Despite its potential, there is no strong consensus on the optimal strategy for implementing these taxes, with values and methodologies varying significantly across countries. Regarding the introduction of a new fixed *ad-valorem* tax, the most commonly proposed value is around 20% of the original food price, which is often considered the optimal rate (Caillavet et al., 2016; Cleghorn et al., 2022; Forero-Cantor et al., 2020; Mytton et al., 2012; Revoredo-Giha et al., 2018; Saxena et al., 2025), presenting as the optimal VAT. While other studies propose lower tax brackets of 5-10%, evidence suggests that these values yield almost negligible changes in the volume of food consumed (Fletcher et al., 2010; Thow et al., 2014).

Alternatively, tax rates can be differentiated across food items. One such approach is a weighted tax, based on the Carbon Footprint (CF) of each product, typically measured in tons of CO2 equivalent (tonCO_2eq). The values suggested in previous literature are highly heterogeneous. In European Union (EU) countries, for example, proposed taxes range roughly from €20.00 to €350.00[12] per tonCO_2eq (Bonnet et al., 2018; García-Muros et al., 2017; Jansson & Säll, 2018; Plinke et al., 2026; Säll et al., 2020; Schaper et al., 2025; Wirsenius et al., 2011). In contrast, for non-EU nations, like Argentina, suggested rates are significantly lower, around $5.00 to $25.00 per ton$CO_2$eq (Mardones & Andaur, 2024). This wide variation is largely driven by differences in food expenditure patterns and baseline price levels in the respective countries (Green et al., 2013).

[12] The values have been deflated using the accumulated inflation over the years for the base year of 2025.

Regardless of the approach, increasing food prices through taxation often faces public resistance, which can undermine political support for the policy (Ejelöv et al., 2025; García-Muros et al., 2017). To address this, revenue-neutral tax policies aiming to keep the optimal allocation of consumed goods emerge as a critical strategy to boost public acceptability (Forde et al., 2025; Siegerink et al., 2024). Systems that combine taxes with subsidies tend to be much better received (Larsson et al., 2026), particularly when tax revenues are earmarked to subsidize more sustainable food options (Ejelöv et al., 2025; Siegerink et al., 2024).

Ultimately, environmental taxation constitutes an important demand-side instrument for mitigating the ecological pressures associated with food consumption. Yet, real-world performance depends not only on technical design and emission coverage but also on social acceptability and perceived fairness. Revenue-neutral reforms, through systematically recycling of revenues, can strengthen both equity and political support, making them a particularly feasible pathway for advancing climate objectives while safeguarding consumer welfare.

2.3 Materials and methods

To evaluate the effectiveness of environmental taxation, our strategy employs a multi-step modeling approach. Initially, we estimate a demand system to determine consumer sensitivity through price and expenditure elasticities. Subsequently, we simulate the impact of specific tax policies on food prices and consumption volumes. In the final step, we link these shifts in consumption to environmental coefficients to assess the impact on GHG emissions, water resources, and land use.

2.3.1 Data

We rely on the Brazilian Household Budget Survey (POF) from 2017-2018 (IBGE, 2019b) as the primary data source for our estimation and analysis. This survey was conducted between July 11, 2017, and July 11, 2018, covering a total of 57,920 households distributed across the Brazilian territory. It provides comprehensive information on household budget composition, living conditions, food expenditures, and quality of life. This cross-sectional microdata represents the largest and most recent dataset of its kind in Brazil.

We established sixteen food groups, following a major division of animal and non-animal-based foods, and then secondary groups regarding the similarity of the foods. In this context, we are left with the following groups: Rice; Beans; Flours and Pasta; Beef; Swine; Fishes; Chicken; Eggs; Dairy products; Processed Meat; Baked Goods; Vegetables; Fruits; Tubers and Roots; Sugar-Sweetened Beverages; and other foods and beverages (residual good). Furthermore, the environmental data related to food consumption is derived from the dataset elaborated by Garzillo et al. (2019). They calculated the environmental impact of each food item consumed in the POF, which we then aggregated into our specific food groups.

2.3.2 Demand system estimation

To assess the changes in demand for the food products evaluated, we first estimate demand elasticities using the Quadratic Almost Ideal Demand System (QUAIDS) model (Banks et al., 1997), which is commonly used to estimate demand elasticities (Plinke et al., 2026; Roche, 2025; Säll et al., 2020; Saxena et al., 2025; Zanin et al., 2019). This model is an extension of the Almost Ideal Demand System (AIDS) model (Deaton & Muellbauer, 1980) with an addition of a quadratic term to account for non-linearities on Engel's curves (income-expenditure relationship). The specification of the QUAIDS follows:

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij}\, \alpha_i \ln p_j + \beta_i \ln\left[\frac{x_r}{a(p)}\right] + \frac{\lambda_i}{b(p)}\left\{\ln\left[\frac{x_r}{a(p)}\right]\right\}^2 + \varepsilon_i \qquad (1)$$

where $w_i = \frac{p_i q_i}{\sum_{i=1}^{n} p_i q_i}$ is the expenditure share of the *i-th* food; x_r is the overall expenditure; p_j is the price of the *j-th* good; α_i, γ_{ij}, β_i, λ_i are the estimated parameters; ε_i is the error term; $b(p) = \prod_j p_j^{\beta_j}$ is an aggregated Cobb-Douglas price index; and $a(p)$ is a translog price index defined by:

$$\ln a(p) = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln(p_i) + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln(p_i)\ln(pj) \qquad (2)$$

The restrictions from the Demand Theory, namely adding-up ($\sum_i \alpha_i = 1$; $\sum_i \gamma_{ij} = 0$, $\sum_i \beta_i = 0$, $\sum_i \lambda_i = 0$;), homogeneity ($\sum_{j=1}^{n} \gamma_{ij} = 0$), and symmetry ($\gamma_{ij} = \gamma_{ji}, \forall\, i \neq j$.) could be imposed or tested. Following Banks et al. (1997), the price and expenditure elasticities are obtained by differentiating equation (1) within the logarithm of the expenditure and price, obtaining:

$$\mu_i = \frac{\partial w_i}{\partial \ln x_r} = \beta_i + 2\frac{\lambda_i}{b(p)}\left\{\ln\left[\frac{x_r}{a(p)}\right]\right\} \qquad (3)$$

$$\mu_{ij} = \frac{\partial w_i}{\partial \ln p_j} = \gamma_{ij} - \mu_i(\alpha_i + \sum_j \gamma_{ij} \ln p_j) - \frac{\lambda_i \beta_j}{b(p)} \left\{ \ln \left[\frac{x_r}{a(p)} \right] \right\}^2 \quad (4)$$

Furthermore, the expenditure elasticity (ε_i) and the uncompensated (Marshallian) price elasticity (ε_{ij}^u) can be expressed as:

$$\varepsilon_i = \frac{\mu_i}{w_i} + 1 \quad (5)$$

$$\varepsilon_{ij}^u = \frac{\mu_{ij}}{w_i} - \delta_{ij} \quad (6)$$

where δ_{ij} is the Delta Kronecker and assumes binary values of 1 and 0 following $\delta_{ij} = \begin{cases} 1 \; if \; i = j \\ 0 \; if \; i \neq j \end{cases}$

2.3.3 Estimation strategy

Using disaggregated data provides significant advantages in demand estimation, as it captures individual preferences and characteristics more accurately. However, this high level of disaggregation can also lead to estimation challenges. Coelho et al. (2010) demonstrate that high disaggregation frequently causes the Zero Consumption Problem (ZCP), where many households appear as non-consumers of certain products. The reasons for zero consumption can vary; for instance, a household may simply not purchase the item during the specific interview timeframe used for the POF data collection[13] (Zanin et al., 2019). Consequently, the ZCP imposes strict limitations on standard econometric methods, requiring specific corrections to avoid biased estimations.

2.3.3.1 Disaggregated and censored data

Considering the occurrence of ZCP, estimation via Ordinary Least Squares (OLS) would yield biased and inconsistent estimates. One solution to this problem would be to elaborate on a two-stage estimation (Shonkwiler & Yen, 1999). The first stage determines the household's decision to purchase a product using a binary choice model (Probit), as a function of sociodemographic variables. The second stage then estimates the target demand system. The procedure can be described as follows:

[13] ZCP may occur from three different scenarios: I) zero consumption due to cultural habits; II) zero consumption due to optimal allocation (corner solution); and III) zero consumption due to non-perishable foods, which could be normally stocked and consumed through time (Zanin et al., 2019).

1st Stage

$$d_{ik}^{*} = z_{ik}^{\prime}\alpha_i + \vartheta_{ik} \qquad d_{ik} = \begin{cases} 1, \ se \ d_{ik}^{*} > 0 \\ 0, \ se \ d_{ik}^{*} \leq 0 \end{cases} \tag{8}$$

2nd Stage

$$w_{ik}^{*} = f(x_{ik}, \beta_i) + \epsilon_{ik},$$

$$w_{ik} = d_{ik}^{*} w_{ik}^{*}, (i = 1, \ldots, m; k = 1, \ldots, K) \tag{9}$$

Whereas w_{ik} and d_{ik} are both dependent variables; d_{ik}^{*} is the latent variable which represents the difference between the welfare of acquiring or not the good i; d_{ik} is a binary variable which represents the individual choice of acquiring or not the good ($d_{ik} = 1 \ or \ d_{ik} = 0$); w_{ik}^{*} is the latent variable related to the expenditure with the i-th good; w_{ik} is the observable variable which represents the expenditure with the i-th good; $f(x_{ik}, \beta_i)$ is the demand function; $z_{ik}^{\prime}$ is a vector with exogenous variables (Table 1); x_{ik} is a vector with exogenous variables (Table 1); and ϑ_{ik} and ϵ_{ik} are random error coefficients.

2.3.3.2 Expenditure endogeneity

We assume that our demand system fulfills the weak separability condition (Edgerton, 1997). Thus, it can be assumed that expenditure is jointly determined with expenditure shares, implying a problem of expenditure endogeneity within the model (Zanin et al., 2019). To address this issue, the correction proposed by Blundell & Robin (1999) is employed, assuming an augmented regression consisting of two stages, where total expenditure (m_r) is first regressed on the set of the model's exogenous variables:

$$\ln(m_r) = \alpha_0 + \sum_k \alpha_k z_{ik} + b_j \ln P + \zeta_k \tag{10}$$

where z_{ik} is a vector of sociodemographic characteristics of the households (Table 1), P is a price index used as an instrument, and ζ_k is a residual term. In the second stage we use the estimated residual term ($\widehat{\zeta_k}$) as dependent variable in the demand equation jointly with the total expenditure (m_r) as a solution to the expenditure endogeneity problem.

2.3.3.3 Price endogeneity

Another issue associated with the use of POF microdata is the lack of explicitly defined prices paid for products. Typically, prices are calculated based on purchased quantities and total expenditure, leading to a price endogeneity problem. Hence, the price paid for food i in household k can be represented as a Unit Values (UV_{ik}), derived from dividing the expenditure on the product (m_{ik}) by the quantity purchased (q_{ik}):

$$UV_{ik} = \frac{m_{ik}}{q_{ik}} \tag{11}$$

Table 1. Sociodemographic variables used in the estimation procedure.

Variable	Description
Urban	Household located in urban zone = 1; otherwise = 0
North	Household located in the North region = 1; otherwise = 0
Northeast	Household located in the Northeast region = 1; otherwise = 0
South	Household located in the South region = 1; otherwise = 0
Middle-West	Household located in the Middle-West region = 1; otherwise = 0
Ln Income*	Household monthly income (Logarithmic)
Bolsa Família program	Household beneficiary of the *Bolsa Familia* program = 1; otherwise = 0
Schooling	Household Head years of study
Age	Household Head age
Gender	Household Head is Female = 1; otherwise = 0
Young Children	The presence of individuals with age < 10 = 1; otherwise = 0
Pre-Adolescent	The presence of individuals with age ≥ 10 and < 15 = 1; otherwise = 0
Adolescents	The presence of individuals with age ≥ 15 and < 18 = 1; otherwise = 0
Elderly	The presence of individuals with age ≥ 60= 1; otherwise = 0
Total of Individuals	Total number of individuals living in the household

Source: Own elaboration.

Note: * only in vector z_{ik} (Probit and Endogeneity Correction).

However, Cox & Wohlgenant (1986) caution that the use of unit values is inappropriate and leads to biased estimates, as they reflect subjective factors such as product quality. Moreover, it is observed that higher-income consumers tend to consume higher-quality food, implying that unit values may be correlated with total expenditure (Travassos & Coelho, 2015). To solve this issue, we use the methodological approach of Cox & Wohlgenant (1986) to correct the price-quality effect. Thus, we regress the value differences between Unitary Values (UV_{ik}) and their respective mean values ($\overline{UV}_{ik}$) through the household sociodemographic characteristics (z_{ik}):

$$UV_{ik} - \overline{UV}_{ik} = \sum_j v_{ij} z_{ik} + \varepsilon_{ik} \tag{12}$$

Then, the adjusted prices are obtained from:

$$p_{ik} = UV_{ik} - \sum_j \hat{v}_{ik} z_{ik} \tag{13}$$

Finally, for the households that do not present any food consumption, we use the regional mean values (Yen et al., 2002; Yen & Huang, 2002), given that even in the absence of consumption, households still face a price for these goods. In this case, it is assumed that the price faced by households corresponds to that of the region in which they are located.

2.3.4 Taxation policies and scenarios

After estimating consumer sensitivity to changes in food prices, we simulate different policy scenarios aimed at taxing environmentally intensive foods[14]. We establish five distinct tax scenarios (Table 2) to evaluate which tax system most efficiently achieves a reduction in environmental degradation in Brazil. In the first scenario, we assess the effectiveness of a single tax applied to beef, simulating possible values from a range of 1 to fifty percent. For the second scenario, instead of using a tax, we explore the results that would come from a subsidy in beans, fruits, vegetables, and tubers and roots, with the same range as the previous scenario. In the third scenario, we combine the instruments from the first and second scenarios, combining taxes and subsidies. The objective of these three scenarios is to penalize foods that have elevated levels of emissions, while rewarding healthy and more sustainable foods, nudging consumers toward better decisions. In the fourth scenario, we simulate a weighted tax related to the volume of GHG emissions of each food group of 0.10 BRL per $kgCO_2eq$, taxing all possible groups and not discriminating among food groups, but rather internalizing the externalities of emissions. Finally, in the fifth scenario we simulate the same tax of the fourth scenario, although discriminating against groups and taxing only foods with a CF of more than 10.0 $kgCO_2eq$ per kilogram.

Table 2. Description of System Taxes and Policy Scenarios

Scenario	Tax Method	Foods Taxed	Tax Value
(1)	Ad-Valorem Tax	Beef	Values from a range of 1-50%.
(2)	Subsidies	Beans, Vegetables, Fruits, and Tubers and Roots	Values from a range of 1-50% equally distributed for each food.
(3)	Taxes and Subsidies	Same groups of (1) and (2)	Values from a range of 1-50% equally distributed for each food.
(4)	Weighted Tax	All groups	0.10BRL per $kgCO_2eq$
(5)	Weighted Tax	Foods with more than 10.0 $kgCO_2eq$ per kg.	0.10BRL per $kgCO_2eq$

Source: Own elaboration.

[14] We assume in our scenarios a complete pass-through mechanism, in which price changes does not affect food supply and impact only the demand-side.

To assess the tax policy effect, we estimate the effect on the quantity of food demanded. The demanded level after taxes could be expressed as the difference in the number of goods consumed before and after the tax: $\Delta q = q_i^1 - q_i^0$, where the superscript 0 is the time before the tax and the superscript 1 is the moment after the introduction of the tax. Thus, following Leifert and Lucinda (2015), the variation in the quantity of food demanded after the price policy could be expressed as:

$$\Delta Q = (E^c * \Delta P^T) \quad (14)$$

where ΔQ is the vector with all the changes in the percentage of food consumed after the introduction of the tax system in the society; E^c is a matrix with the uncompensated own-price and cross-price elasticities for all food groups; and ΔP^T is a matrix with the percentage change of prices of all foods after the inclusion of the tax.

Furthermore, to assess changes in environmental quality, we build upon the framework proposed by Säll and Gren (2015), which quantify as:

$$\Delta E^q = \sum_j^n e_{ij}^q \Delta Q_j \quad (15)$$

where ΔE^q represents the environmental change following the reduction in food consumption; and e_{ij}^q is the average environmental impact value of the *i-th* food. We extend their analysis by incorporating three distinct environmental measures, assessing the environmental quality change according to the Carbon Footprint, Water Footprint, and Ecological Footprint of each food group.

2.4 Results

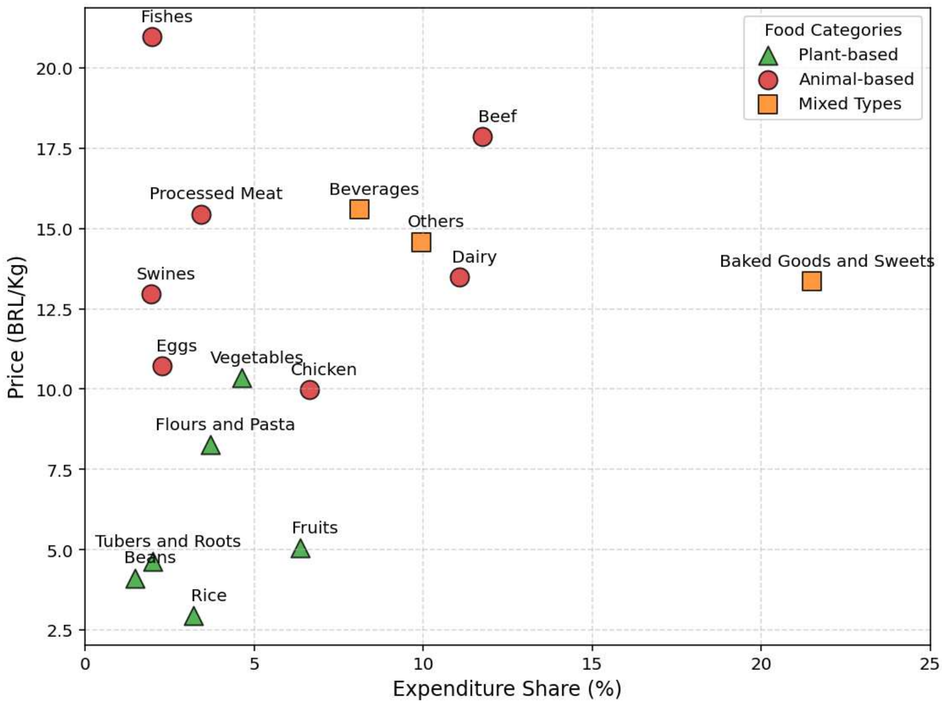
2.4.1 Descriptive Statistics

The expenditure levels and budget shares of Brazilian households and food group prices are reported in Figure 1[15]. The largest share of total food expenditure is allocated to the Baked Goods and Sweets category, which accounts for 21.49% of overall food spending, followed by Beef and Dairy, representing 12.25% and 11.17%, respectively. At the lower end of the distribution, Beans exhibits a negligible expenditure share (1.48%). Similarly, Eggs (2.26%), Tubers and Roots (2.00%), and Swine (1.95%) account for relatively small proportions of household food expenditures.

[15] Detailed values and additional information are presented in the Table 1B and Fig. 1B, at the Appendix.

Substantial heterogeneity is also observed in price levels across food categories. Fish presents the highest average price per kilogram (BRL 20.96), followed by Beef (BRL 17.75) and Beverages (BRL 15.62). In contrast, staple and healthy food items display considerably lower prices, particularly Rice (BRL 2.94), Beans (BRL 4.12), Tubers and Roots (BRL 4.63), and Fruits (BRL 5.06). These differences suggest marked variation in the cost structure of food groups, which may influence household consumption patterns and expenditure allocation.

Fig. 1. Average values of expenditure shares and price for each food group presented in the estimated demand system.



Source: Own elaboration.

When animal-based products, including Beef, Fish, Chicken, Eggs, Pork, and Dairy, are aggregated, they account for 38.45% of total food expenditure. The combined expenditure on nutritionally desirable food groups, such as Fruits, Vegetables, and Tubers and Roots, represents only 13.03% of total food spending. Consistent with these expenditure patterns, the average price of animal-based products substantially exceeds that of non-animal products[16], with average prices of BRL 14.65 and BRL 6.32, respectively. This price differential may constitute an important determinant of observed

[16] The classification of non-animal products excludes the Bread and Sweets category, as several items within this group may contain milk derivatives or other animal-based ingredients, as well as Sugar-Sweetened Beverages.

consumption choices and expenditure shares. Regarding the household characteristics (Table 3), the average household is in urban areas, with a male head of age 50 with eight years of educational level. The households contain an average of three members and an average total expenditure on food of 105.03 BRL.

Table 3. Summary of Household Characteristics

Household Sociodemographic Characteristics	Mean
Weekly Food Expenditure (R$)	105.03 (107.54)
Ln Income (R$)	8.17 (0.89)
Urban	0.86 (0.34)
North	0.07 (0.25)
Northeast	0.27 (0.44)
South	0.15 (0.36)
Middle-West	0.07 (0.26)
Household beneficiary of the *Bolsa Família* policy	0.16 (0.36)
Educational Level (in years)	8.37 (5.12)
Household Head Age	50.29 (15.65)
Female Household Head	0.41 (0.49)
Share of individuals with less than 9 years	0.29 (0.45)
Share of individuals with more than 9 years and less than 15 years	0.19 (0.39)
Share of individuals with more than 14 years and less than 18 years	0.13 (0.34)
Share of individuals with more than 60 years	0.34 (0.47)
Total number of household members	3.08 (1.53)

Source: Own elaboration.

Note: Standard Deviation between parentheses.

2.4.2 Household Food Environmental Impact

Table 4 details the weekly environmental characteristics of household food acquisition, presenting both aggregate footprints and per-kilogram environmental footprints across food groups. On average, households presented a weekly footprint related to food of 72.35 kgCO_2eq of emissions, 64,196.26 liters of water use, and 488.52 g-m^2 of land use. Converting these metrics, Brazilian households have an average per capita 1.22 tCO_2eq of emissions, 1.08 million liters of water, and 8,247.7 g-m^2 yearly.

Comparatively, in European countries, household per capita emissions related to foods were not higher than 0.5 tCO_2eq in 2018 (Barrutiabengoa et al., 2022), almost half of Brazilian household's food emissions.

Table 4. Environmental characteristics of Household Food Acquisition, per week.

Weekly Total Environmental Footprints			
Total Carbon Footprint ($kgCO_2eq$)			72.35 (83.51)
Total Water Footprint (Liters)			64,196.26 (68,134.15)
Total Ecological Footprint (g-m^2)			488.52 (574.02)
Food Groups	**CF (kgCO2eq) per kg**	**WF (Liters) per kg**	**EF (g-m2) per kg**
Rice	1.07	648.03	5.29
Beans	0.37	1,416.33	3.88
Flours and Pasta	1.84	1,463.93	8.53
Beef	35.57	22,877.76	156.05
Swine	6.41	10,568.23	55.86
Fish	12.94	489.21	333.14
Chicken	4.55	6,318.79	36.11
Eggs	3.44	3,166.98	21.64
Dairy	4.72	3,637.44	33.48
Processed Meat	13.73	15,256.01	60.46
B. Goods and Sweets	2.31	1,947.16	12.44
Vegetables	0.51	1,094.59	4.16
Fruits	0.85	3,637.35	6.13
Tubers and Roots	0.41	910.64	4.44
Beverages	0.38	868.34	8.66
Others	4.68	5,015.21	34.28

Source: Own elaboration.

Note: Standard Deviation between parentheses.

Furthermore, the high standard deviations indicate a heterogeneous dietary preference, where a substantial number of households are likely to acquire environmentally intensive foods. Moreover, regarding each group's environmental pressure, we highlight animal-based foods, specifically meats, with the highest values of Carbon, Water, and Ecological Footprint. For Beef, the average level of emissions is 35.57 $kgCO_2eq$ per kilogram, while Fruits, Vegetables, and Tubers and Roots exhibit less than 1.0 $kgCO_2eq$ per kilogram. Thus, traditional staple foods such as Rice, Beans, Vegetables, and Tubers and Roots consistently display minimal footprints compared to animal products.

We underscore fish as the group with the highest value of Ecological Footprint, almost 333.14 g-m^2, more than double that of the second highest group, Beef, with 156.05

g-m². On the other hand, Fish have the lowest Water Footprint, of only 489.21 Liters of water, followed by Rice, with 648.03. Beef and Processed Meat have extremely high water footprints compared to the other food groups (22,877.76 and 15,256.01 Liters, respectively).

2.4.3 Estimated Elasticities

Our initial estimates relate to the expenditure elasticities for all food groups within our demand system (Table 5). It is crucial to highlight that all estimated coefficients are statistically significant at the 1% level ($p < 0.01$). We underscored Beef with the highest elasticity (1.424), as the food group most sensitive to expenditure changes. Furthermore, meat consistently demonstrated the highest elasticities, regardless of animal origin. Interestingly, traditional staple foods, such as Rice (1.164), Beans (1.114), and Flours and Pasta (1.142), exhibit expenditure elasticities greater than unity, implying that household expenditure on these foundational items increases more than proportionately with expenditure growth. Only five groups yielded elasticities lower than one. Specifically, Eggs, Baked Goods and Sweets, Vegetables, and Beverages are characterized as necessity goods, given their positive but inelastic responses to expenditure changes, while the group with other foods and beverages presented a negative elasticity (-0.163).

Table 6 presents the average estimated uncompensated own-price and cross-price elasticities from the final specification, after all procedures of endogeneity and censored data corrections. All own-price elasticities have a value lower than zero, with a normal behavior of the price-demand relationship for all food groups. The most price-sensitive group is Fish, with an own-price elasticity of -2.69, followed by Eggs (-1.91), and Swine (-1.83). Meanwhile, only two groups present inelastic behavior, which are Beans (-0.41) and Beef (-0.95). All other food groups have own-price elasticities values between 1 and 1.5.

The results also reveal a dense network of statistically significant cross-price elasticities, highlighting the high degree of interdependence within the consumers' basket and preferences. We underscore a high predominance of positive coefficients, suggesting that most food categories act as substitutes. In this context, the significant cross-price effects of Beverages on fruits, vegetables, and tubers and roots indicate that taxation could effectively nudge consumers towards healthier alternatives. Moreover, Vegetables present a positive cross-price elasticities for almost all meat groups, highlighting a substitutional relationship between these groups. Simultaneously, Fruits, Vegetables, and

Tubers and Roots present all negative coefficients between them, highlighting their complementary relationships where a price increase in one category inadvertently suppresses demand in another.

Table 5. Average estimated Expenditure Elasticities for each food group.

Food Groups	Mean
Rice	1.152*** (0.014)
Beans	1.113*** (0.019)
Flours and Pasta	1.130*** (0.012)
Beef	1.422*** (0.009)
Swine	1.346*** (0.022)
Fish	1.315*** (0.018)
Chicken	1.368*** (0.011)
Eggs	0.852*** (0.019)
Dairy	1.137*** (0.009)
Processed Meat	1.300*** (0.014)
Baked Goods and Sweets	0.336*** (0.006)
Vegetables	0.895*** (0.013)
Fruits	1.026*** (0.012)
Tubers and Roots	1.060*** (0.018)
Beverages	0.960*** (0.010)
Other Foods and Beverages	-0.380*** (0.025)

Source: Own elaboration.

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$. Standard errors are in parentheses.

On the other hand, among animal-based groups, we observe that Eggs seem to be a substitute for Beef, Swine, and Fish, meanwhile Fish is the only group among meats with a positive elasticity effect among other meat group, underscoring a substitutive consumption. The widespread effect and significance across the matrix imply that any simulation of tax scenarios must account for these complex spillover effects, as a unilateral price shock will inevitably trigger a systemic reallocation of consumption that could either amplify or offset the intended policy outcomes.

Table 6. Uncompensated Own-Price and Cross-Price elasticities. Stone Price Index.

P/Q	Rice	Beans	Flours	Beef	Swine	Fish	Chicken	Eggs	Dairy	P. Meat	B&S	Vegetables	Fruits	T&R	Beverages	Others
Rice	-1.334***	-0.469***	-0.204***	-0.232***	0.475***	0.185***	0.125***	0.216***	-0.042***	-0.017	0.128***	-0.015	0.131***	0.181***	0.115***	-0.397***
	(0.047)	(0.029)	(0.020)	(0.038)	(0.052)	(0.039)	(0.038)	(0.030)	(0.015)	(0.029)	(0.021)	(0.017)	(0.024)	(0.022)	(0.013)	(0.021)
Beans	-0.778***	-0.409***	-0.305***	0.084	-0.233***	0.647***	0.109**	0.136***	-0.017	0.018	0.001	-0.054**	0.021	-0.026	0.086***	-1.168***
	(0.049)	(0.061)	(0.028)	(0.052)	(0.076)	(0.055)	(0.052)	(0.041)	(0.020)	(0.044)	(0.029)	(0.023)	(0.032)	(0.032)	(0.016)	(0.054)
Flours	-0.251***	-0.227***	-1.073	-0.003	0.251***	0.119***	0.051*	-0.018	0.063***	0.048***	0.060***	-0.024*	-0.019	-0.013	0.036***	-0.601***
	(0.024)	(0.021)	(0.019)	(0.028)	(0.036)	(0.030)	(0.027)	(0.022)	(0.012)	(0.018)	(0.015)	(0.013)	(0.017)	(0.014)	(0.010)	(0.036)
Beef	-0.104***	0.019	-0.011	-0.950***	-0.115***	-0.001	-0.092***	0.057***	-0.082***	-0.043***	-0.109***	-0.025***	-0.017	0.001	-0.030***	0.020
	(0.016)	(0.013)	(0.009)	(0.027)	(0.024)	(0.020)	(0.018)	(0.015)	(0.008)	(0.012)	(0.011)	(0.009)	(0.011)	(0.010)	(0.007)	(0.026)
Swine	0.345***	-0.109***	0.138***	-0.236***	-1.838***	0.727***	-0.069*	0.055	-0.136***	-0.105***	-0.007	0.021	0.009	-0.036	-0.058***	-0.667***
	(0.039)	(0.034)	(0.022)	(0.043)	(0.079)	(0.049)	(0.041)	(0.035)	(0.018)	(0.029)	(0.024)	(0.019)	(0.025)	(0.022)	(0.015)	(0.076)
Fish	0.113***	0.252***	0.052***	-0.023	0.641***	-2.693***	-0.009	0.082***	0.062***	0.076***	-0.083***	0.030**	-0.106***	0.045***	0.038***	1.309***
	(0.026)	(0.022)	(0.016)	(0.032)	(0.043)	(0.046)	(0.031)	(0.025)	(0.015)	(0.021)	(0.018)	(0.015)	(0.020)	(0.017)	(0.013)	(0.056)
Chicken	0.071***	0.038**	0.016	-0.128***	-0.037	0.007	-1.440***	-0.003	-0.046***	-0.019	-0.062***	0.022*	-0.021	0.008	0.014	0.249***
	(0.023)	(0.019)	(0.013)	(0.026)	(0.033)	(0.028)	(0.035)	(0.020)	(0.011)	(0.016)	(0.014)	(0.011)	(0.015)	(0.013)	(0.009)	(0.039)
Eggs	0.261***	0.100***	-0.007	0.211***	0.105*	0.166***	0.029	-1.906***	-0.123***	0.024	0.113***	0.034*	-0.025	-0.032	0.091***	0.915***
	(0.034)	(0.029)	(0.020)	(0.041)	(0.054)	(0.044)	(0.038)	(0.046)	(0.018)	(0.028)	(0.023)	(0.018)	(0.025)	(0.021)	(0.015)	(0.059)
Dairy	-0.022**	-0.004	0.038***	-0.076***	-0.093***	0.099***	-0.018	-0.088***	-1.237***	0.132***	-0.012	0.002	-0.002	0.003	0.029***	-0.019
	(0.011)	(0.008)	(0.007)	(0.014)	(0.017)	(0.016)	(0.012)	(0.010)	(0.009)	(0.007)	(0.007)	(0.006)	(0.008)	(0.006)	(0.006)	(0.014)
P. Meat	-0.025	0.011	0.038**	-0.120***	-0.153***	0.146***	-0.039	0.011	0.198***	-1.486***	-0.088***	0.046***	-0.007	0.018	-0.009	0.355***
	(0.034)	(0.031)	(0.017)	(0.034)	(0.046)	(0.039)	(0.031)	(0.028)	(0.013)	(0.034)	(0.018)	(0.014)	(0.019)	(0.017)	(0.011)	(0.042)
B&S	0.102***	0.017*	0.060***	0.053***	0.051***	0.002	0.065***	0.057***	0.083***	0.008	-1.056***	0.061***	0.105***	0.039***	0.061***	0.158***
	(0.011)	(0.009)	(0.006)	(0.013)	(0.016)	(0.014)	(0.012)	(0.010)	(0.006)	(0.008)	(0.010)	(0.006)	(0.008)	(0.006)	(0.005)	(0.013)
Vegetables	-0.006	-0.034**	-0.013	0.002	0.064**	0.089***	0.090***	0.040***	0.026**	0.066**	0.090***	-1.149***	-0.138***	-0.174***	0.057***	0.433***
	(0.021)	(0.017)	(0.013)	(0.025)	(0.031)	(0.028)	(0.023)	(0.020)	(0.011)	(0.015)	(0.014)	(0.016)	(0.015)	(0.012)	(0.010)	(0.025)
Fruits	0.124***	0.015	-0.009	0.020	0.038	-0.115***	0.004	-0.028	0.007	0.009	0.100***	-0.105***	-1.238***	-0.101***	0.051***	0.269***
	(0.021)	(0.017)	(0.012)	(0.024)	(0.030)	(0.027)	(0.022)	(0.019)	(0.010)	(0.014)	(0.013)	(0.010)	(0.019)	(0.011)	(0.009)	(0.023)
T&R	0.321***	-0.025	-0.016	0.036	-0.066	0.138***	0.041	-0.055*	0.009	0.035	0.072***	-0.254***	-0.203***	-1.330***	0.068***	0.241***
	(0.039)	(0.034)	(0.020)	(0.040)	(0.051)	(0.045)	(0.037)	(0.032)	(0.016)	(0.025)	(0.022)	(0.017)	(0.022)	(0.025)	(0.014)	(0.028)
Beverages	0.110***	0.050***	0.033***	0.012	-0.035*	0.083***	0.064***	0.060***	0.053***	0.012***	0.024***	0.036***	0.055***	0.037***	-1.472***	0.478***
	(0.011)	(0.009)	(0.007)	(0.015)	(0.018)	(0.017)	(0.013)	(0.011)	(0.007)	(0.008)	(0.008)	(0.007)	(0.009)	(0.007)	(0.009)	(0.009)
Others	-0.247***	-0.511***	-0.309***	0.268***	0.213***	1.585***	0.463***	0.636***	0.141***	0.287***	0.434***	0.330***	0.326***	0.138***	0.527***	-3.902***
	(0.016)	(0.025)	(0.022)	(0.047)	(0.073)	(0.065)	(0.049)	(0.039)	(0.016)	(0.027)	(0.021)	(0.016)	(0.020)	(0.012)	(0.008)	(0.076)

Source: Own elaboration.

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$. Standard errors are between parentheses.

2.4.4 Tax Scenarios

We present at Table 7 the summarized results for all tax scenarios[17]. In the first scenario, we simulated the effect of applying an *Ad-Valorem* tax to beef, with rates ranging from 1% to 50%. We observed a significant reduction in the quantity acquired of these products as the tax rate increases. Beef demonstrates a robust decline, dropping from approximately 0.93 kg to almost 0.5 kg per week with a 50% tax. At a 20% tax threshold, the acquisition of beef experiences a weekly sharp reduction of 19.0%. We highlight that while the demand for beef products declines, other food groups, such as Eggs, show a slight upward trend, suggesting that consumers may be reallocating their budgets toward cheaper, non-taxed categories. Moreover, we observed that Rice, Swine and Processed Meat presented a considerable drop, reducing its acquisition as the tax on beef increases.

Moreover, we present the environmental impacts of this scenario, measured through changes in the Carbon Footprint, Water Footprint, and Ecological Footprint that result from the households' new consumption patterns. Our simulation demonstrates a direct and linear correlation between the implemented tax level and the reduction of all environmental burdens associated with food consumption. As the proposed tax on beef and dairy increases, the total reduction in footprints also increases, underscoring the effectiveness of this policy in mitigating environmental externalities. In this tax system boundary, at the maximum tax level, the reductions in emissions could achieve almost 15.5kgCO_2eq (approximately a reduction of 21.4% of the total), meanwhile water and land waste reduced by 9,857.8L (14.5%) and 67.6g-m^2 (13.8%), respectively. At the 20% tax threshold, the policy already achieves significant environmental gains, highlighting a reduction of 6.2kgCO_2eq (8.33%) in the Carbon Footprint, alongside a 27.0g-m^2 (5.5%) decrease in the Ecological Footprint. Furthermore, the impact on Water Footprint is particularly striking, with a reduction of almost 3,943 liters of water per household (5.8%). These results suggest that targeting high-impact animal-based products can be a powerful instrument for achieving climate mitigation goals within the agricultural sector in Brazil.

In the second scenario, we estimated the effect of subsidies on Beans, Vegetables, Fruits, and Tubers and Roots, varying from 1% to 50%. By implementing a subsidy on

[17] Additional information is available at Appendix B.

these essential, plant-based categories, our simulated scenario reveals a significant upward trajectory in their acquired quantity. Fruit acquisition increases from 1.8 kg to over 3.1 kg at the 50% subsidy level. Additionally, at the 20% threshold, we observe a robust growth of 28.6%. In addition, at this subsidy level, Vegetables and Tubers and Roots show increases of 29.9% and 36.2%, respectively. The acquisition of beans increased by 9.4%, the lowest in the group. Furthermore, the acquisition of vegetables rises from about 0.9 kg to almost 1.6 kg, while tubers and roots increase from 0.7 kg to 1.3 kg at the maximum subsidy level. We emphasize that these categories are highly price-sensitive, making subsidies an effective tool for promoting a higher intake of these healthy foods. Moreover, we observed a complementary effect across non-subsidized groups. Categories like Rice and Flours present an upward trend, with consumption increasing as the subsidy rises. Meanwhile, the quantity of animal-based products remains remarkably stable. This indicates that, within this model, the budget saved from subsidized plant-based goods may be reallocated toward specific or essential items rather than triggering a universal increase in the consumption of other food groups.

Regarding the environmental impacts of the subsidy, the new consumption patterns presented environmentally ambiguous results. The simulation that we made shows an increase in emissions and water waste, with an increase of about 0.4kgCO_2eq (0.4% of household total footprint) and 4,651.5 liters (6.8%) with a 50% subsidy. Meanwhile, we underscored a decrease in land use, by almost 3.7 g-m^2 (0.8%) at the maximum level of subsidies. At the 20% threshold, the policy still presents irrelevant results, increasing emissions by 0.1kgCO_2eq (0.2%) and reducing land waste by 1.5g-m^2 (0.3%), concurrently with an increase in water use of 1,861 liters (2.7%). To reduce environmental pressure from food consumption, subsidies in low-intensive groups seem to be inefficient.

Table 7. Impacts by Food Group, Environmental Footprint, and Net Fiscal Result across all scenarios.

Food Group	Scenario 1 Beef Tax	Scenario 2 Veggies Subsides	Scenario 3 Taxes and Subsidies	Scenario 4 Weighted Tax	Scenario 5 Selected Weighted Tax
1. Changes in food consumption (%)					
Rice	-4.64%	+3.44%	-1.20%	-6.5%	-3.6%
Beans	+1.67%	+9.35%	+11.04%	-2.1%	+5.8%
Flours and Pasta	-0.06%	+5.66%	+5.60%	-2.6%	+1.1%
Beef	-19,0%	+0.43%	-18.56%	-20.9%	-19.3%
Swine	-4.72%	+2.30%	-2.42%	-11.6%	-1.1%
Fishes	-0.46%	-4.42%	-4.88%	-8.1%	-16.4%
Chicken	-2.55%	-0.94%	-3.50%	-8.6%	-2.7%
Eggs	+4.21%	-1.54%	+2.68%	+3.7%	+5.4%
Dairy	-1.51%	+0.02%	-1.50%	-5.0%	+0.3%
Processed Meat	-2.39%	-1.35%	-3.76%	-13.9%	-14.7%
Baked Goods & Sweets	+1.06%	-4.44%	-3.38%	+1.6%	+1.1%
Vegetables	+0.04%	+29.90%	+29.94%	+2.6%	+1.2%
Fruits	+0.40%	+28.5%	+28.98%	-0.8%	-0.2%
Tubers and Roots	+0.72%	+36.24%	+36.96%	+2.0%	+1.9%
Beverages	+0.32%	-3.56%	-3.32%	+3.2%	+0.9%
Others	+5.36%	-5.66%	-0.30%	+10.5%	+17.7%
2. Changes in environmental footprints (%)					
Carbon Footprint	-8.33	+0,18%	-8.15%	-10.52%	-7.97%
Water Footprint	-5.80%	+2.74%	-3.06%	-7.74%	-4.81%
Ecological Footprint	-5.54%	-0.31%	-5.84%	-7.89%	-6.20%
3. Net Fiscal Result (BRL per household/yearly)					
Tax Burden	+138.32 BRL (Revenue)	-318.24 BRL (Deficit)	-179.92 BRL (Deficit)	+346.32 BRL (Revenue)	+167.96 (Revenue)

Source: Own elaboration.

Note: Scenarios 1, 2, and 3 fixed at the 20% threshold (1–50% range). Scenarios 4 and 5 are based on a tariff of 0.10 BRL/kg CO_2eq. Additional information about the simulated scenarios is available at Appendix B.

In the third scenario, we estimated the effect of combining taxes on Beef with subsidies on Beans, Vegetables, Fruits, and Tubers and Roots, with rates varying from 1% to 50%. The changes in the volume of kilograms per household for each group are similar to those observed in previous scenarios, with the addition that the subsidy for healthy groups offsets the substitution effect of the taxes. This results in a reduction in the acquisition of Beverages, rather than an increase as seen in the first scenario. Fruits Tubers and Beans appear to benefit slightly more from this combination compared to the second scenario. Additionally, the taxed groups exhibit a slightly softened downward trend, presenting a smaller decrease in the quantity of food acquired when compared to the first scenario.

Furthermore, regarding the environmental outcomes of this combined tax and subsidy approach, we observed that the magnitude of the effect largely follows the same downward trend as the first scenario. These results suggest that levying a tax on Beef leads to an overall reduction in water footprint, even when accounting for the subsidy on plant-based products, which individually increased water usage in the second scenario. For environmental purposes, this scenario successfully achieves its goal of enhancing sustainability indicators.

In this combined system, at the maximum tax and subsidy rates, the reduction in emissions reaches 15.2 kgCO2eq (20.4% of household total footprint), while the reductions in water and land use also show significant improvements of 5,236.4 L (7.7%) and 71.3g-m^2 (14.6%), respectively, which are values close to the presented in the first scenario. Using the threshold of 20% tax and subsidy, we observe effective environmental gains highlighting a reduction of 6.1kgCO_2eq (8.2%) in the Carbon Footprint, alongside a decrease of 28.5g-m^2 (5.8%) in the Ecological Footprint and a decrease of 2,083L (3.1%) on Water Footprint.

In the fourth scenario, we proposed assessing the effect of a weighted tax of 0.10 BRL per KgCO_2eq on each food group. By implementing this tax, we observed an overall increase in prices, especially for animal proteins, with a highlight for Beef, with an increase of 19.9%. Processed Meat and Fish also presented the second and third highest price increase, with 8.9% and 6.2%, respectively. Other food groups presented increments of between 1% and 5%, except Beans, Vegetables, Tubers and Beverages.

The volume of food acquired changes drastically in this scenario. By implementing the weighted tax, we observed that Beef and Processed Meat are the two groups with the most sharpened drops in total acquisition (20.9% and 13.9%, respectively). We underscore that using this weighted tax, every food is affected by it, whereas only six groups did not present a drop in their total acquisitions. The group with the highest benefit from this tax system is the other foods and beverages, which appear to have an increase in their acquisition of almost 10.5%, followed by Eggs (3.7%), Beverages (3.2%), Vegetables (2.6%), Tubers (2.0%) and Baked Goods (1.6%). Meanwhile, Rice and Beans exhibited a decrease of 6.5% and 2.1%, respectively. We observed in this scenario that, even considering an overall increase in food prices, specific groups would benefit more from it, increasing their acquisition.

Environmental outcomes from this scenario presented a relevant drop in every indicator. We underscore the decrease in emissions of 7.8 kgCO2eq (10.5% of total footprints), water waste by 5,261.6 L (7.7%), and land use of 38.6 g-m^2 (7.9%). These results suggest that the use of a weighted environmental tax could effectively internalize part of the environmental damage provided by food production, exhibiting an effective outcome for environmental purposes, achieving its main goal.

Finally, in the fifth and last scenario, we explored the effect of the weighted tax of 0.10 BRL only for food groups with more than 10.0 kgCO_2eq per kilogram (Beef, Processed Meat, and Fish). The direct impact on prices for tax-targeted categories is the same as the previous scenario, where Beef experienced the highest increase at 19.9%, followed by Processed Meat at 8.9%, and Fishes at 6.2%. As this tax policy is strictly isolated to these high-emission categories, all other food groups remained completely unaffected in terms of pricing, showing a 0.0% change.

However, despite prices remaining stable for most items, we observed a ripple effect across the newly acquired quantities in this scenario. Looking directly at the taxed groups, Beef seemed to have the sharpest effect, decreasing by 19.3%, less than before; meanwhile, Fish demonstrated a higher decrease compared to the previous scenario (16.4%), close to Processed Meat, which decreased near to 14.7% in total acquisition. Only three non-taxed products showed a decrease in the overall acquisition, probably due to their complementarity with the taxed products. Rice is the most affected group, with a decrease of 3.6%, followed by Chicken (2.7%) and Swine (1.1%). We also underscore the difference in the quantity of Beans acquired by the households, which increases by 5.8% after the taxes, close to Eggs (5.4%). Other foods and beverages presented a sharp increase in their acquisitions, of almost 17.7%.

In this last scenario, the change in the environmental indicators follows the same pattern presented in the previous scenario. The difference in this scenario is strictly in magnitude, with an overall lower reduction in carbon, water, and ecological footprint. We underscore the decrease in emissions of 5.9 kgCO2eq (8.0% of total footprints), water waste by 3,270.3 L (4.8%), and land use of 30.3 g-m^2 (6.2%). These results highlight that focusing on specific high emitter groups, the aggregate effect of a tax may be effective, reducing the environmental burden and internalizing the externalities that come from these groups.

To evaluate the consumers' acceptance of these fiscal policies, we calculated the tax burden for each specific proposed scenario. Assessing the initial three scenarios we underscore distinct economic impacts. Implementing a tax-only policy at a 20% threshold would result in an estimated annual financial burden of 138.32 BRL per household, achieving its plateau at almost 50%. In contrast, applying a 20% subsidy strictly to sustainable food groups represents a substantially higher financial commitment, driving the annual policy cost to almost 318.24 BRL per household. Particularly, a mixed policy framework that combines both taxation and subsidies at the same 20% threshold proves to be the most economically balanced approach in these three scenarios. Combining both taxes and subsidies, the policy cost would be 179.92 BRL per household per year, at the same 20% threshold. The third scenario effectively mitigates the overall economic impact, yielding a reduced net policy cost for households while promoting better environmental and social performance.

Moreover, we calculated the tax burden for the possibilities of a weighted tax, as proposed in the fourth and fifth scenarios. The scenario, which is applied to every food group, without discrimination, we calculated an overall tax burden of 346.32 BRL per year for each household; meanwhile, for the alternative scenario taxing only high emitter foods, the tax burden is nearly 167.96 BRL yearly, almost half of the value. In the fourth scenario, almost 40% of the tax burden comes from the taxes on Beef, while the second major value comes from Dairy (approximately 15.0%), highlighting the relevance of these two food groups to the overall revenue. Meanwhile, at the fifth scenario, only three groups are taxed, but the contribution of Beef taxes to the overall tax burden achieves 82.2%, as Processed Meat contributes 12.1% and Fish only 6.5%.

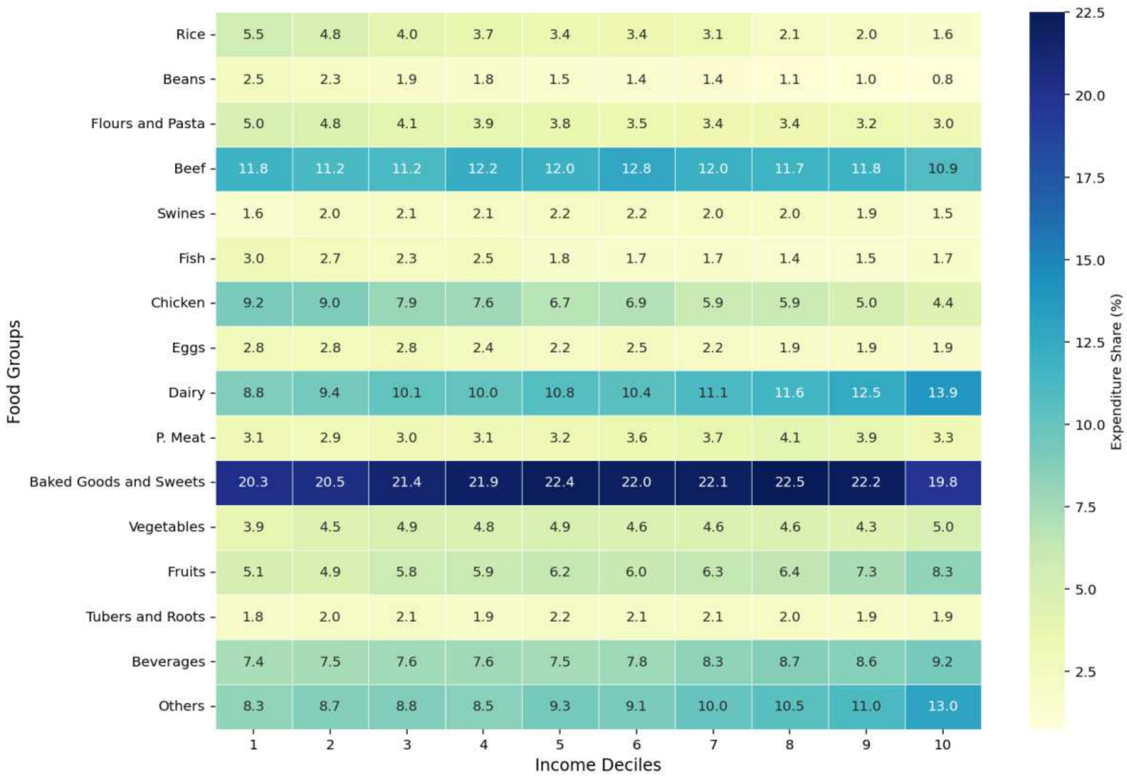
Comparing all scenarios, we assessed effective policies that aimed to reduce overall environmental impact, lowering emissions, water, and land waste. The scenario that presented the highest reductions is the fourth one, using a weighted tax of 0.10 BRL per kgCO_2eq with the goal of internalizing the externalities from the food sector. However, in this scenario, we account for a total taxation policy, increasing the prices of every food group, carrying the highest tax burden among all scenarios, which could sound extremely regressive for society, increasing inflation and going against specific groups of interest. In addition, this approach may increase the high complexity in the Brazilian current tax system (Hoppe et al., 2023; Nunes, 2025). Moreover, adding a new technical layer of taxes to be paid might increase tax evasion. In the scenario where the policy only subsidizes sustainable foods (second scenario), even if it could sound popular and socially welcomed by society, we observed almost a null effect on emissions and land use, in addition to a relevant increase in water use. Thus, midterm scenarios, such as the one combining taxes and subsidies, or only taxing high-emitter groups, seemed to be more plausible, relying on the effectiveness of reducing environmental damage while promoting alternative options for consumers.

2.4.5 Income Heterogeneity

We also propose expanding our findings for households through different income groups. In Figure 2, we show the expenditure on food share distribution between all 16 food groups among 10 different income groups, where the first decile is the lowest income and the tenth decile is the highest income group. We observe heterogeneous distributional behavior across food groups. Specifically, for Dairy products, we observe the highest increase in food expenditure share, rising from 8.8%, at the lowest group, to 13.9% at the highest. Moreover, Fruits and Beverages also underscore an increase in their expenditure share across income groups. On the contrary, Rice loses relevance, decreasing from 5.5% to 1.6%, meanwhile Chicken and Beans also experience a declining share in household food expenditure.

Baked Goods and Sweets dominates budget allocation across the entire population, remaining the single largest expenditure category for every income decile (ranging from 19.8% to 22.5%). In addition, Beef represents a remarkably stable share of food expenditure across all income brackets, oscillating between 10.9% and 12.8%. This reflects the strong cultural centrality of beef in Brazilian diets regardless of household income, peaking in middle-to-upper deciles. Because lower-income deciles spend a higher proportion of their budget on staples and chicken, regressive taxes on basic foodstuffs would disproportionately burden poor families. Conversely, taxing high-carbon items like beef would impact budget shares relatively evenly across all income groups.

Fig. 2. Expenditure shares heat-map according to income deciles and food groups.



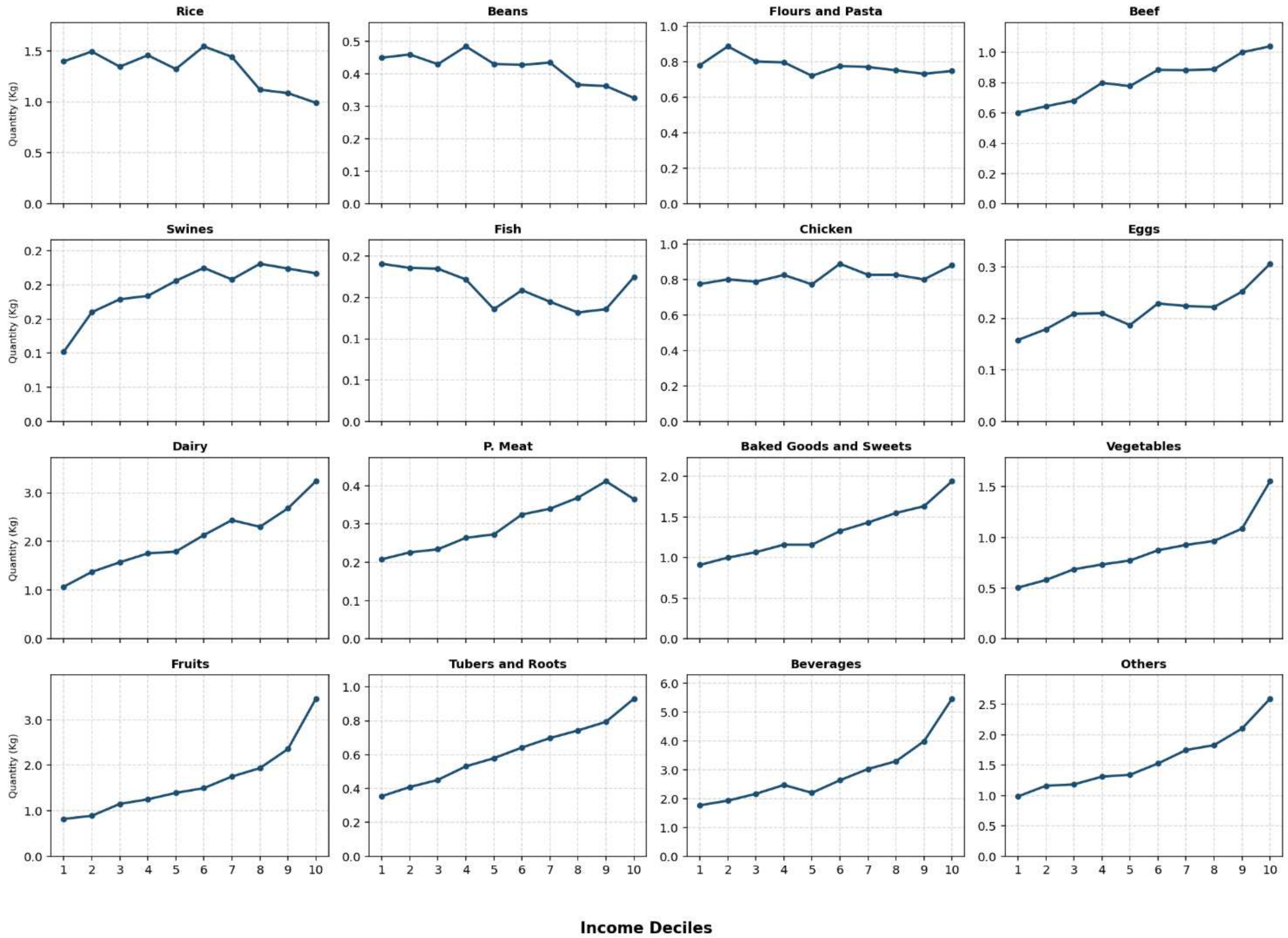
Source: Own elaboration.

Note: Deciles varying from 1 to 10, where 1 is the lowest and ten the highest decile.

Looking at the quantity (in kilograms) of food purchased by income groups, we highlight an extremely heterogeneous behavior (Fig. 3). Wealthier families acquire much more specific foods than lower-income households. Specifically, Fruits is the group with the highest overall increase, followed by Beverages, Vegetables and Dairy. All these groups presented increases of almost 200%, meanwhile stable foods such as Rice and Beans presented a reduction in their acquisition. Regarding animal-based proteins, richer households increase mainly the consumption of Beef, meanwhile other groups kept stable across income groups.

We also evaluated household environmental footprint across income deciles aiming to assess how these indicators change between groups (Fig. 4). Our three panel charts demonstrate a strong, positive correlation between household income deciles and total dietary environmental impacts across all evaluated metrics. As households move from the lowest to the highest income decile, their environmental burden nearly doubles across every indicator. Specifically, the carbon footprint increases from approximately 48.0 kgCO_2eq to over 91.0 kgCO_2eq, while the water footprint escalates from around 42.0 liters to nearly 89.0 liters. Similarly, the ecological footprint expands from roughly 328.0 g-m^2 to over 605.0 g-m^2.

Fig. 3. Food acquisition gridline according to income deciles and food groups.

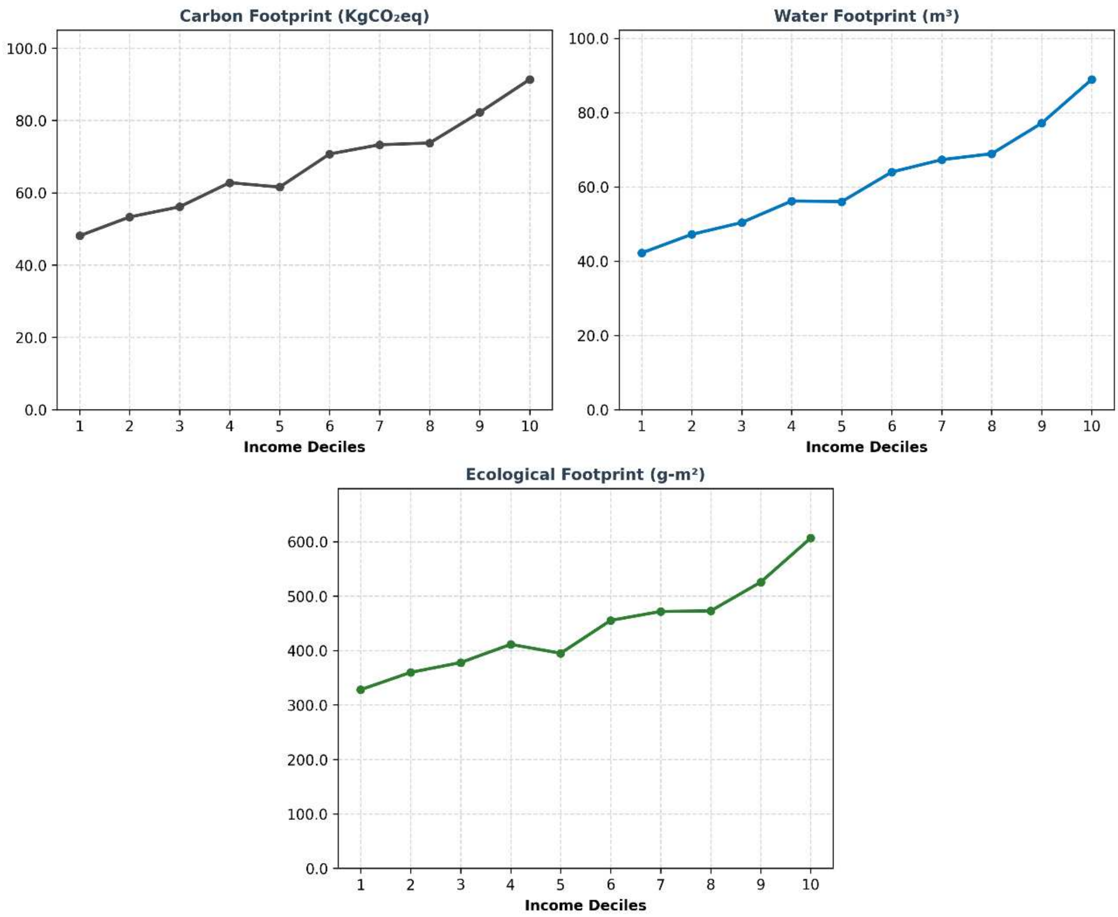


Source: Own elaboration.

Note: Deciles varying from 1 to 10, where 1 is the lowest and ten the highest decile.

In summary, the analysis of income heterogeneity underscores the critical interplay between socioeconomic status, dietary composition, and environmental impact in Brazil. While lower-income households spend a higher proportion of their budget on basic staples, higher-income groups consume substantially larger physical quantities of high-footprint foods such as beef, dairy, and beverages, driving aggregate carbon, water, and ecological footprints to nearly double from the lowest to the highest decile.

Fig. 4. Average environmental indicators according to income deciles.



Source: Own elaboration.

Note: Deciles varying from 1 to 10, where 1 is the lowest and ten the highest decile.

2.5 Discussion

We presented relevant findings for policy makers which goals align with climate change agendas, mainly those correlated to Sustainable Development Goal 12, Sustainable Consumption and Production. Our results show a clear link between the employment of taxes to reduce the pressure that the agrifood sector has on the environment. Previous literature also exploits this link, suggesting that taxes on food could be an effective instrument to mitigate environmental damage (Cleghorn et al., 2022; Forero-Cantor et al., 2020; Larsson et al., 2026; Mardones & Andaur, 2024; Moberg et al., 2021; Plinke et al., 2026; Säll et al., 2020; Springmann, Dinivitzer, et al., 2025).

In Europe, Plinke et al. (2026) suggest an overall decrease in emissions of 3.5% to almost 6% after removing the current VAT reduction on meat products. Moreover, in Sweden, Moberg et al. (2021) highlight that taxing animal products could reduce emissions by almost 8%; meanwhile, Larsson et al. (2026) suggest a 6% decrease. In New Zealand, Cleghorn et al. (2022) suggest that tax reforms on foods could reduce emissions between 4 and 7%. These previous results are strictly aligned and consistent with our findings, even though the tax effect is slightly superior for the Brazilian case, which could be explained by the prominent and higher meat consumption in Brazil (Crippa et al., 2021; FAO, 2022).

Moreover, we exhibited that households have an average yearly emission of 3.76 tCO_2eq, which is extremely close to the findings of Cachola & Pacca (2023), highlighting that families in Brazil have an average annually emission of 3.73 tCO_2eq. Thus, taxes (at a 20% maximum) can effectively reduce domiciliary emissions from 8 to 11% in a year (0.30 to 0.41 tCO_2eq per household), which represents a meaningful effect reducing household's environmental burden.

However, standalone taxation policies frequently face significant public resistance and low political acceptability due to the direct financial burden they impose on consumers (Ejelöv et al., 2025; Larsson et al., 2026; Siegerink et al., 2024), which could be even worse for low-income households (Klenert et al., 2023; Ranganathan et al., 2016). Moreover, we must emphasize that promoting tax policies, which consequently increase food prices, is specifically critical for nations like Brazil, as it could strengthen further food insecurity. This may happen as part of the tradeoff between a higher environmental sustainability and less social equality (lower accessibility to foods), going against the goals of sustainable development (IPCC, 2023). Thus, considering the aggregate levels of inequality in Brazil, increasing prices to compensate environmental impacts from agrifood systems may be severely worse for low-income households (Tavares et al., 2024). Nevertheless, tax policies are not necessarily ineffective in promoting better social outcomes aligned with economic and environmental goals.

To overcome this inequality barrier and prevent regressive economic impacts, a mixed fiscal strategy becomes essential (Forde et al., 2025). Combining environmental taxes on high-emitter foods with subsidies for sustainable alternatives not only mitigates the overall cost for households but also creates a dual-incentive structure (Klenert et al., 2023; Siegerink et al., 2024). This combined approach discourages environmental damage while actively making sustainable choices more accessible and affordable (Forde et al., 2025; Roche, 2025). In specific cases, the policy may become even more efficient and effective (Cleghorn et al., 2022; Gren et al., 2021; Latka et al., 2021; Thow et al., 2014).

In Brazil a combined tax/subsidy system was already analyzed for the case of healthy and unhealthy foods, enhancing the policy goals to achieve better health outcomes, and preserving social equity (Julião et al., 2024; Pereda et al., 2024). Our main contribution to the literature is presenting the combined tax system approach for high-emitters and sustainable foods. In the third scenario, we presented a significant drop in footprints concurrently with an increase in the consumption of alternatives and sustainable products, suggesting a well-distributed balance between acquired foods, while reducing environmental impact. Thus, combining taxes and subsidies in Brazil may promote better environmental food policies in addition to healthier choices.

Furthermore, policymakers could go further in translating this combined system framework into more social policies within the Brazilian context. Considering the average tax burden calculated in the scenarios, it may be possible to promote subsidies only for low-income households registered through the Brazilian National Registry for Social Programs (*CadÚnico)*. While a baseline environmental tax could be applied to high-emitter foods at the retail level for the general population, households registered in *CadÚnico* could receive an additional, targeted financial incentive to purchase specifically sustainable foods. This could be operationalized through green cash transfers integrated into established welfare programs like *Bolsa Família*, improving the mechanisms of the program and fulfilling its previous limitations to promote better nutritional status of the population (Maciel & Duarte, 2023; Magalhães et al., 2024; Neves et al., 2022). Thus, linking environmental taxation with targeted social welfare creates a politically viable pathway for a just transition, empowering economically vulnerable populations to adopt sustainable diets while resolutely safeguarding their food security.

Moreover, another challenge for the proposed taxation policies is related to the negative effect on agricultural producers (Gren et al., 2021; Jansson & Säll, 2018).

Previous experiences suggested that the introduction of a food tax decreased the overall income of agricultural establishments, with heterogeneous effects over production size, as bigger producers faced lower proportional losses (Bíró, 2021; Cornelsen & Carriedo, 2015). However, the distributional impacts on the supply side in Brazil may be less pronounced than expected and highly uneven across producer groups. Although approximately 30% of Brazilian beef production is exported, the sector is largely dominated by large-scale establishments (ABIEC, 2025; IBGE, 2019a), which may mitigate adverse effects of taxation. In contrast, family farming plays a central role in domestic food supply (Silva, 2022) and could benefit from subsidies targeting more sustainable food groups. Nevertheless, if standalone taxes disproportionately affect smaller producers (such as the all-tax system), they may exacerbate rural inequalities and contribute to market concentration. Therefore, the proposed combined fiscal framework should extend beyond consumer price adjustments to explicitly account for producer welfare and distributional outcomes.

2.6 Final Remarks

In this study, we presented and evaluated whether demand-side fiscal policies would be effective in decreasing environmental impact from the Brazilian agrifood sector. We estimated price and expenditure elasticities through a QUAIDS model based on national household data. Our findings are consistent, demonstrating that while standalone environmental taxes on high-emitting foods effectively reduce greenhouse gas emissions, land use, and water waste, they impose a severely regressive financial burden on consumers. Consequently, our results strongly advocate for a combined fiscal framework. Combining taxation on carbon-intensive products with subsidies for sustainable alternatives emerges as the most balanced and viable pathway to drive dietary shifts, optimizing environmental mitigation while significantly reducing the economic strain on households.

Beyond the environmental outcomes, the social dimension of these fiscal interventions is necessary for policy viability and acceptance. In a nation characterized by profound socioeconomic disparities like Brazil, only employing environmental taxes on beef presents a significant challenge due to their regressive nature, which could inadvertently worsen food insecurity. Therefore, we propose that these taxes be integrated into a broader climate justice framework. By earmarking tax revenues for targeted 'green' cash transfers or direct subsidies for households registered in the *CadÚnico*, policymakers can effectively mitigate financial strain and increase policy acceptability. This dual-policy approach ensures that the transition toward a sustainable food system is inclusive, protecting the purchasing power of the most vulnerable while simultaneously incentivizing lower-impact consumption patterns.

Despite the evidence provided by the simulated scenarios, we must emphasize some important limitations of our study that should guide future research. A primary constraint is the absence of a comprehensive nutritional analysis within the simulated scenarios. Although our results indicate a shift toward more sustainable food groups, we did not quantify the impacts on macro and micronutrient intakes (such as protein quality, sodium, or sugar levels). Consequently, while the policies reduce environmental footprints, their net effect on public health, particularly regarding the potential substitution for cheap ultra-processed foods, remains to be fully elucidated. In addition, the environmental dataset used here does not account for the specificness of Brazilian agricultural production process, which could lead to over or underestimated environmental effects. Furthermore, as a demand-side analysis based on household survey data, this study does not account for supply-side reactions or price transmission mechanisms. Future studies should integrate nutritional profiling and estimate models that could capture the broader macroeconomic and health-related repercussions for the Brazilian population.

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APPENDIX B

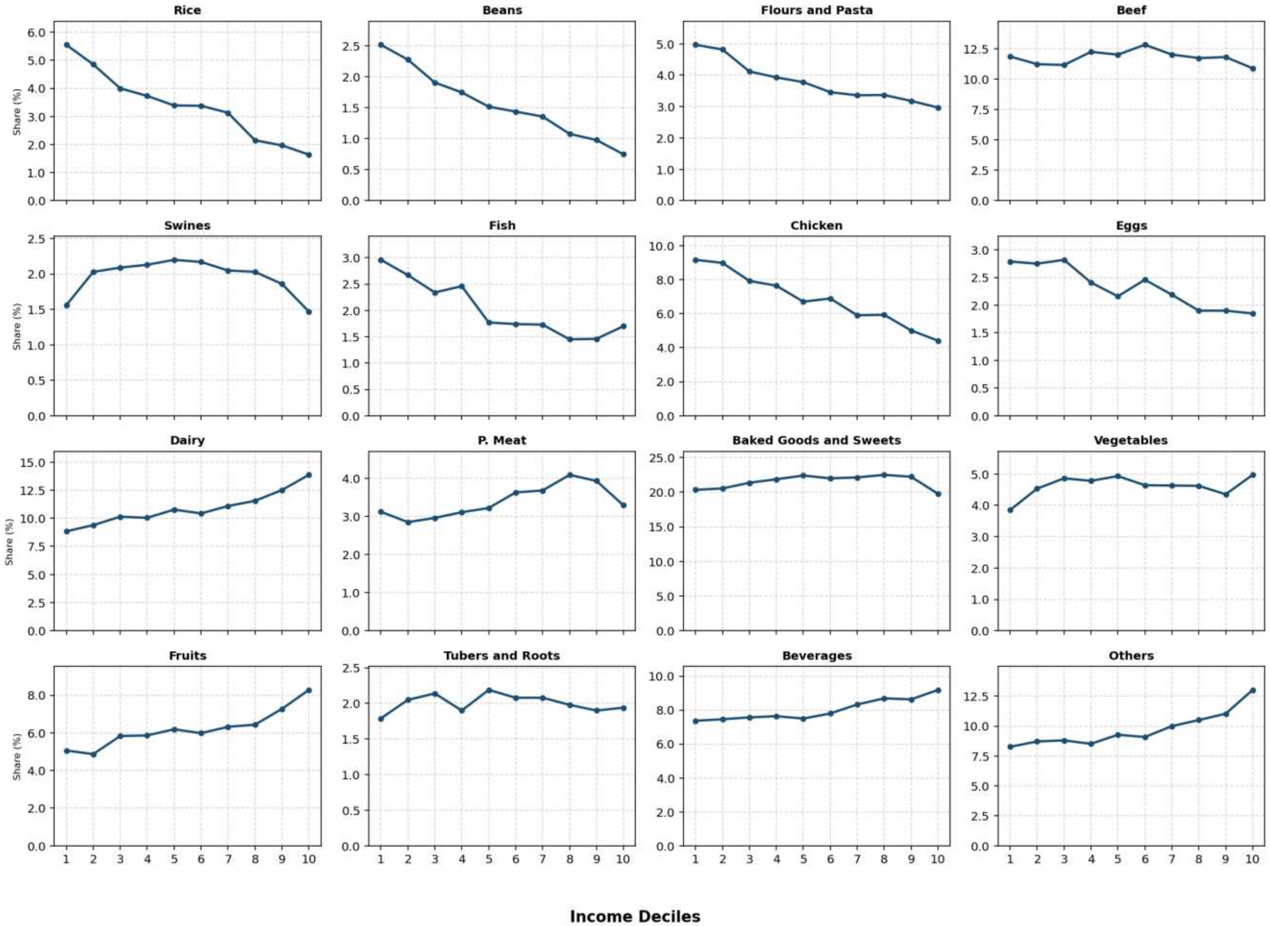
Table 1B. Average values of expenditure shares and price for each food group presented in the estimated demand system.

Food Group	Price (BRL/Kg)	Expenditure share (%)
Rice	2.939	3.21%
	(1.377)	(0.088)
Beans	4.118	1.48%
	(1.021)	(0.049)
Flours and Pasta	8.268	3.72%
	(4.243)	(0.080)
Beef	17.855	11.91%
	(4.784)	(0.191)
Swine	12.957	1.95%
	(2.269)	(0.074)
Fishes	20.963	2.06%
	(5.511)	(0.083)
Chicken	9.972	6.63%
	(5.604)	(0.132)
Eggs	10.724	2.26%
	(10.042)	(0.074)
Dairy	13.483	11.04%
	(8.474)	(0.155)
Processed Meat	15.442	3.43%
	(5.454)	(0.073)
Baked Goods and Sweets	13.381	21.32%
	(11.826)	(0.251)
Vegetables	10.336	4.60%
	(75.864)	(0.098)
Fruits	5.061	6.31%
	(11.639)	(0.125)
Tubers and Roots	4.635	2.00%
	(7.441)	(0.057)
Beverages	15.619	8.07%
	(17.012)	(0.132)
Other foods and Beverages	14.559	10.00%
	(49.940)	(0.141)

Source: Own elaboration.

Note: Standard deviation between parentheses.

Fig. 1B. Expenditure shares gridline according to income deciles and food groups.



Source: Own elaboration.

Note: Deciles varying from 1 to 10, where 1 is the lowest and ten the highest decile

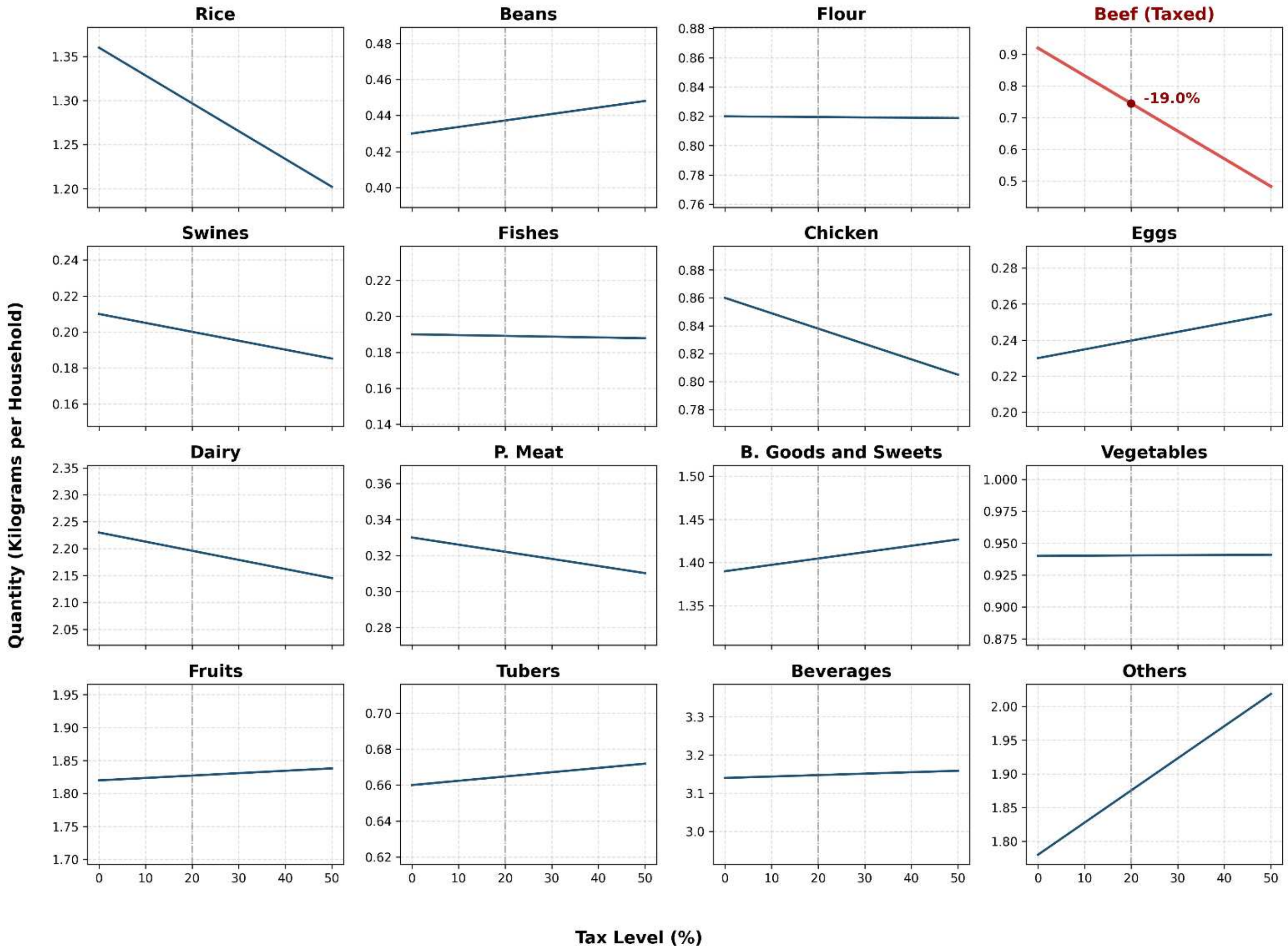
Table 2B. Complementary and Substitution behavior between food groups.

P/Q	Rice	Beans	Flours	Beef	Swine	Fish	Chicken	Eggs	Dairy	P. Meat	B&S	Vegetables	Fruits	T&R	Beverages	Others
Rice	C	C	C	C	S	S	S	S	C		S		C	C	C	S
Beans	S		S		C	S	S	S				C			S	S
Flours	C	C			S	S	S		S	C	S	C			S	S
Beef	C				C		C	S	C	C	C	C			C	
Swine	S	C	S	C		S	C		C	C					C	S
Fish	S	S	S		S			S	S	S	C	S	C	S	S	C
Chicken	S	S		C					C		C	S				C
Eggs	S	S		S	S	S			C		S	S			S	C
Dairy	C		S	C	C	S		C		S					S	
P. Meat			S	C	C	S			S		C	S				C
B&S	S	S	S	S	S		S	S	S			S	S	S	S	C
Vegetables		C			S	S	S	S	S	S	S		C	C	S	C
Fruits	S					C					S	C		C	S	C
T&R	S					S		C			S	C	C		S	C
Beverages	S	S	S		C	S	S	S	S	S	S	S	S	S		C
Others	C	C	C	S	S	S	S	S	S	S	S	S	S	S	S	

Source: Own elaboration.

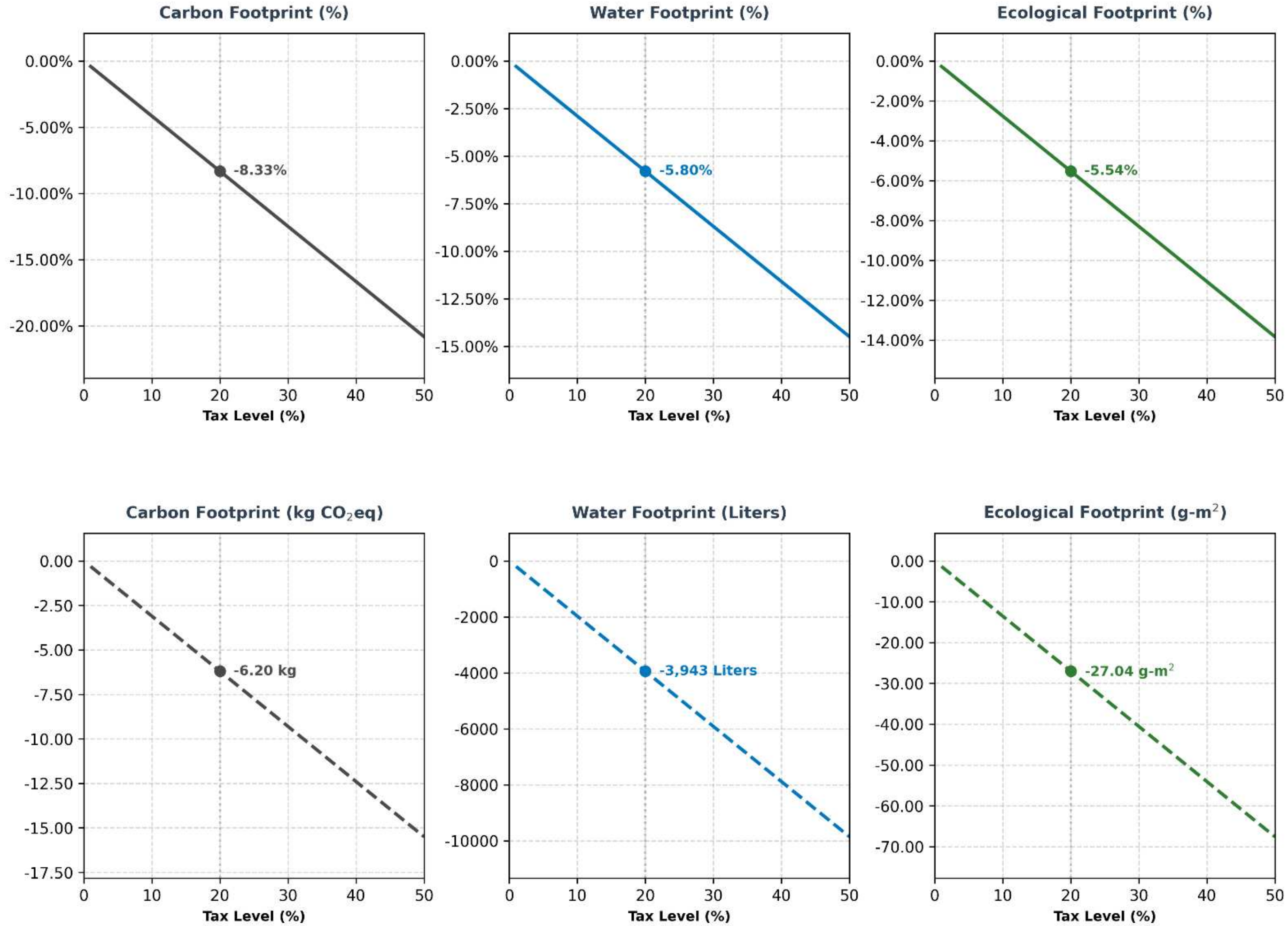
Note: C = Complementary Goods; S = Substitute Goods. Blank values are not significative with p-value higher than 0.10.

Fig. 2B. Effect of an *Ad-Valorem* Tax from one to 50% over food acquisition (Scenario 1). Values displayed per household for a week.



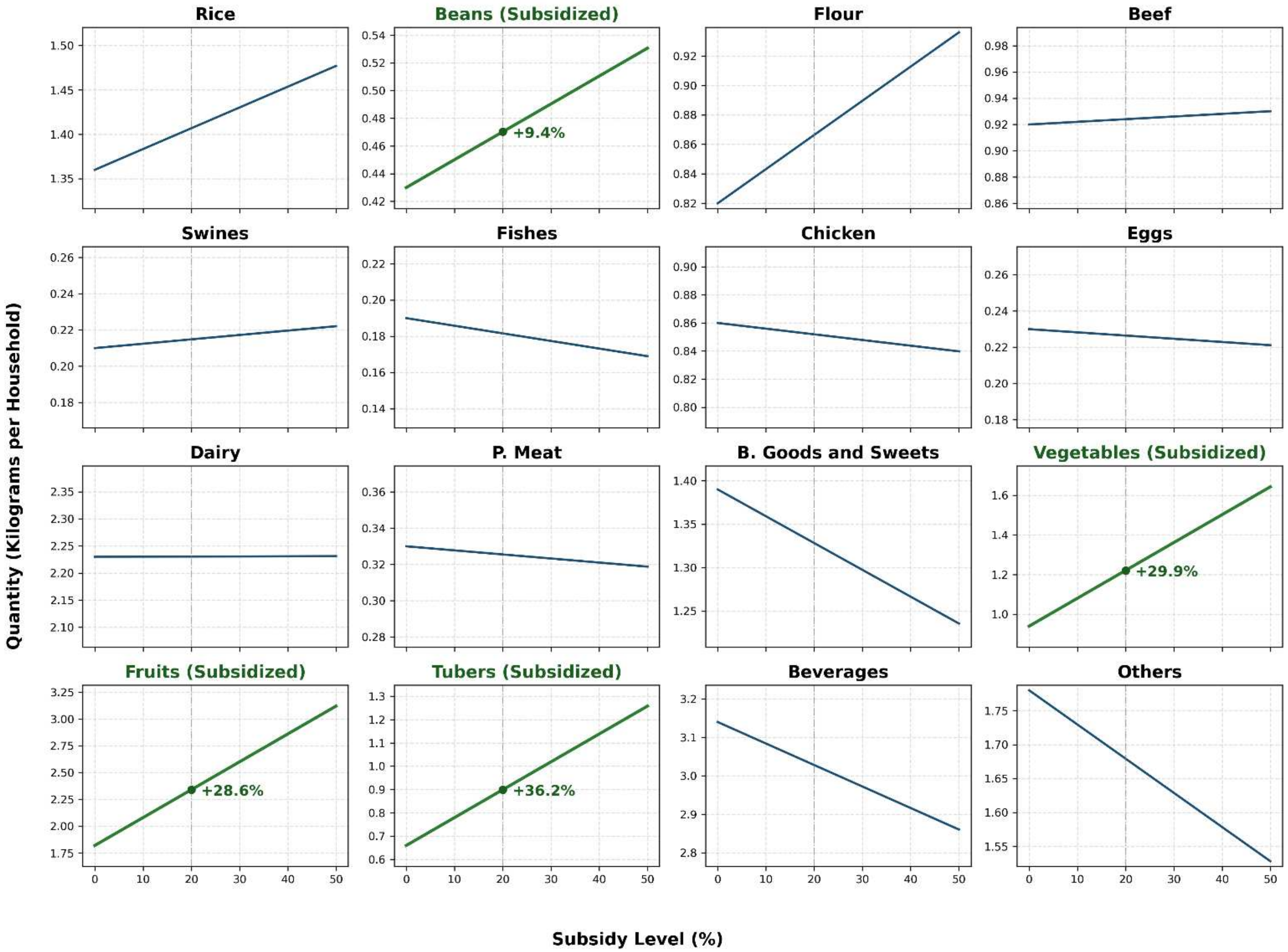
Source: Own elaboration.

Fig. 3B. Effect of an *Ad-Valorem* Tax from one to 50% over environmental indicators (Scenario 1). Values displayed per household for a week.



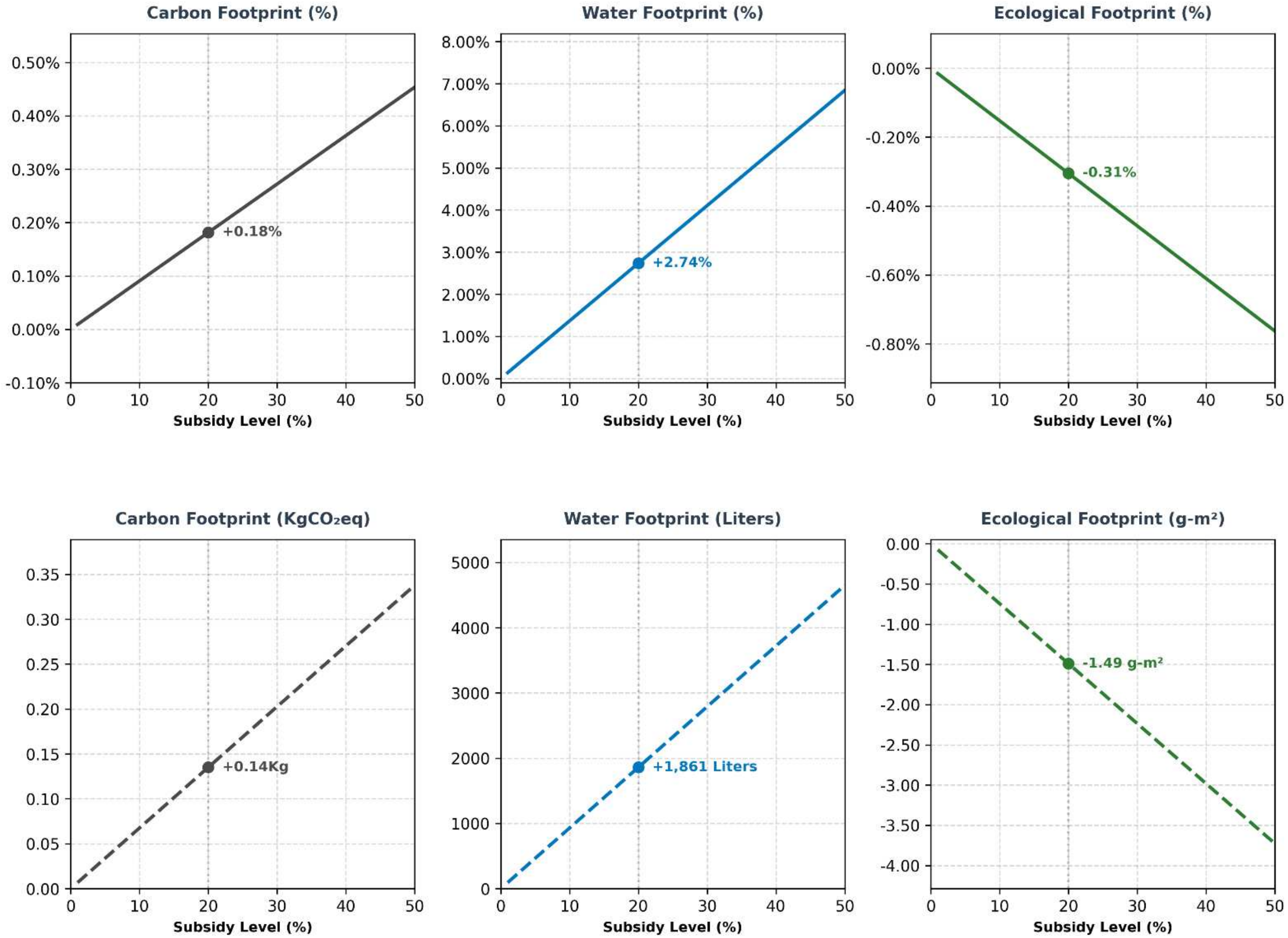
Source: Own elaboration.

Fig. 4B. Effect of subsidy from one to 50% over food acquisition (Scenario 2). Values displayed per household for a week.



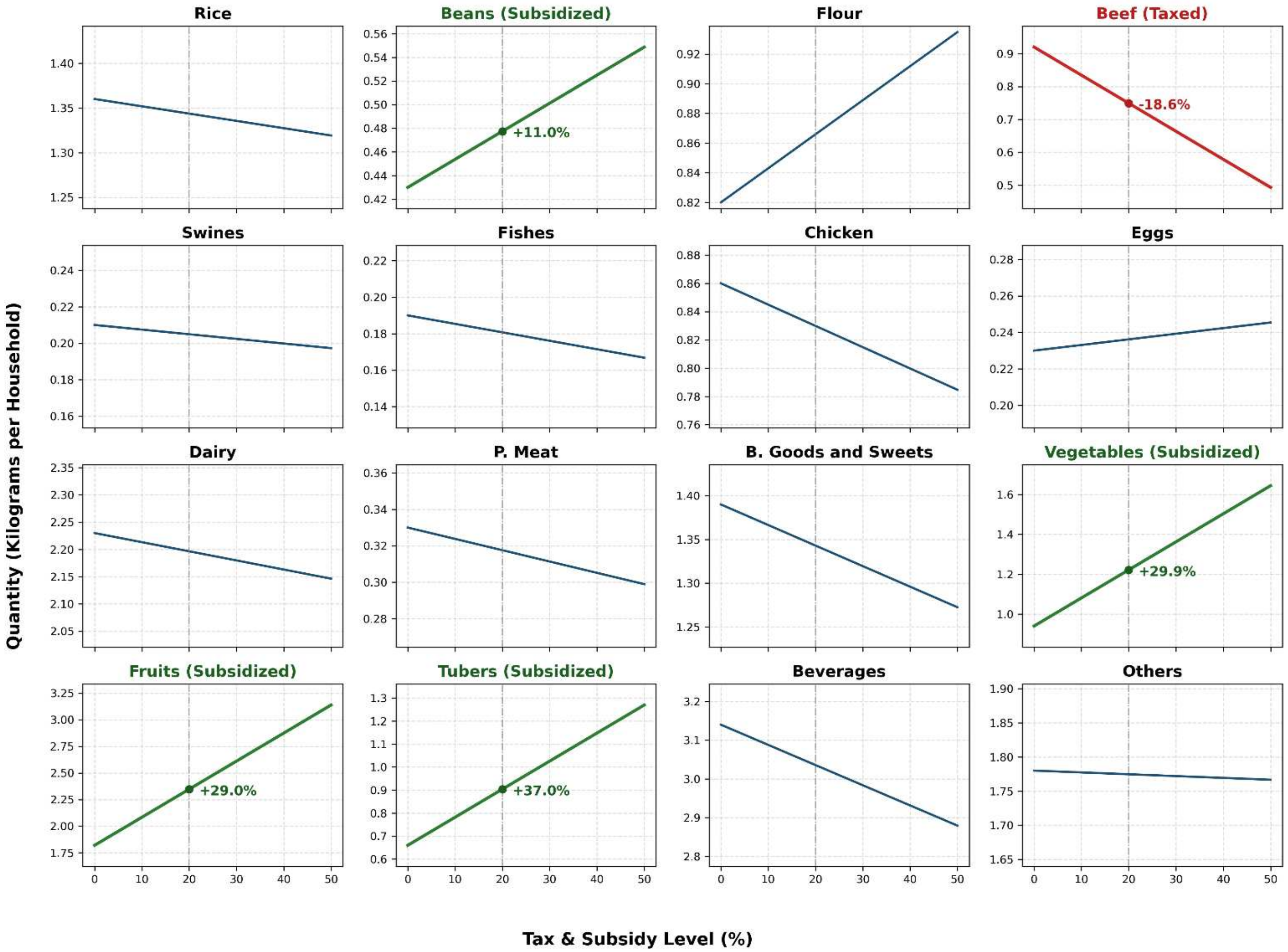
Source: Own elaboration.

Fig. 5B. Effect of subsidy from one to 50% over environmental indicators (Scenario 2). Values displayed per household for a week.



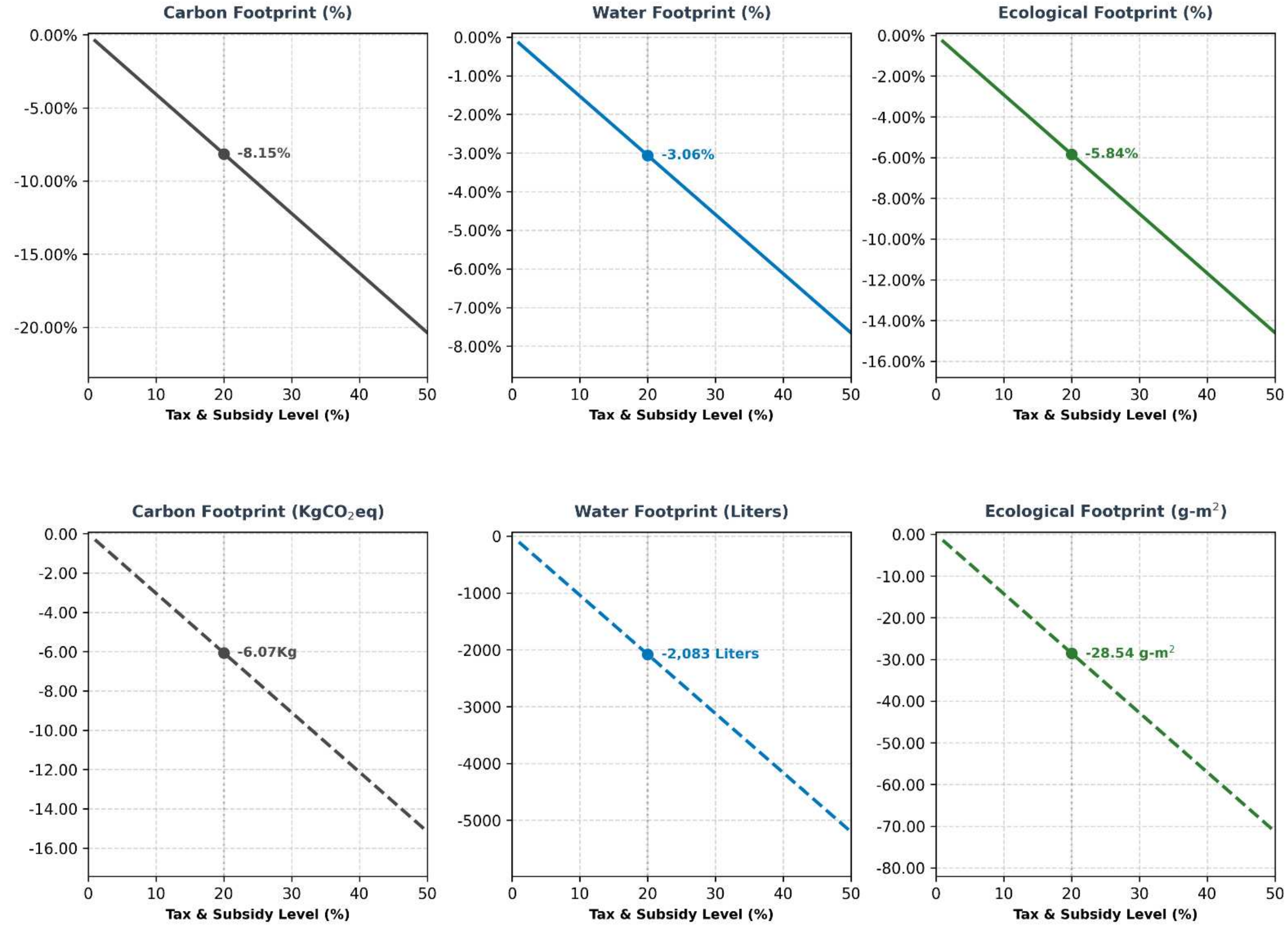
Source: Own elaboration.

Fig. 6B. Effect of an *Ad-Valorem* tax and subsidy from one to 50% over food acquisition (Scenario 3). Values displayed per household for a week.



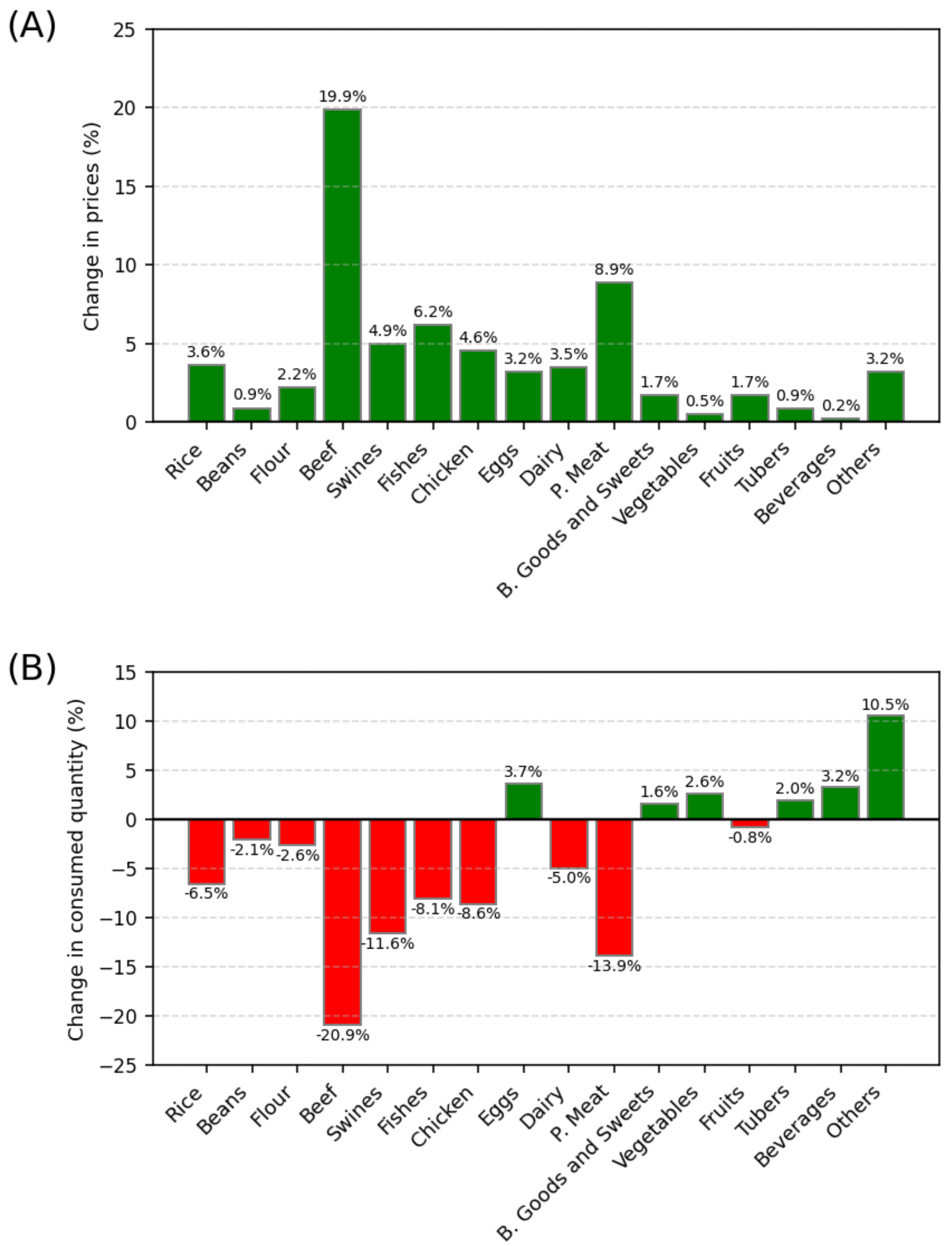
Source: Own elaboration.

Fig. 7B. Effect of an *Ad-Valorem* tax and subsidy from one to 50% over environmental indicators (Scenario 3). Values displayed per household for a week.



Source: Own elaboration.

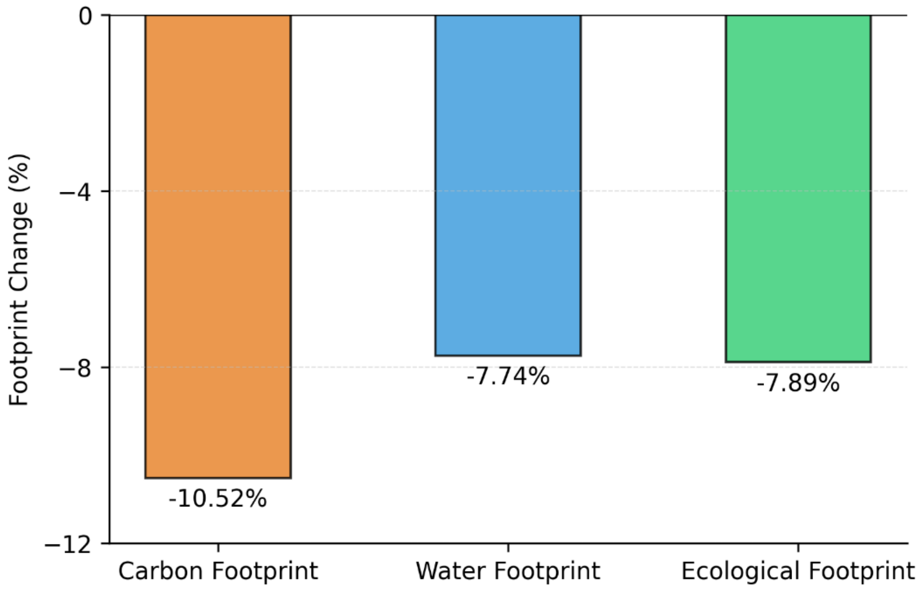
Fig. 8B. Effect of a weighted carbon tax of 0.10 BRL per $kgCO_2eq$ (Scenario 4).



Source: Own elaboration.

Note: Panel (A) presents the change in food prices after the tax, while Panel (B) refers to the effect on the quantity consumed in each household within a week.

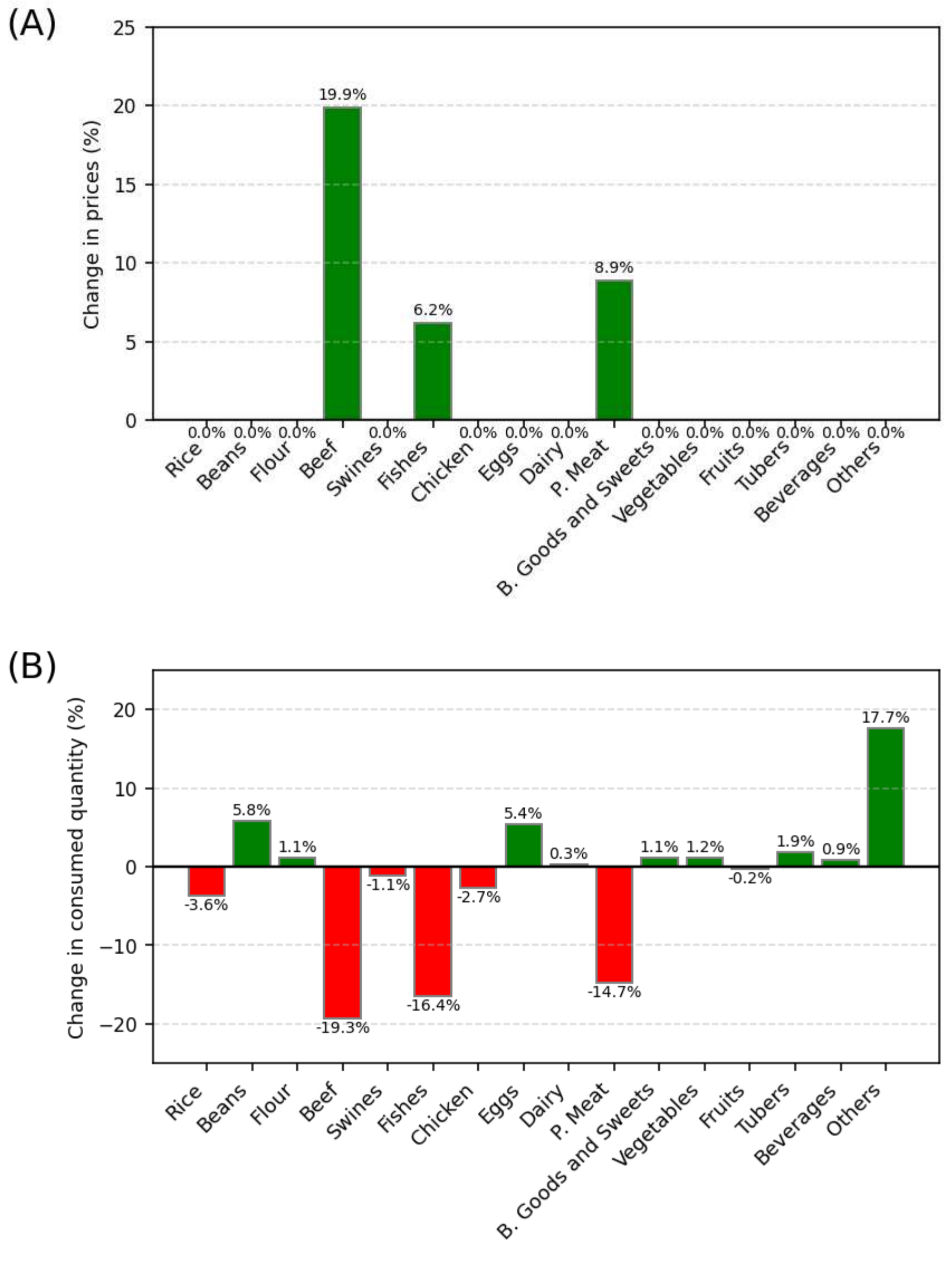
Fig. 9B. Effect of a weighted carbon tax of 0.10 BRL per $kgCO_2eq$, weekly values (Scenario 4).



Source: Own elaboration.

Note: Values are presented per household.

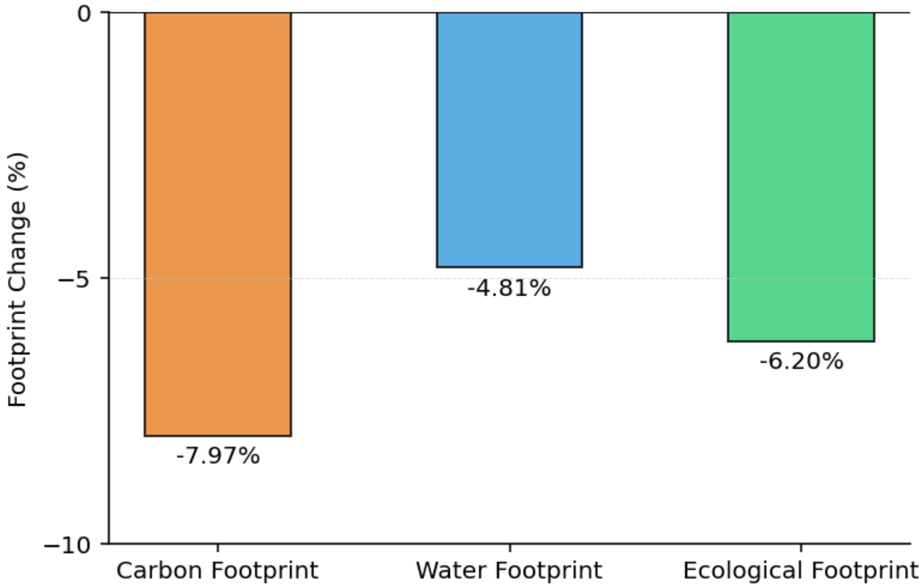
Fig. 10B. Effect of a weighted carbon tax of 0.10 BRL per $kgCO_2eq$ only for groups with more than 10.0 $kgCO_2eq$ per kilogram (Scenario 5).



Source: Own elaboration.

Note: Panel (A) presents the change in food prices after the tax, while Panel (B) refers to the effect on the quantity consumed in each household within a week.

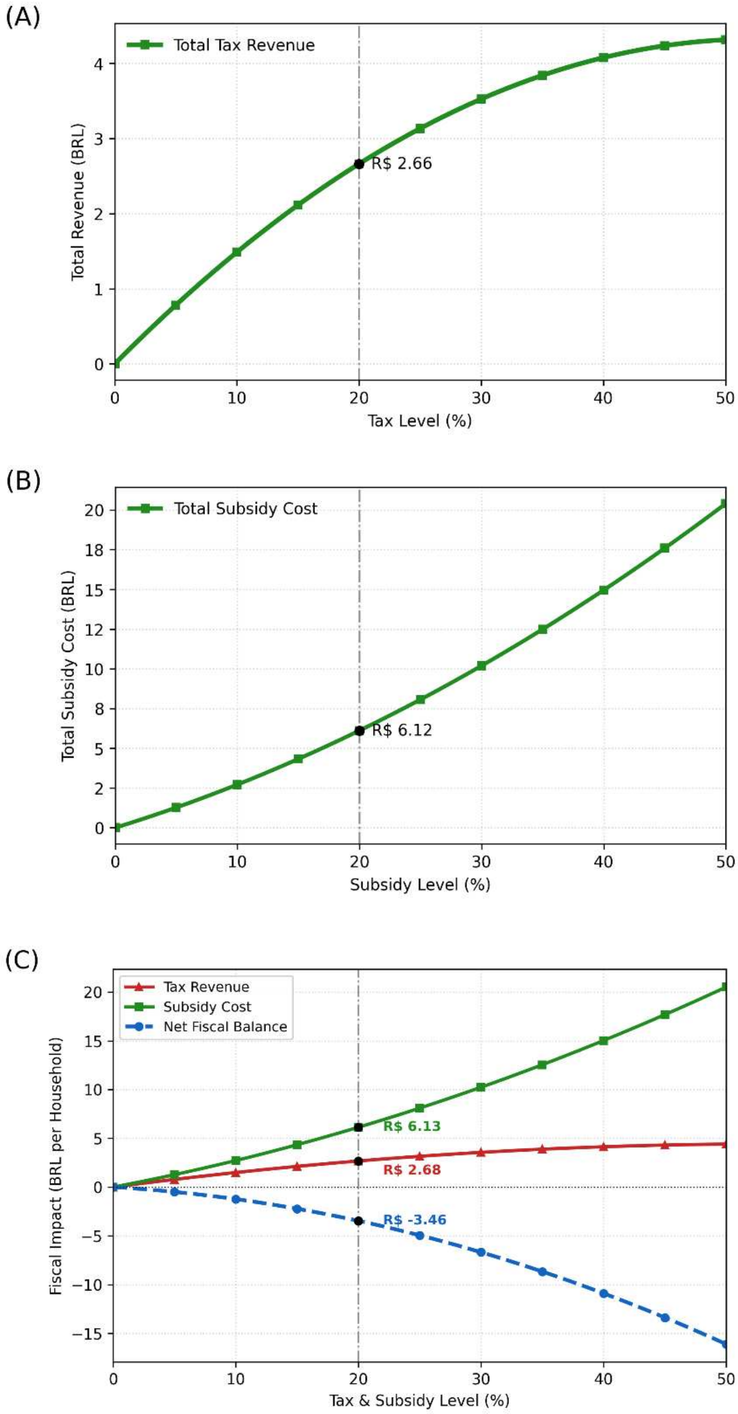
Fig. 11B. Effect of a weighted carbon tax of 0.10 BRL per $kgCO_2eq$, only for groups with more than 10.0 $kgCO_2eq$ per kilogram, weekly values (Scenario 5).



Source: Own elaboration.

Note: Values are presented per household.

Fig. 12B. Weekly income revenue from tax policies. Scenarios (1), (2), and (3).

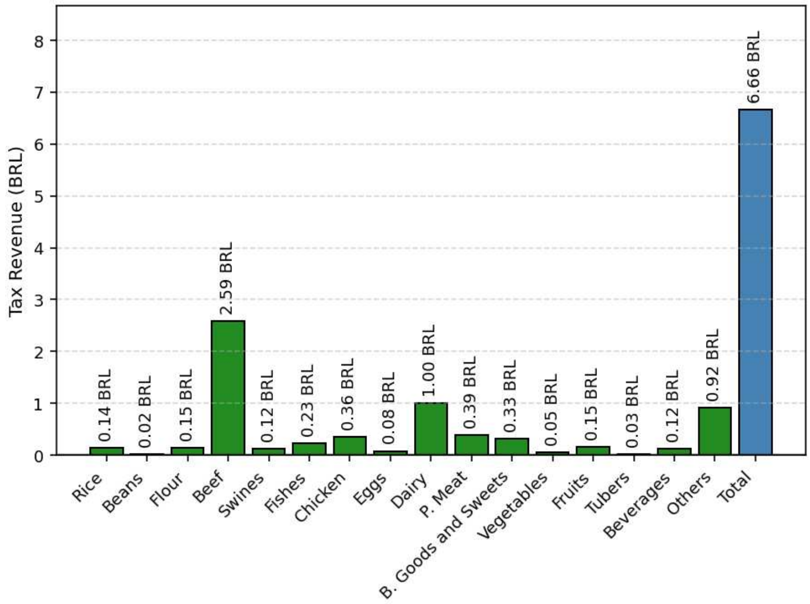


Source: Own elaboration.

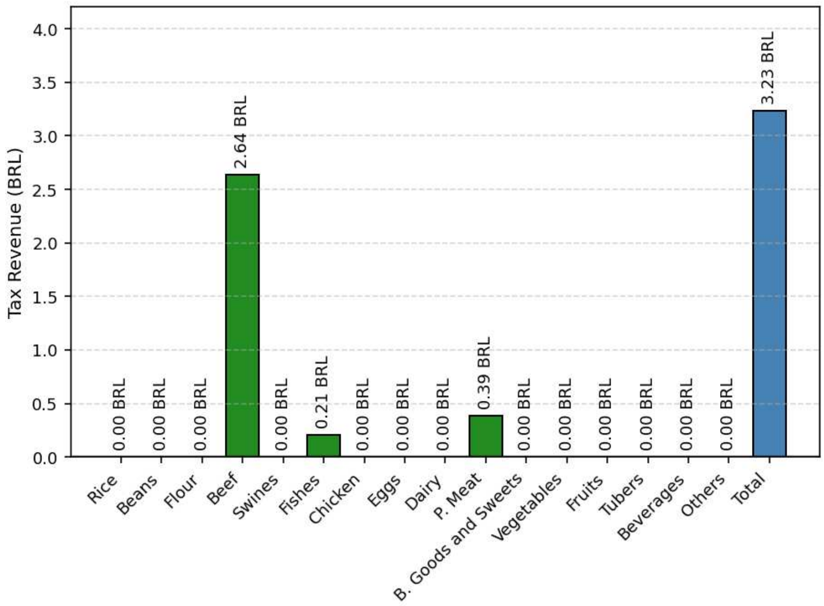
Note: Panel (A) presents the total tax revenue that comes from the proposed system in Scenario (1); Panel (B) refers to the total cost to subsidize food groups in Scenario (2); Panel (C) is due to the combination of tax policies and subsidies in Scenario (3). Values per household during a week.

Fig. 13B. Weekly income revenue from tax policies. Scenarios (4), and (5).

(A)



(B)



Source: Own elaboration.

Note: Panel (A) presents the total tax revenue that comes from the proposed system in Scenario (4); Panel (B) refers to the total tax revenue in Scenario (5). Values per household during a week.

Table 3B. Food category types in each food group.

Food Groups	Food category types
Rice	White rice, Brown rice, Red rice, Parabolized rice, and other rice types.
Beans	Black beans, Brown, Yellow and Tan beans, Red, Pink and Purple beans, and Specialty beans.
Flours and Pasta	Wheat flours, cereal grains, corn flours, dry and traditional pasta, pre-cooked pasta, prepared pasta, prepared doughs, cereal supplements, and others type of flours.
Beef	Fresh beef, Prime and Premium cuts, Standard Cuts, Ribs, Ground beef, Offal, Viscera, and Cured/Dried beef
Swine	Fresh swine, Prime loin, Tender cuts, Pork ribs, Offal, Viscera, Whole pork, and other parts (nose, foot, cheek).
Fish	Freshwater and saltwater fish, and seafoods.
Chicken	Whole chicken, Breast cuts, Thighs and Drumsticks, Wings, Mixed cuts, Ground poultry, Turkey, Duck, and other parts.
Eggs	Chicken eggs, Turkey eggs, Duck eggs, and Quail eggs.
Dairy	Milk, Cheeses, Cream Cheese, Yogurts, Fermented milk, Butter, Cream and dairy fats, Condensed milk, and flavored milk.
Processed Meat	Sausages, Frankfurters, Hams, Sliced meats, Mortadella, Bacon, Smoked cuts, Salted meats, Burgers, Nuggets, and Breaded meat products.
Baked goods and Sweets	Breads and bakery rolls, Cakes, Sweet pies, Pastries, Biscuits, Wafers, Candies, Gums, Traditional sweets, Jams, Ice Creams, and dessert mixes.
Vegetables	Leafy greens and salad vegetables, Fruiting vegetables, Cruciferous vegetables, Squash and pumpkins, Canned, frozen and processed vegetables, and Culinary herbs.
Fruits	Citrus fruits, Tropical and subtropical fruits, Native and regional Brazilian fruits, Temperate and stone fruits, Melons and watermelons, Berries and small fruits, Dried and dehydrated fruits, Frozen pulps, and Organic and specialty fruits.
Tubers and roots	Ware potatoes, Cassava/manioc, Yams, taro and air potatoes, Sweet potatoes, Carrots, Beets, Radishes, Turnips, and Pea.
Beverages	Carbonated soft drinks, Fruit juices, Bottled mineral water, Ready-to-drink teas and mate, and Energy and isotonic sports drinks.

Others	Coffee, Condiments, Spices, Sauces, Salty snacks, chips and popcorn, Ready-to-eat foods, Alcoholic beverages, Fats and oils, Coconut, and Nuts.

Source: Own elaboration.