Politecnico di Torino

Politecnico di Torino

Master of Science Degree in Management Engineering

Management of Sustainability and Technology

A.a. 2023/2024

Graduation Session March/April 2024

THE ROLE OF DIETARY SHIFT FOR SUSTAINABLE FOOD SYSTEMS

Supervisors:

Prof. Marta Tuninetti
Ing. Vittorio Giordano

Candidate:

Pietro Reale

Table of Contents

Abstract

In recent decades, the global challenges concerning food sustainability have intensified by the urgent need to address environmental degradation, public health concerns, and social equity issues. A significant aspect that has garnered attention is the phenomenon of dietary transitions and shifts. As societies evolve economically, socially, and culturally, so do their dietary patterns. These transitions, often characterized by changes in consumption habits, technical innovations, political policies, and economic drivers in food systems, highlight aspects and challenges to the sustainability of our alimentary systems such as greenhouse gas emissions, deforestation, water scarcity, biodiversity loss and a notable rise in the consumption of resource-intensive foods including meat, dairy, and processed foods. In these processes, positive tipping points are properties and events that influence systems dynamics that prompt transformations in individual and collective practices in order to promote sustainable and innovative enrichment in society. The purpose of this thesis is to analyze the dynamics of modern food system sustainability, to assess with a specific focus on determining and understanding the main drivers in transitions and shifts through analysis, case studies and final considerations. The thesis presents a statistical analysis of the past time-series of food consumption covering the key food categories, with global coverage and regional resolution. Relevant trends are shown for bovine meat, milk, poultry meat providing their critical role in diet transition for food system sustainability. The statistical framework proposed in this thesis is also combined with a case-study analysis aiming at showing relevant past examples and drivers of changes in food consumption.

1 INTRODUCTION

1.1 The Current Challenges of the Food System

The challenges surrounding food systems have become a critical global concern for our planet. From issues of food security to the environmental impact of production, distribution, and waste, the alimentary landscape requires focus and effort to mitigate.

The agriculture sector contributes significantly to anthropogenic greenhouse gas emissions (GHGs), collectively accounting for nearly a quarter of the total emissions (FOLU Organization, 2019). Furthermore, intensive farming practices, deforestation, land and water resources use stress and pollution, and biodiversity loss continue to put pressure on global ecological welfare. Farmers, aquaculture producers, and other stakeholders of the alimentary chain must rapidly adapt their practices and technologies to mitigate the adverse impacts of climate change. Yet, individual efforts alone may not suffice. Recent initiatives within the European Commission such as the Green Deal signed in 2019 (Guyomard et al., 2023) aim to carbon neutrality by fostering green innovation, investing in clean technologies, and promoting sustainable practices across various sectors.

Food insecurity remains a concerning reality for millions, characterized by issues such as unequal distribution, climate change-induced issues, and geopolitical conflicts. Around 820 million people in the world are undernourished and 2 billion encounter food insecurity issues every day (Durán-Sandoval et al., 2021).

In essence, the challenge of climate change necessitates a comprehensive and collaborative approach to reshaping food systems. Only through decisive policy action towards climate change, food security, and sustainable development, can ensure a resilient and equitable future for all.

1.2 Possible Pathways Towards Sustainable Food System

In order to achieve such sustainable goals and objectives, the alimentary system needs a multifaced approach that addresses challenges across the supply chain, from production to distribution and consumption to waste management. Currently, on a global scale, roughly one-third of food produced is not consumed and is instead wasted, according to the Food and Agriculture Organization (Durán-Sandoval et al., 2021). Correct and efficient management of waste and food loss could not only reduce costs across the supply chain but also mitigate problems related to food security as Figure 2 describes.

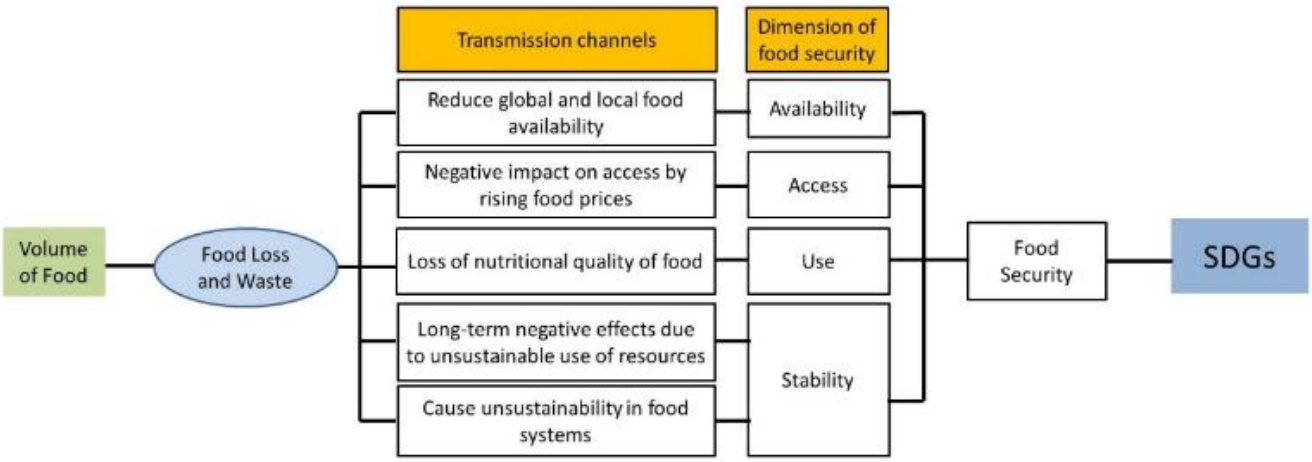

Figure 1 Impacts of food loss and waste on food security and Sustainable Development Goals (SDGs).

Regenerative agriculture is a crucial tool for conserving and rehabilitating food and farming systems. This approach permits increasing biodiversity, improving the water cycle, enhancing ecosystem services, increasing resilience to climate change and strengthening the health and vitality of farm soil. For this exact purpose, the European Commission enacted the Farm to Fork Strategy, a reform that lies at the core of the European Green Deal, with the primary goal of transforming the agrifood supply chain to be equitable, health-conscious, and environmentally sustainable (Gilles Billen, 2024).

This strategy not only addresses these pressing issues but also opens new opportunities across the food value chain. Advancements in technology and scientific knowledge, coupled with growing public awareness and demand for sustainable products, are poised to benefit all stakeholders involved. Maintaining food affordability while fostering fair economic returns could enhance the competitiveness of the EU's supply sector, and demand for equitable trade practices (*European Commission Food Safety*, 2024).

The last stakeholder of the food system chain, the consumer has a huge impact on its sustainability. Consumer choice and behaviour are drivers key factors in the diet transition. According to research, the adoption of more sustainable diets could lead to a reduction in greenhouse gas emissions by up to 70%, along with a significant decrease in water consumption (Davies et al., 2023). By 2050, a shift towards diets more focused on local and seasonal products, and especially reduced consumption of animal-derived foods, could free up several million square kilometers of land previously used for feed production and livestock farming. This liberation of land would have a positive impact on biodiversity conservation and ecosystem regeneration (Kenny Torrella, 2022). Understanding healthy and sustainable diets implies growing attention to the interplay between diet, health, and environmental outcomes. However the absence of a singular definition for such diets and the need for a global perspective to address diverse dietary patterns, the following study proposes a convergence strategy involving diversification of plant foods, reduced food intake among those with "western-type" diets, and increased consumption among poor countries. The EAT-Lancet (Willett et al., 2019) offers a culturally flexible global diet that meets nutritional needs while addressing environmental concerns, as the following Table 1 describes.

Table 1 The EAT-Lancet Commission introduced the "Planetary Health Diet" in 2019. This dietary approach aims to provide a sustainable and healthy eating pattern for the global population while considering environmental sustainability. By promoting a shift towards plant-based foods and reducing the consumption of animal products, this approach could help mitigate greenhouse gas emissions associated with agriculture, preserve land and water resources, and contribute to environmental conservation efforts. (Willett et al., 2019)

	Macronutrient intake (possible range), g/day	**Caloric intake kcal/day**
Rice, wheat, corn, and other	232	811
Tubers or starchy vegetables	0-100	39
Vegetables	200-600	80
Fruits	100-300	126
Dairy foods	0-500	153
Protein sources		
Beef and lamb	0-14	15
Pork	0-14	15
Poultry	0-58	62
Eggs	0-25	19
Fish	0-100	40
Legumes	0-300	570
Added fats	0-90	450
Added sugars	0-31	120

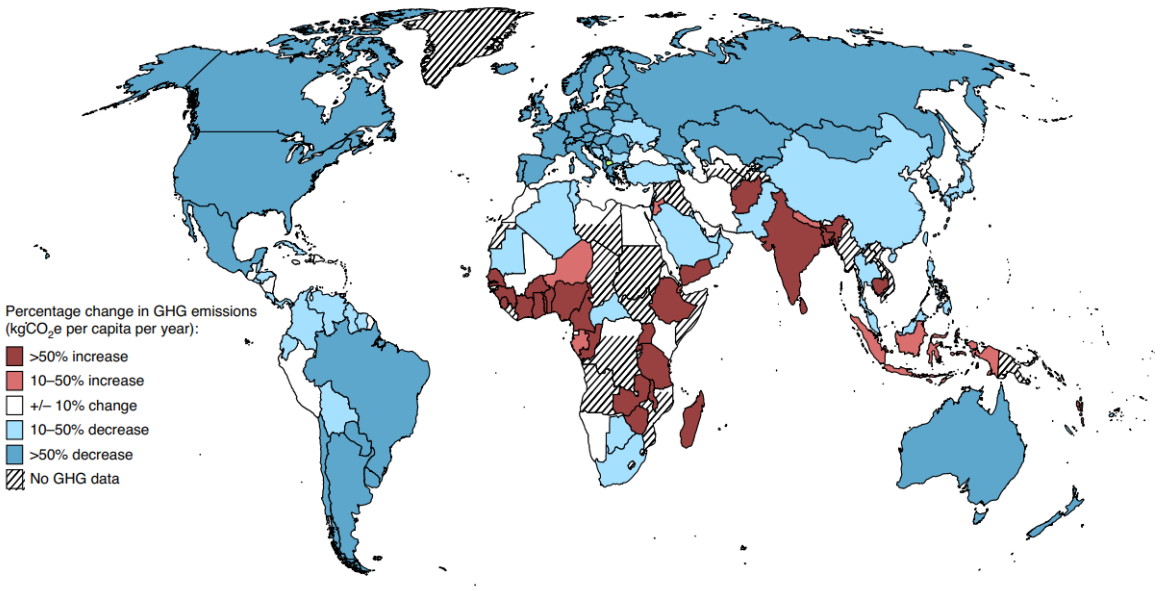

Figure 2 Each nation is characterized by a colour that describes the intensity of change in the percentage of GHG emissions associated with a hypothetical transition to the Planetary Health Diet proposed by EAT-Lancet (see Table 1). Not all nations would reduce their environmental impact, but the overall result would be effective in combating the climate crisis (Semba et al., 2020).

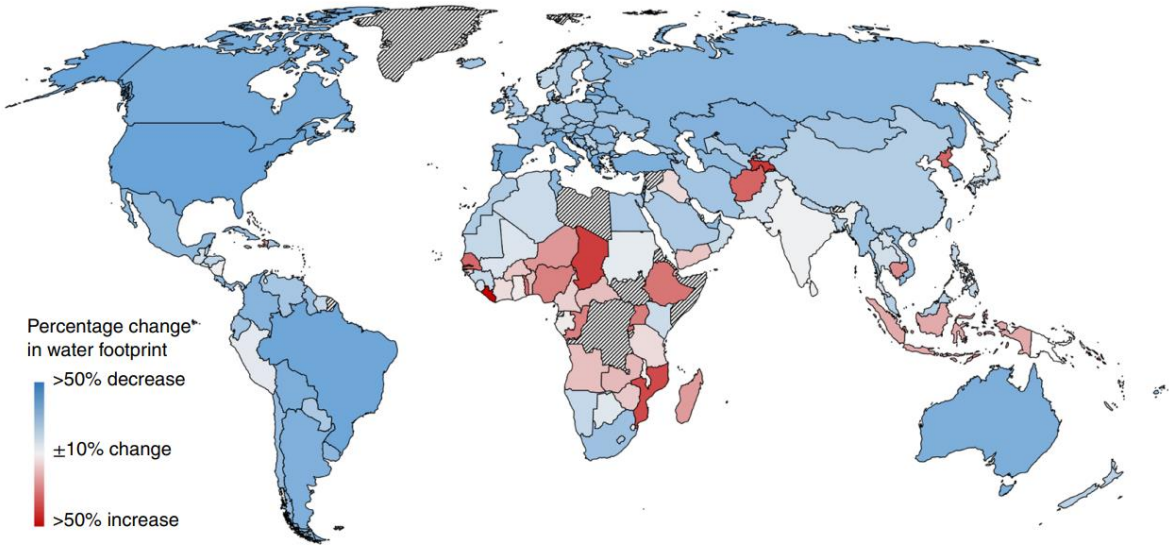

Figure 3 Each nation is characterized by a colour that describes the intensity of change in the percentage of water footprint associated with a hypothetical transition to the Planetary Health Diet proposed by EAT-Lancet (see Table 1). Not all nations would reduce their environmental impact, but the overall result would be effective in fighting water scarcity (Tuninetti et al., 2022).

1.3 The Role of Dietary Shift Towards Sustainable Food System

A pivotal aspect of transitioning towards sustainable food systems lies in dietary shifts, as we noted before in Fig.2 and Fig.3, adopting the EAT-Lancet Planetary health diet can significantly reduce carbon (Semba et al., 2020) and water (Tuninetti et al., 2022) footprint. Therefore, promoting shifts towards more sustainable diets emerges as a crucial strategy for resource use, environmental impact, and human health outcomes. If the world's population implemented a plant-based diet transition instantly, it would alleviate climate stress due to GHGs for 30 years, buying time to implement the carbon-free transition in industries (Kemper et al., 2023).

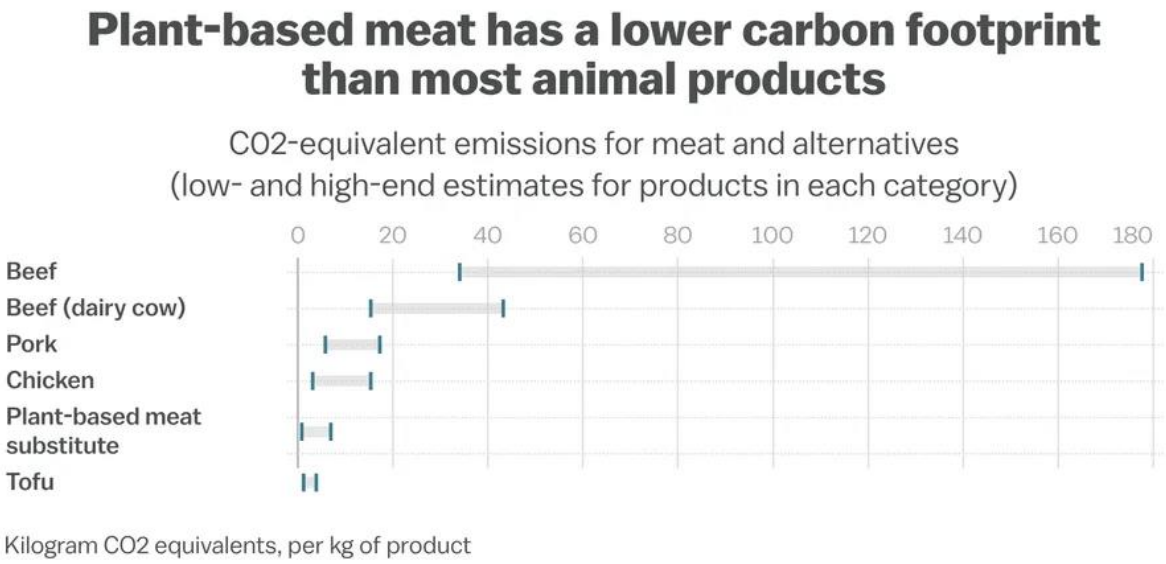

Figure 4 The image compares the CO2 equivalent emissions of common meat cuts with plant-based meat and tofu. The span for each product indicates the maximum and the minimum of emissions the product can release. (Vox Media, 2024)

As of now, alternative proteins collectively account for 2% of the animal protein market (Systemiq, 2023). This sector has experienced significant growth, with European sales increasing by approximately 50% over two years from 2018 to 2020. In the United States, sales witnessed a remarkable 72% increase compared to 2019, outpacing the growth rate of total food sales by three times. China, a key player in the plant-based protein market, surpassed the U.S. in 2018 with a market value of $910 million, and it is projected to grow by 20–25% (Systemiq, 2023). Adoption of plant-based diets faces barriers including cultural norms, accessibility, taste preferences, nutritional concerns, and marketing influences (Lehto et al., 2023). Solutions involve promoting alternatives, enhancing accessibility, educating on nutrition, and challenging cultural norms.

1.3.1 Tipping points

Tipping points represent critical junctures in complex systems where a small change can lead to a significant and often irreversible shift in the system's state or behaviour. These complicated systems are nonlinear due to the interaction of different dynamics constituted by many “systems of systems” (David Tàbara et al., 2018). For this reason, multiple tipping points cannot be treated in isolation, as they are not independent: crossing one point deeply affects the likelihood of crossing another, creating either catastrophic or beneficial synergies (Van Der Ploeg, 2016). Progress toward positive tipping points is often propelled by reinforcing feedback loops in the development and adoption of new solutions. For dietary shifts, for example, increases in production lead to higher performance, economies of scale, greater adoption, and further production, creating a self-reinforcing cycle. Rising awareness of environmental and health benefits is driving increased interest in plant-based eating (Lehto et al., 2023) and as plant-based options become more widely available and accepted, the tipping point momentum of this transition will reach its purpose.

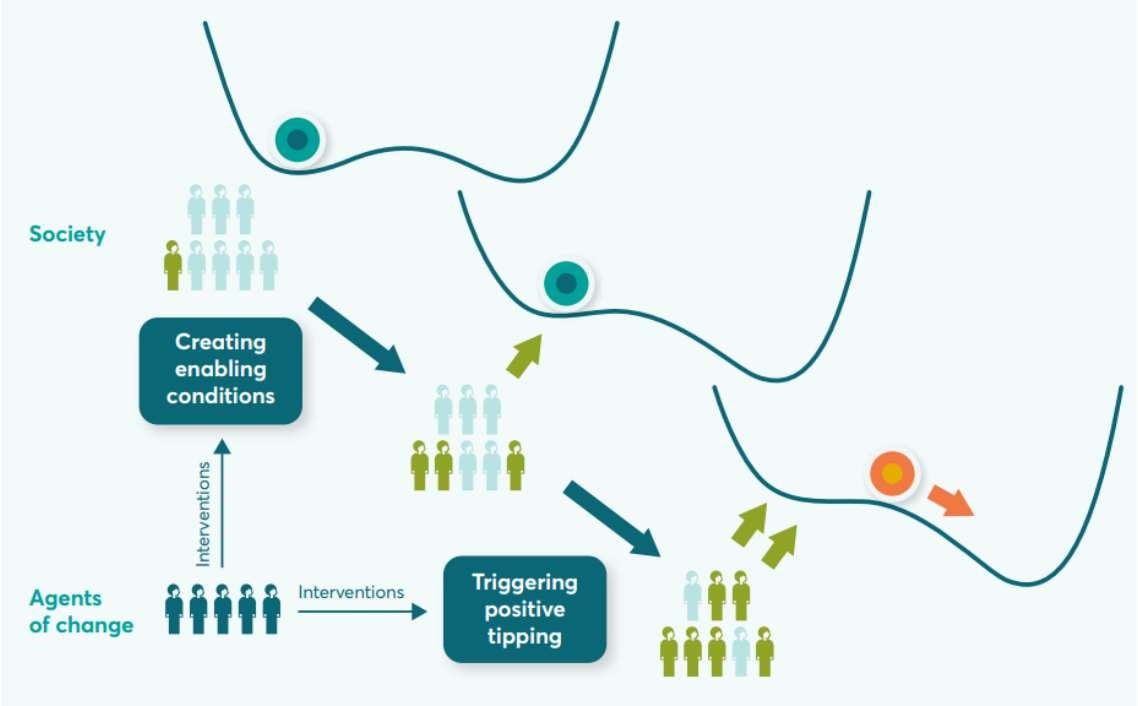

Figure 5 In this conceptualization of systemic tipping points, the current state of the system is likened to a "ball," while the shape of the "valley" it rests in represents its resilience to perturbations. The figure illustrates how interventions by agents of change can establish enabling conditions and subsequently initiate a shift in the system towards an alternative state, depicted as the transition to another valley. Source: FOLU “Positive Tipping Points for Food and Land Use Systems Transformations” 2021.

Initiatives that promote fair trade, equitable distribution, and sustainable practices contribute to interconnecting positive tipping points and fostering their development simultaneously to trigger changes in the global food system (Winkelmann et al., 2022). The transformation of global food systems is an intricate task that demands a holistic approach. Governmental policies, societal choices, and technological advancements must converge to create a sustainable and resilient alimentary future. For this reason, a collective commitment to change can pave the way for a world where food systems assure sustainability (Moberg et al., 2021).

1.4 Objectives of the Present Thesis

Given the conceptual framework in which modern food systems operate, this study aims to:

1. Developing a statistical framework to analyze dietary patterns in relation to per capita GDP.
2. Providing a literature analysis to assess the role of technological, cultural, economic and scientific factors in driving past dietary shifts.
3. Highlighting relevant case studies to demonstrate successful and ineffective past dietary shifts in relation to their guiding factors and processes.

The overarching goal of this thesis is thus provide a framework to support future studies on positive tipping points in the food systems.

2 DATA AND METHODS

2.1.1 Data

The primary dataset for this study was sourced from the Food and Agriculture Organization (FAO) statistics webpage (*FAO Statistics*, 2024). These data encompassed temporal considerations, geographic scope, and the specific variables essential to address the research questions at hand.

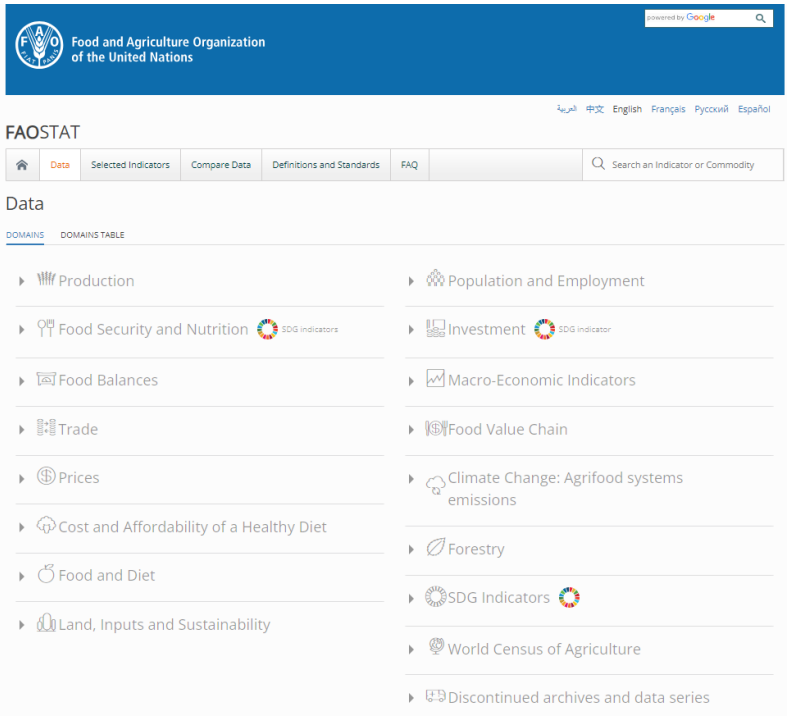

Figure 7 FAO statistic homepage and the related statistics field available.

We had some setbacks in this process, in particular, that the FAO statistics database is split into two parts. This is because the organization implemented a new methodology very different from the original one, for accounting goods and related statistics (Food Balances) over the years. The old methodology was used for account data from 1961 to 2013 and the new methodology from 2010 to 2021, as the figure below shows.

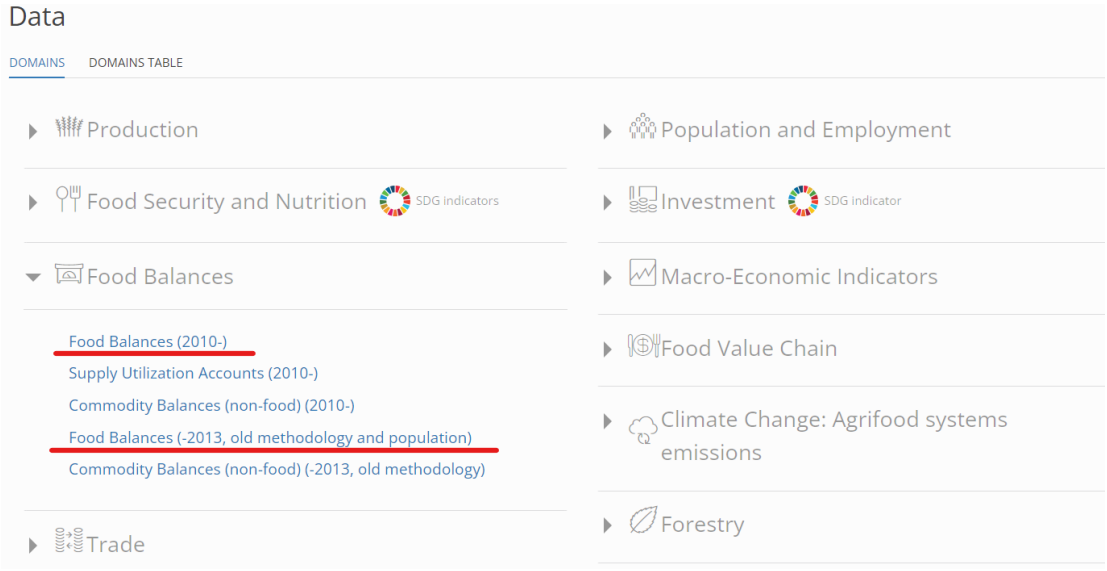

Figure 8 The old and new methodology for Food Balances, in FAOstat web page.

In the proper section, FAO explains the new methodology and its differences from the older one. In the past, when there were discrepancies or errors in the data, a variable known as the "balancer" would absorb these errors, often leading to inaccuracies in specific components of the FBS (Food Balances System). However, with the new methodology, instead of relying on a single balancer variable, dedicated modules are used to generate imputations for FBS components where data is often missing or incomplete. After these imputations are generated, a balancing mechanism is employed to distribute any remaining imbalances proportionally among all the components, ensuring a more equitable distribution of errors and potentially improving the accuracy of the overall system.

Hence the two data series did not match. We tried to mitigate the gap between the datasets using the average data related to the years in common to the two methodologies 2010-2013. We also tried to translate the old dataset of the mean value of the deviation, keeping data integrity. It was unsuccessful due to non-homogeneity in the results: in some cases, data showed accuracy and in others, data values were too imprecise to continue with further analysis. So, we decided to keep the old methodology dataset and move on even if data stopped in 2013. Excel and MATLAB were selected as the primary analytical tools for their

complementary capabilities MATLAB facilitated advanced statistical analyses, contributing to a deeper understanding of the relationships within the dataset. This step was essential in uncovering patterns and trends that form the basis for the subsequent interpretation of results

Table 2 Definitions and standards of FAO Statistics describing how they account for these three goods and what they book to register the consumption level. Source: FAO Statistics.

Domain	**Item**	**Description**
Food Balances: Food Balances (-2013, old methodology and population)	Bovine Meat	Meat, beef, dried, salted, smoked, 873 Meat, extracts, 874 Meat, beef and veal sausages, 875 Meat, beef, preparations, 876 Meat, beef, canned, 877 Meat, homogenized preparations, 947 Meat, buffalo
Food Balances: Food Balances (-2013, old methodology and population)	Poultry Meat	Default composition: 1058 Meat, chicken, 1060 Fat, liver prepared (foie gras), 1061 Meat, chicken, canned, 1069 Meat, duck, 1073 Meat, goose and guinea fowl, 1080 Meat, turkey
Food Balances: Food Balances (-2013, old methodology and population)	Milk - Excluding Butter	Default composition: 882 Milk, whole fresh cow, 888 Milk, skimmed cow, 889 Milk, whole condensed, 890 Whey, condensed, 891 Yoghurt, 892 Yoghurt, concentrated or not, 893 Buttermilk, curdled, acidified milk, 894 Milk, whole evaporated, 895 Milk, skimmed evaporated, 896 Milk, skimmed condensed, 897 Milk, whole dried, 898 Milk, skimmed dried, 899 Milk, dry buttermilk, 900 Whey, dry, 901 Cheese, whole cow milk, 903 Whey, fresh, 904 Cheese, skimmed cow milk, 905 Whey, cheese, 907 Cheese, processed, 908 Milk, reconstituted, 909 Milk, products of natural

		constituents nes, 910 Ice cream and edible ice, 917 Casein, 951 Milk, whole fresh buffalo, 954 Milk, skimmed buffalo, 955 Cheese, buffalo milk, 982 Milk, whole fresh sheep, 984 Cheese, sheep milk, 985 Milk, skimmed sheep, 1020 Milk, whole fresh goat, 1021 Cheese of goat mlk, 1023 Milk, skimmed goat, 1130 Milk, whole fresh camel

2.2 The Bennett's Law

In order to fulfil the first objective of our work, we rely on Bennett's Law. It posits that as incomes increase, dietary patterns shift towards consuming fewer calorie-dense starchy staples and more nutrient-dense foods like meats, oils, sweeteners, fruits, and vegetables.

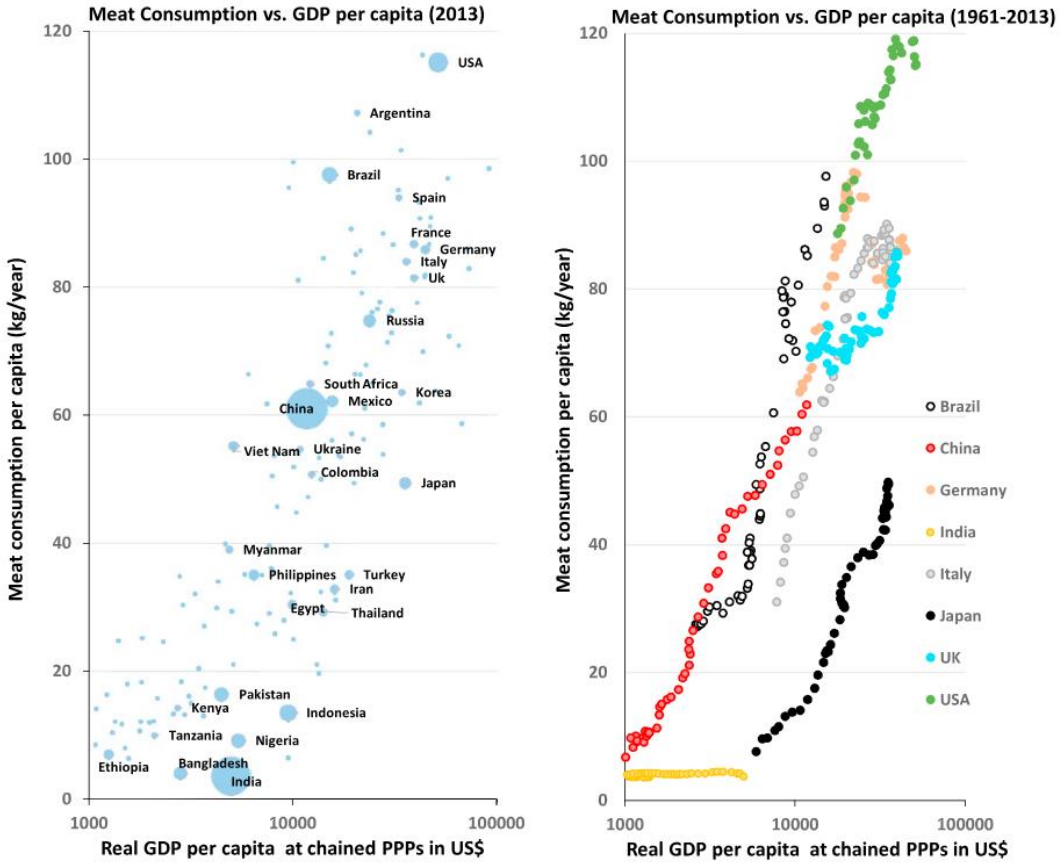

Figure 6 Bennett's law justifies the relationship between meat consumption and income levels, as expressed in terms of GDP per capita in US $ at chained purchasing power parity (PPP). In the right figure, we can observe a clear increasing trend in meat consumption as income rises, this is a perfect demonstration of Bennett's law (D'Odorico et al. 2018).

In our analysis, we've chosen to focus on bovine meat, poultry meat and milk (excluding butter). We chose these three types of foods given their massive impact to GHG emissions given by the countless intensive livestock farms around the world (Godfray et al., 2018) . These foods, all three of which are animal-based, are finding alternatives such as cultured meat and plant-based milk, so they could

be game changers in the dietary shift . Initially, we analyzed and plotted the consumption trends of these three goods for each region of the world surveyed (18), putting the good consumption (kg/year per capita) on the y-axis and GDP (US $/year) on the x-axis for each region. This allowed us to compare trends of the goods with those of the GDP to identify communicative patterns. Additionally, analyzing the consumption trends of goods in different regions can be useful for highlighting regional habits and drivers. Although the method is clear, regional regrouping could conceal possible findings at the national level.

2.2.1 Linear regression to fit Bennett's Law to past consumption trends

To assess the values of the data, we proceeded with a linear regression method used to model the relationship between two variables, where the independent variable is used to predict the value of the dependent variable, respectively food consumption (kg/year per capita) as the dependent variable and GDP (US $/year) as the independent variable. In this case, a single linear regression is sufficient as there is only one independent variable. The relationship between the variables is assumed to be linear, meaning that a change in the independent variable x is associated with a constant change in the dependent variable y. To find the regression line we chose the method of Ordinary Least Squares (OLS) which is an optimization technique that allows finding a function that closely approximates a set of data. In particular, the found function should be the one that minimizes the sum of the squares of the distances between the observed data (consumption for specific GDP) and those of the curve representing the function itself. The goal of this analysis is to find a correlation between the two variables to establish if Bennett's law correctly describes the consumption trend as GDP changes or not.

The equation for a simple linear regression model is typically written as:

$$y=\beta 0+\beta 1*x+\varepsilon$$

The regression analysis estimates the values of β_0 and β_1 that best fit the data, while ε is the error term representing the difference between the observed and predicted values. These estimated coefficients can then be used to predict the value of the dependent variable for a given value of the independent variable. Along with the regression function, we computed the R squared value, also known as the coefficient of determination. It describes the proportion of the variance in the dependent variable that is explained by the independent variable. In other words, R squared measures how precisely the data fits the regression line. A higher R squared value indicates a better fit, meaning that a larger proportion of the variability in the dependent variable can be explained by the independent variable. Otherwise, a scarce value shows a poor correlation between the two parameters. To assess the statistical significance of the relationship (described by R^2) between the variables we also computed the p-value. It is the probability, for a supposed true hypothesis (called the null hypothesis), of obtaining results equally or less compatible than those observed during the test, with the hypothesis. In other words, the p-value helps to understand whether the difference between the observed result and the hypothesized one is due to the randomness introduced by sampling, or whether such a difference is statistically significant, meaning it is difficult to explain through randomness due to sampling. A low p-value suggests that it is unlikely to observe such a result by random chance alone, indicating that the independent variable likely has a meaningful impact on the dependent variable. Conversely, a high p-value suggests that the observed result is reasonably likely to occur even if there were no real relationship between the variables. In such cases, we may not have enough evidence to conclude that the independent variable significantly influences the dependent variable. In particular, we computed the p-value associated with the Student test, t. The Student's t-test is a statistical hypothesis test used to determine if there is a significant difference between the means of two data groups, hence GDP and consumption. Consequently, the p-value is calculated, which represents the probability of observing the test statistic under the null hypothesis, finding statistical significance in the relationship between the two parameters. In our computation, we refer to a p-value minor to 1% with three asterisks *** (extremely significative), when the p-value ranges 1%-5% we refer

to it as two asterisks ** and when its value is between 5% and 10%, we refer it to one *. If the p-value exceeds 10% we don't rely on its significance.

In conclusion, the reliability of fitting is essential to ensure that the regression model provides accurate and valid estimates of the parameters, as well as reliable predictions for the dependent variable.

2.3 Literature Analysis to Address Additional Drivers Besides GDP

Shifting social behaviour (Nyborg et al., 2016) toward sustainable choices is a complex yet crucial aspect in addressing drivers of transforming food systems. Consumer preferences are often influenced by price, health implications, availability, novelty, cultural traditions etc. In this section, we focused on identifying the factors and drivers (other than GDP) that determine or influence the consumption of the three commodities studied: beef, poultry meat and milk. At this stage, it is difficult to attribute the exact impact of each factor on consumption, as we have chosen to conduct a qualitative analysis. Understanding how these processes affect consumption trends can lay the foundation for developing a multiple linear model that can better describe the phenomenon. Under normal circumstances, these elements/processes are a possible tipping point for the foods studied, as they are able to promote the conditions and development of the process. In the next chapter, we present a table that categorizes and contextualizes these candidate tipping elements.

2.4 Learning from the Past Case Studies

We analyzed some historical events on a national scale that led to diet transition through a series of actions and processes. This research could be instrumental in understanding how diets can be concretely transformed and by what. Indeed, not

only consumer choices shape markets and demands, but also socioeconomic changes, scientific innovations, and government policies.

This chapter delves into the dynamic relationship between these processes and their outcomes, to categorize them as catalysts for transformative shifts in dietary patterns.

Table 3 Case studies scheme which describes food type, process and drivers of the event, further analysis in chapter 3.3.

Case study	Food type	Process and drivers
China	Bovine meat	Urbanization, globalization, economic growth
Samoa	Poultry meat: turkey tails and chicken backs	Globalization, trades, health reforms
Denmark	Saturated fats food	Taxation, health concerns, price elasticity, consumer choice
Chicken of Tomorrow	Poultry meat	Artificial breeding, technological innovations, food demand

3 RESULTS

This chapter aims to show the analysis of consumption trends and their correlation with income availability, exploring consumer behaviour and addressing the drivers behind consumption patterns. The chapter begins by showing trends and linear regression on a regional scale to identify similar patterns and relationships between income levels and consumption habits. Subsequently, the chapter presents case studies from the past to provide real-world examples and contextualize the findings within historical and socio-economic contexts.

3.1 Bennett's law at the regional scale

3.1.1 Africa

3.1.1.1 Northern Africa

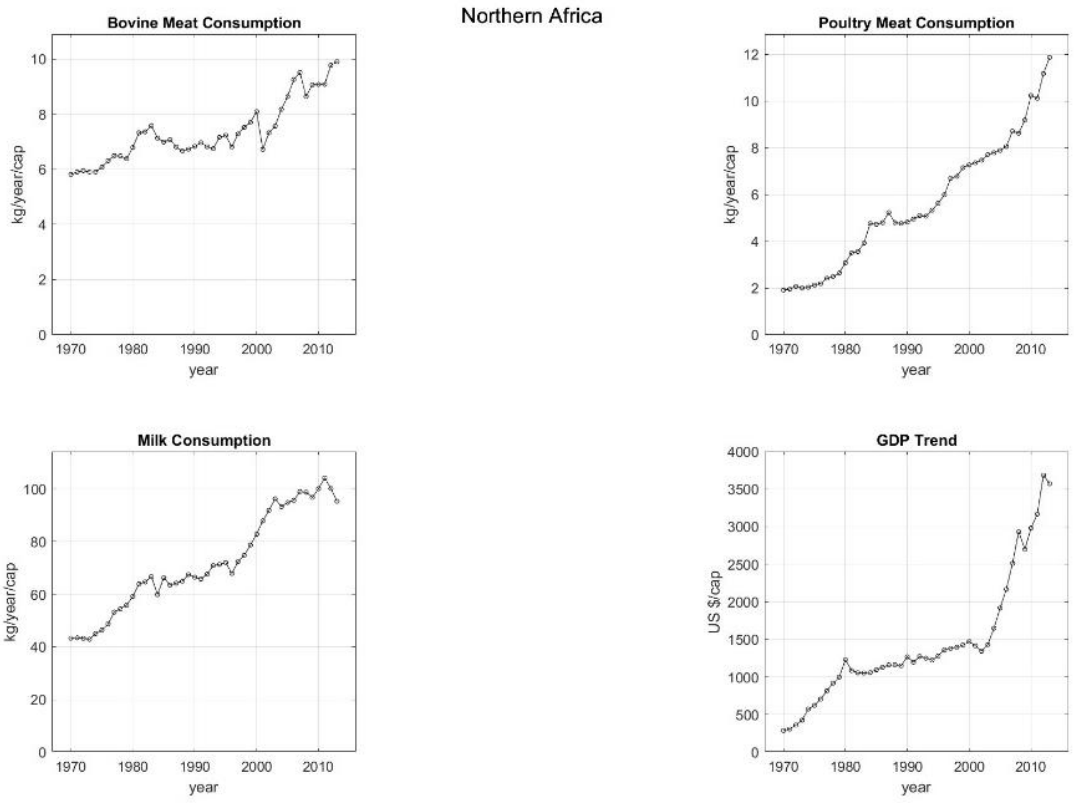

Figure 9 Northern Africa trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Northern Africa includes Algeria, Egypt, Morocco, Sudan and Tunisia. The bovine meat consumption trend starts from 6 reaching 10 kilograms over the years, the poultry one instead follows the GDP trend regularly, reaching 12 kg in 2013. This corresponds to a modest fit between the two parameters as we will see in the next figure. Milk usage grew reaching the maximum in 2011 with more than 100 kg per year.

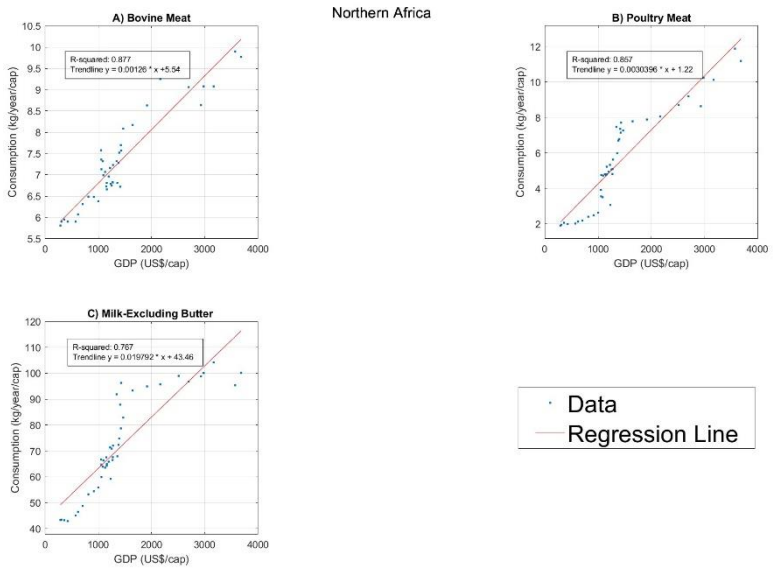

Figure 10 Linear regression of the trend of the three goods in relation to the average Northern Africa GDP.

It's noticeable that Northern Africa linear regression shows very good fits, in particular, the R^2 value is 0.877 for bovine meat, 0.857 for poultry meat and 0.767 for milk consumption. This implies that data closely follows the trend line. Here is a solid example of Bennett's law.

3.1.1.2 Eastern Africa

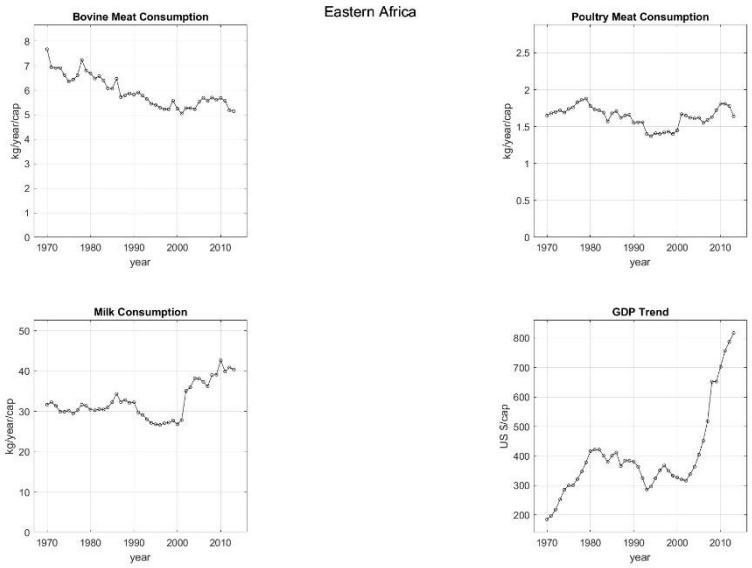

Figure 11 Eastern Africa trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Eastern Africa covers Djibouti, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Uganda, Tanzania, Zimbabwe, and Zambia.

Eastern Africa shows relatively low consumption of goods in general. They are also constant over time, indicating that maybe these products aren't the main portion of the diet.

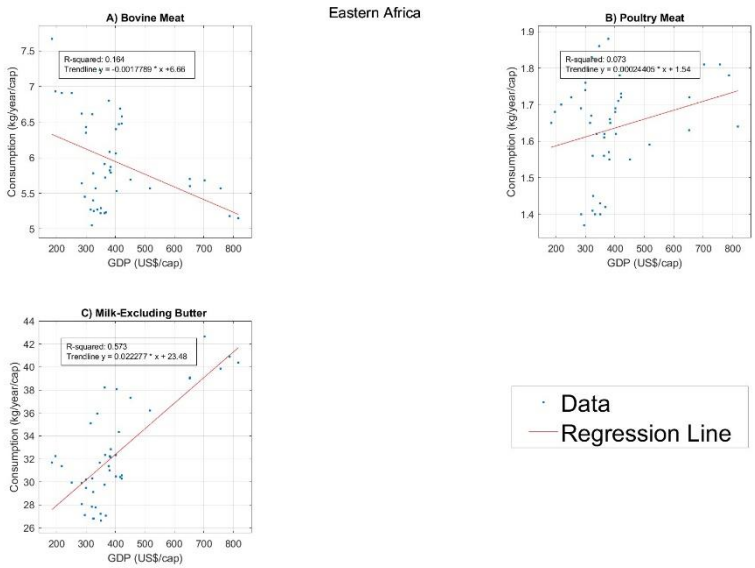

Figure 12 Linear regression of the trend of the three goods in relation to the average Eastern Africa GDP.

In this graph, we can see that the correlation between the GDP growth and the bovine meat consumption is meagre, at least before 2006. Poultry meat also doesn't follow the GDP trendline at all, giving an R^2 value equal to 0.0073. Regarding milk, we can observe a better connection between the two parameters, especially in the last years. Computation shows in fact that the R^2 value for milk is 0.573. As poultry meat, panel A) displays a poor correlation value of 0.164.

3.1.1.3 Middle Africa

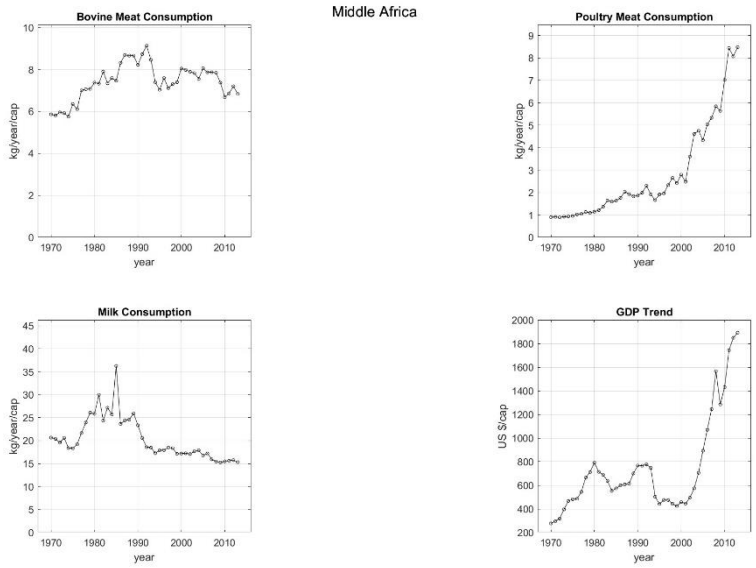

Figure 13 Middle Africa trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Middle Africa includes Angola, Cameroon, Chad, Congo, Gabon, Sao Tome and Principe, Central African Republic.

While bovine meat consumption remains steady, poultry meat trend has exponentially increased since 2000, following economic growth. Milk data shows a peak in consumption during the 80's and then a slight decrease reaching 15 kilograms per year.

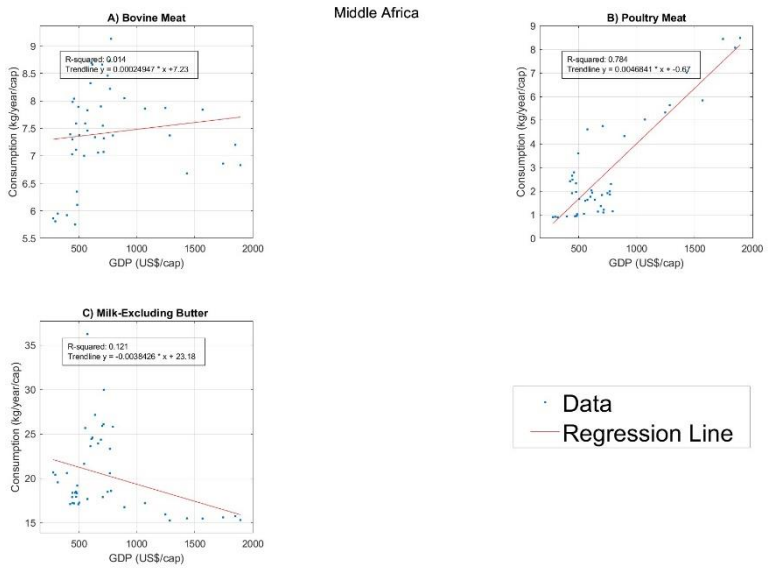

Figure 14 Linear regression of the trend of the three goods in relation to the average Middle Africa GDP.

As in the previous case, Middle Africa has a very low fit in the graph. This means that there is a 1.4% probability that the data follows the trend line. We saw a stable linearity in Figure 5 between poultry and GDP data, resulting in a robust fit of 0.784. Milk trend consumption doesn't respect the Bennett Law as there's a very poor correlation explained by R^2 equal to 0.121.

3.1.1.4 Southern Africa

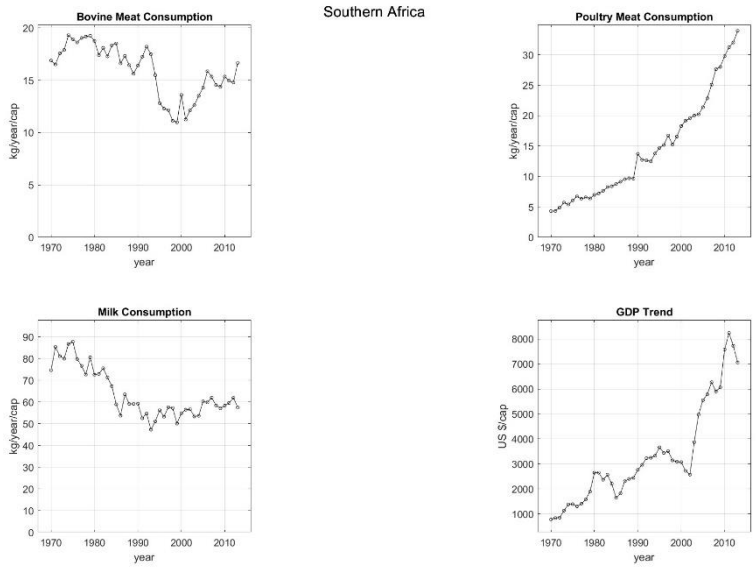

Figure 15 Southern Africa trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Southern Africa covers Botswana, Eswatini, Lesotho, Namibia, South Africa.

We can immediately notice a general increase in goods consumption. This could be driven by the economic difference with the previous African regions. The milk trend decreased after 1982, the poultry one is constantly increasing and the bovine meat trend denotes ups and downs.

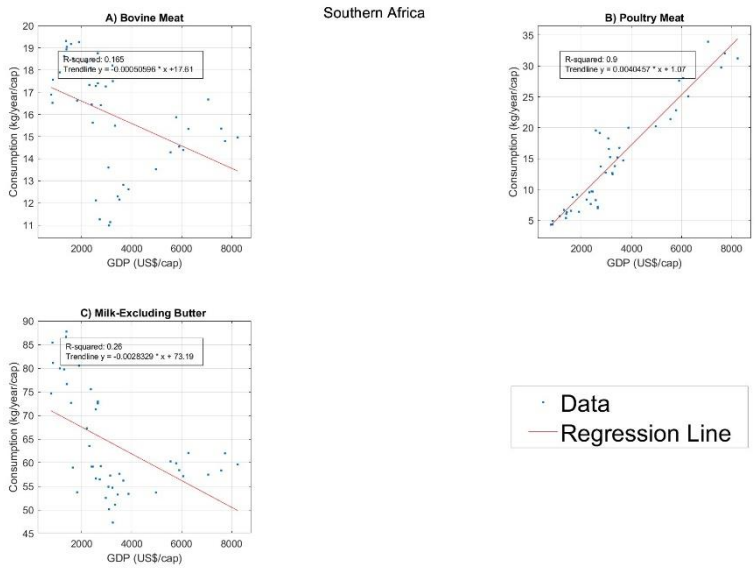

Figure 16 Linear regression of the trend of the three goods in relation to the average Southern Africa GDP.

Southern Africa also presents a scarce correlation between the variables, except for the poultry meat trend which finds an extremely good relationship with GDP. Hence Bennett's law doesn't justify a change in bovine meat(R^2=0.105), and milk consumption as GDP varies (R^2=0.26), while it also results in a 0.9 value for R squared for poultry data.

3.1.1.5 Western Africa

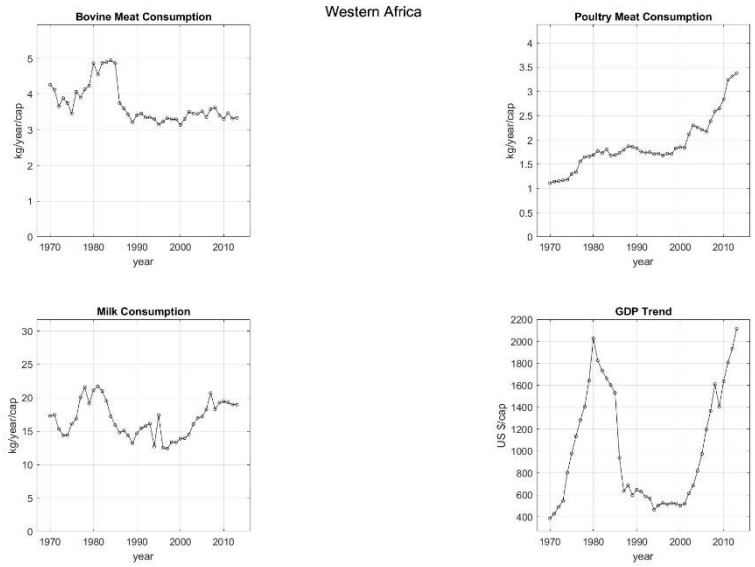

Figure 17 Western Africa trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Western Africa comprises Benin, Burkina Faso, Cote d'Ivoire, Gambia, Ghana, Guinea, Mali, Nigeria, Senegal, Sierra Leone, Togo, Liberia, Mauritania, Niger, Guinea-Bissau, Cabo Verde, Benin.

Western Africa plots show a quite homogeneous dispersion of the data. Milk and bovine meat trends are likely to vary over time without relevant peaks or valleys. Poultry trend has been slightly increasing, especially in the last years. GDP is present a huge swing due to wars and other economic crisis.

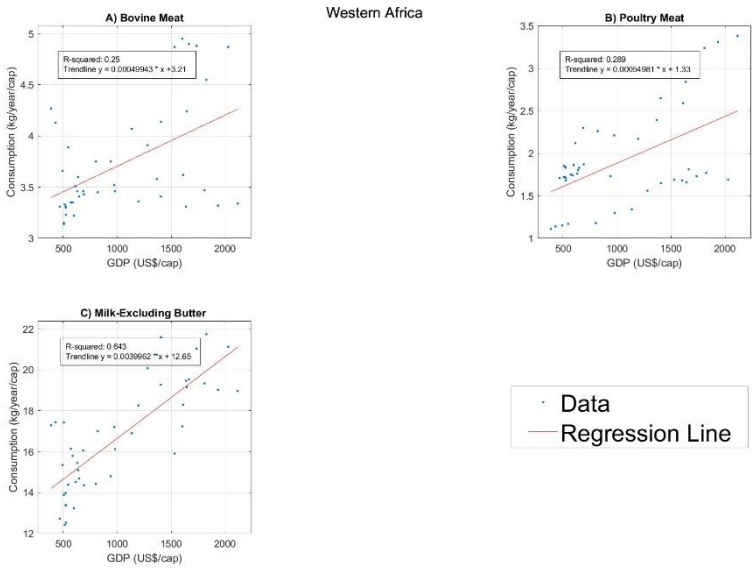

Figure 18 Linear regression of the trend of the three goods in relation to the average Western Africa GDP.

From the values we find from the analysis, we can deduce that Western Africa region is not a good example to explain the correlation between GDP and the goods consumption trends given little R^2 values of 0.25 for bovine meat, 0.289 for poultry meat and 0.643 for milk.

In summary, only the North African region presents a clear example of the law. This phenomenon can be explained by the fact that the latter is the African region most involved in globalization and trade with the rest of the world. In the rest of the continent, a simple lifestyle still prevails following cultural traditions such as pastoralism, hunting, and basic cultivation. Very often the poverty of these countries does not allow world trade, at least in beef, which is considered one of the best qualities of meat.

3.1.2 Asia

3.1.2.1 Central Asia

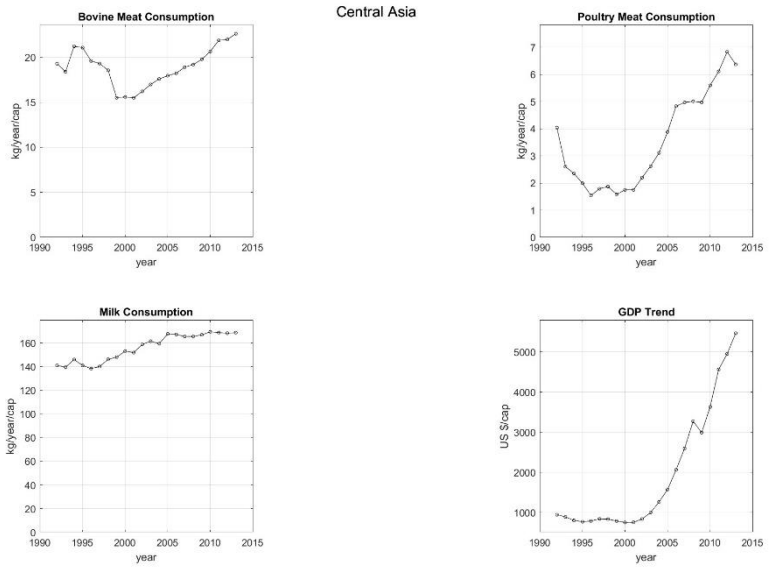

Figure 19 Central Asia trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

It contains Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.

Regarding this specific region FAOstats consumption data are starting from 1990, hence further analysis is conducted in a shorter period, 1990-2013.

Central Asia pictures a very clear increasing trend line starting in the 2000s for both types of meat. A high level of milk consumption characterizes this region reaching above 160 kilograms consumed per year. GDP had exponential growth starting from 2000, stopping just for the 2008 global crisis.

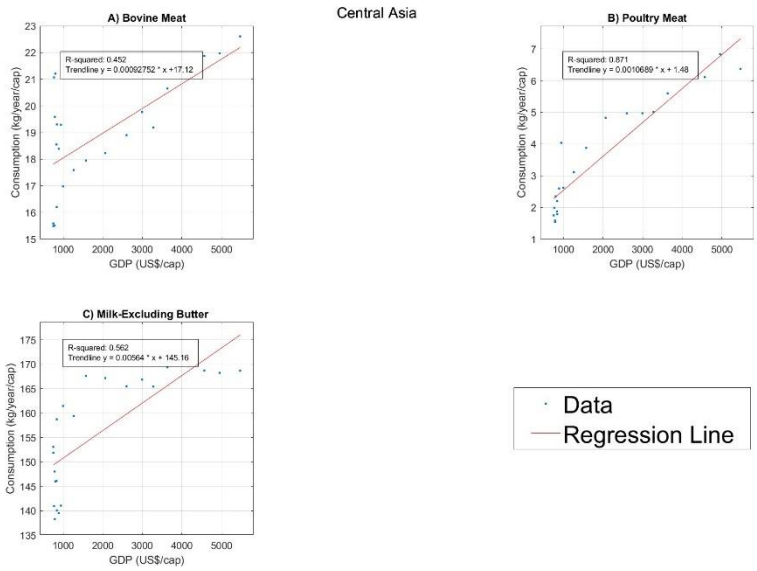

Figure 20 Linear regression of the trend of the three goods in relation to the average Central Asia GDP.

Given the poorness of the sample in the Central Asia case study, we have reduced data hence a less precise model. Except for the poultry meat (R^2=0.871), we cannot draw any consistent conclusion. For instance, we can notice that the last data point in panel B) is a very clear sign of a growing trend. For the other two linear regressions, we can observe R^2 values of 0.452 for bovine meat and 0.562 for milk, so we cannot draw any precise conclusion.

3.1.2.2 South-eastern Asia

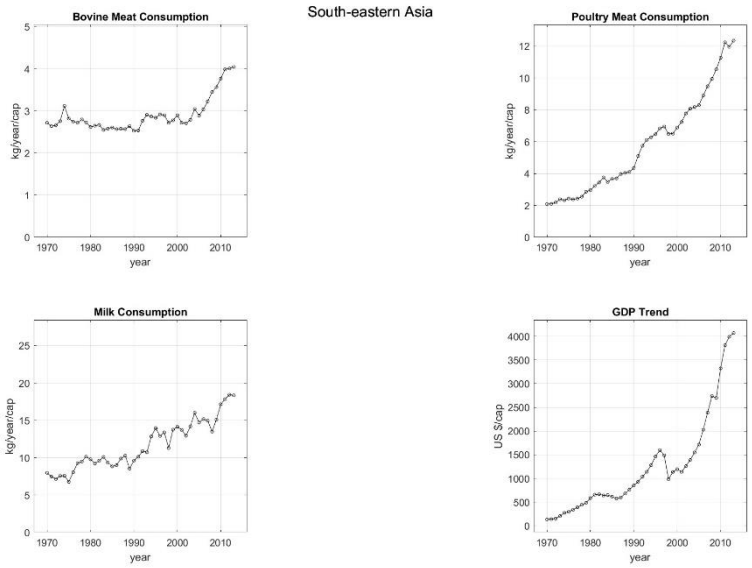

Figure 21 South-east Asia trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

This region includes Indonesia, Cambodia, Lao Democratic Republic, Malaysia, Philippines, Timor-Leste, Thailand, Vietnam, Brunei Darussalam, and Myanmar.

As per the previous graph, the consumption here has constantly grown since the 90s in the bovine meat case. Milk trend is growing constantly and poultry usage seems to follow the GDP growth.

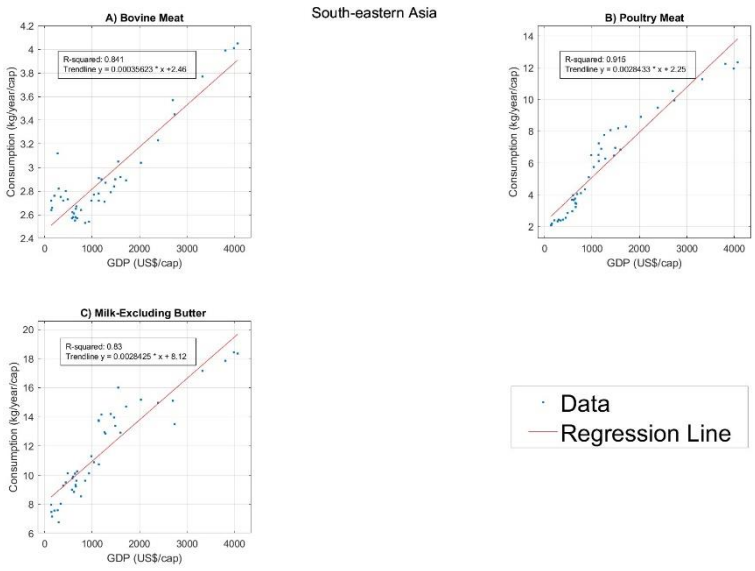

Figure 22 Linear regression of the trend of the three goods in relation to the average region GDP.

Fits are very strong, especially in the poultry case, in which we can trust the trend line with a 91.5% probability of predicting next years' data. The other R^2 values are similar: 0.841 and 0.83, respectively for bovine meat and milk.

3.1.2.3 Southern Asia

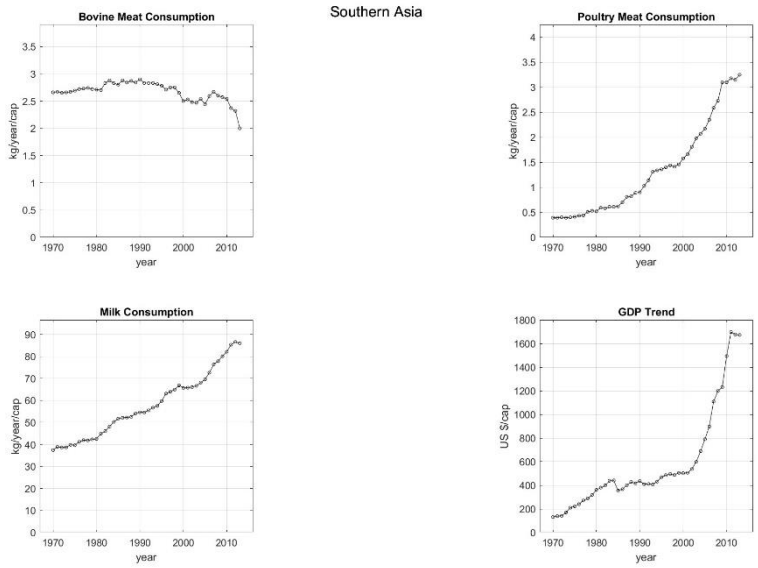

Figure 23 Southern Asia trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

This region regroups India, Iran, Maldives, Nepal, Bangladesh, Pakistan, Afghanistan, Sri Lanka.

Southern Asia is characterized by the presence of India and its faiths. The country presents the highest percentage of vegetarian citizens in the world as many communities don't consume any type of meat for their beliefs. In addition, Hinduism forbids the consumption of bovine meat as it considers cows as holy creatures. Because all this consumption level is going to be lower and lower even if GDP increases. Poultry meat and milk consumption increased during the years doubling milk usage level and reaching 3.5 kilos of poultry meat consumed.

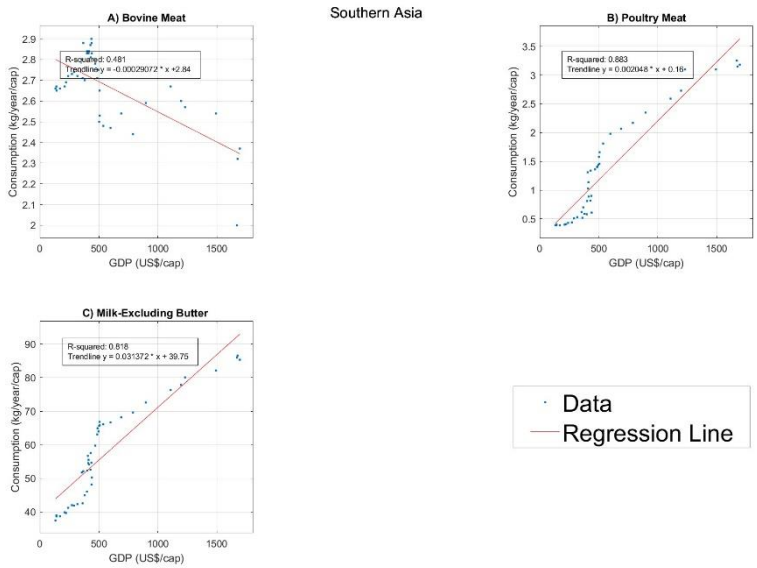

Figure 24 Linear regression of the trend of the three goods in relation to the average Southern Asia GDP.

As we predicted, the consumption of bovine meat is not related to income level (R^2=0.481), while milk and poultry are more likely to follow the law with R^2 values respectively of 0.818 and 0.883.

3.1.2.4 Eastern Asia

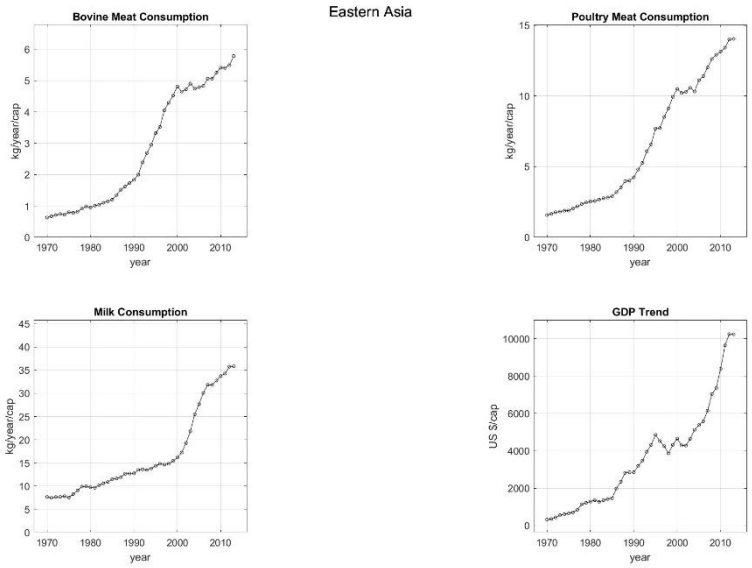

Figure 25 Eastern Asia trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Eastern Asia involves Japan, Democratic Republic of Korea, Republic of Korea, Macao, Mongolia, Taiwan, China, Hong Kong.

We can clearly observe a steep increase in all three goods usage levels over time.

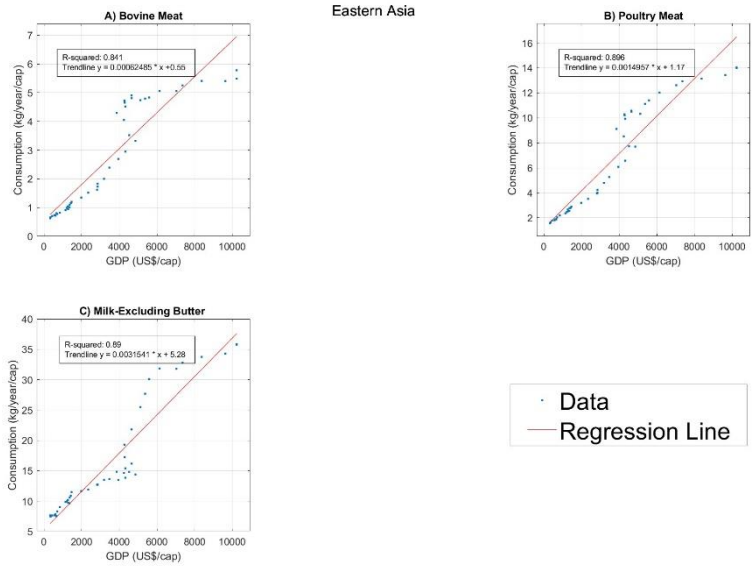

Figure 26 Linear regression of the trend of the three goods in relation to the average Eastern Asia GDP.

Eastern Asia data gives us a robust fit in all three linear regressions: R^2=0.841 for bovine meat, R^2=0.896 for poultry meat and R^2=0.890 for milk. We can notice a small hump in all the graphs due to an economical flatness from ’95 to ’05.

3.1.2.5 Western Asia

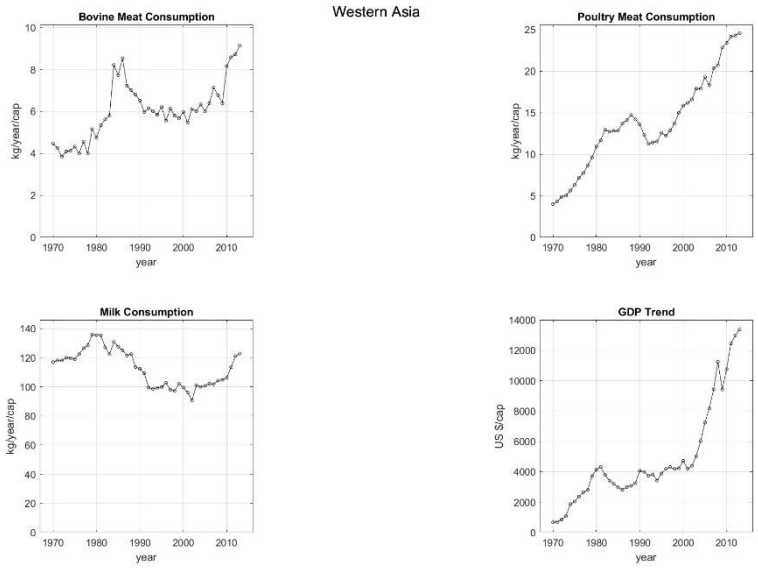

Figure 27 Western Asia trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Western Asia contains Armenia, Iraq, Israel, Jordan, Kuwait, Lebanon, Saudi Arabia, Oman, Türkiye, United Arab Emirates, Yemen, Cyprus, Azerbaijan, and Georgia.

Bovine meat consumption level has doubled over the years, while the milk one remains constant. Poultry meat consumption is more likely to follow economic growth.

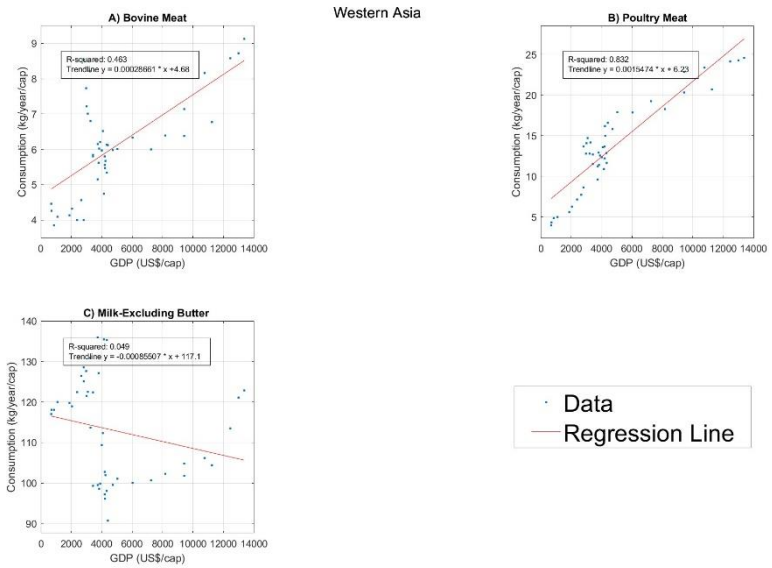

Figure 28 Linear regression of the trend of the three goods in relation to the average Western Asia GDP.

The only regression that confirms the law is once again the poultry one with an R^2 value equal to 0.832. Bovine meat regression shows a medium fit value of 0.463, milk computation instead presents a low value of 0.049.

In all Asian regions, we can note a limpid increasing trendline after 1990-2000 for all the goods. This tells us that globalization plays a crucial role in this study. Easier and faster ways of communication and logistics benefit global trade. Also, urbanization and innovation crushed Asia in this way. In conclusion, Bennett's law explains the increase in demand for beef as income grows and this continent is the clearest evidence of this phenomenon.

3.1.3 America

3.1.3.1 Central America

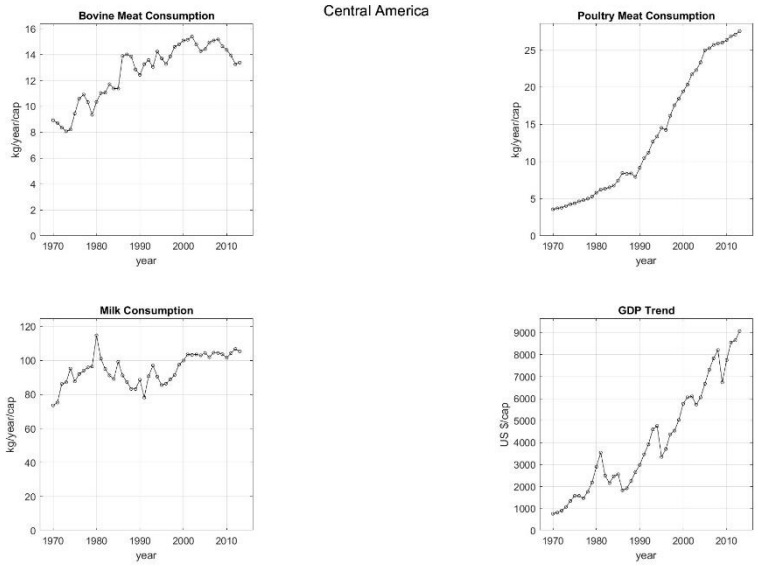

Figure 29 Central America trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Central America comprehends Mexico, Nicaragua, Panama, Belize, Costa Rica, El Salvador, Guatemala, Honduras.

GDP level has been swinging through the years but keeping a positive trendline. This growth is tracked by poultry consumption but not by the other two goods as they increase overall but at a scarce pace.

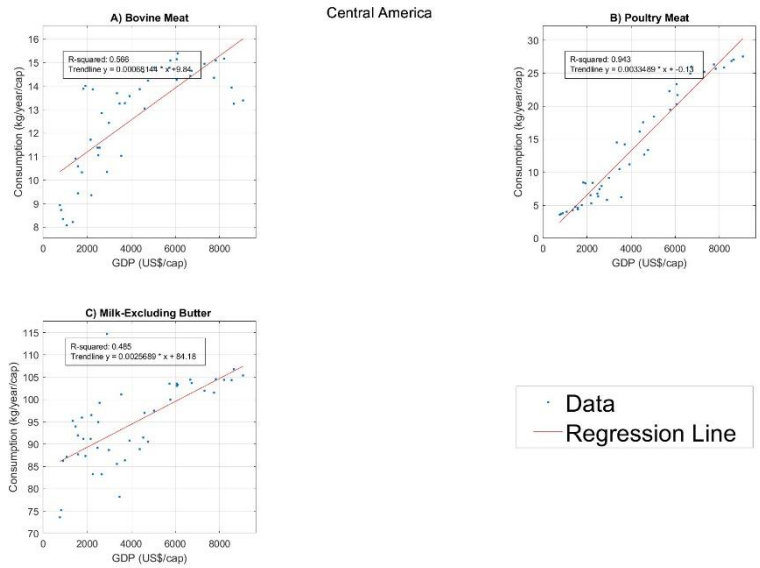

Figure 30 Linear regression of the trend of the three goods in relation to the average Central America GDP.

Here we find the best R^2 value of 0.943 for poultry meat consumption. Regarding the other two goods, we see data points scattered not really following the trendline. R^2 value of bovine linear regression is 0.566 while the milk one equals 0.485.

3.1.3.2 Northern America

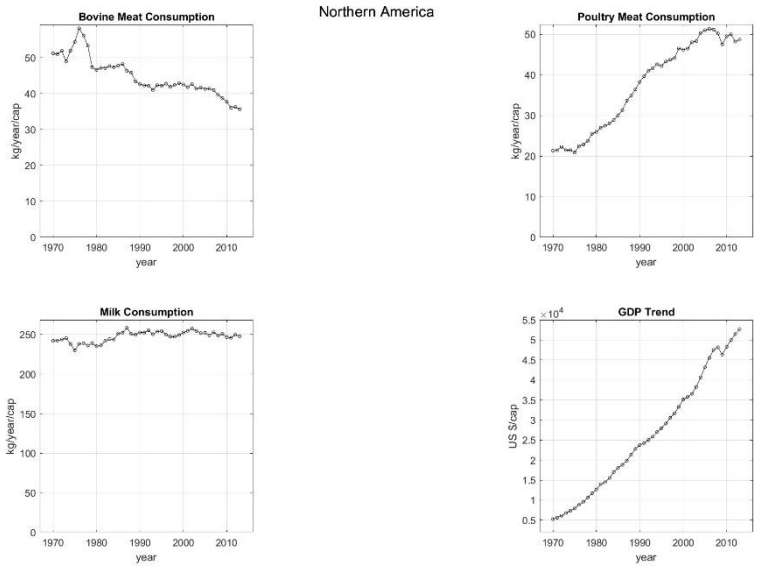

Figure 31 Northern America trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Northern America contains United States of America, Canada, Bermuda.

All three goods' consumption levels are extremely high compared to the ones we saw before. Although milk consumption remains stable and bovine meat consumption decreases. Poultry meat usage has also diminished in the last few years. GDP increase only stops for the 2008 crisis.

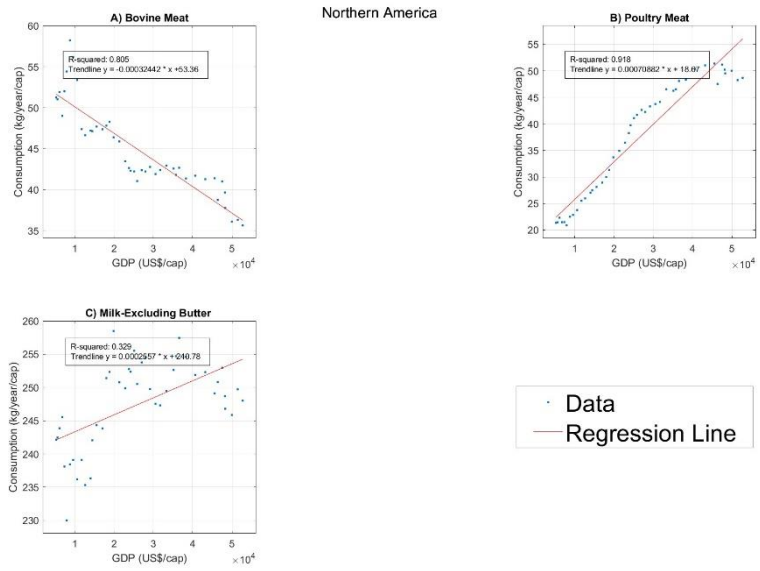

Figure 32 Linear regression of the trend of the three goods in relation to the average Northern American GDP.

Even if the bovine meat consumption pro capita is still extremely high in North America, the plot shows us a crisp decreasing trendline with an accurate fit of R^2 = 0,805. Here we can do a hypothesis that puts a limit level of consumption in Bennett's law. Hence after a determinate value of income, the consumer starts to vary his diet. Milk usage doesn't change much as income increases, hence the fit is low (0.329). Poultry meat data remained close to the trendline until last year still giving a high R^2 value of 0.918. Although this region maintains a very high level in beef consumption, the trend in the last years seems to have stabilised or even decreased. This could be due to a limit value level of meat demand in which an increase in income doesn't recall an increase in consumption. Countries such as the USA and Canada are among the biggest consumers in the globe.

3.1.3.3 South America

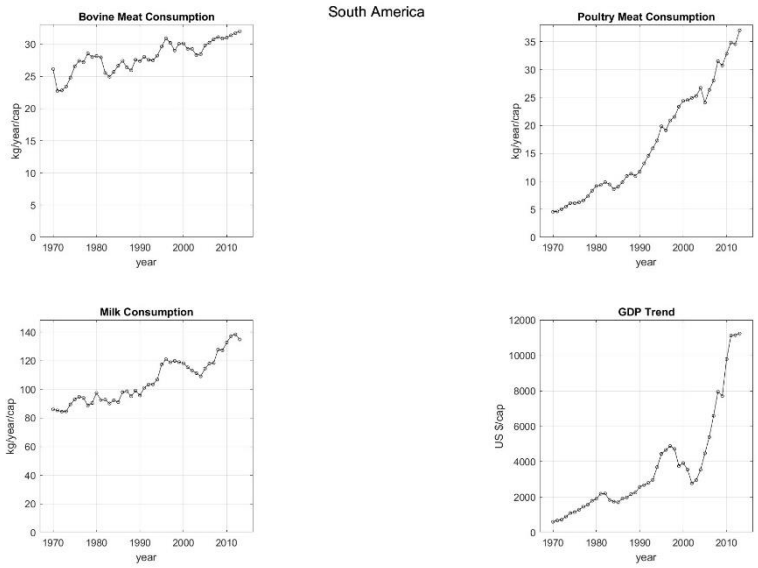

Figure 33 South America trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

This region contains Paraguay, Peru, Bolivia, Suriname, Brazil, Uruguay, Venezuela, Chile, Colombia, Ecuador, Argentina, and Guyana.

Poultry meat and milk consumption levels are slowly increasing during the years while poultry meat usage grows even when income decreases.

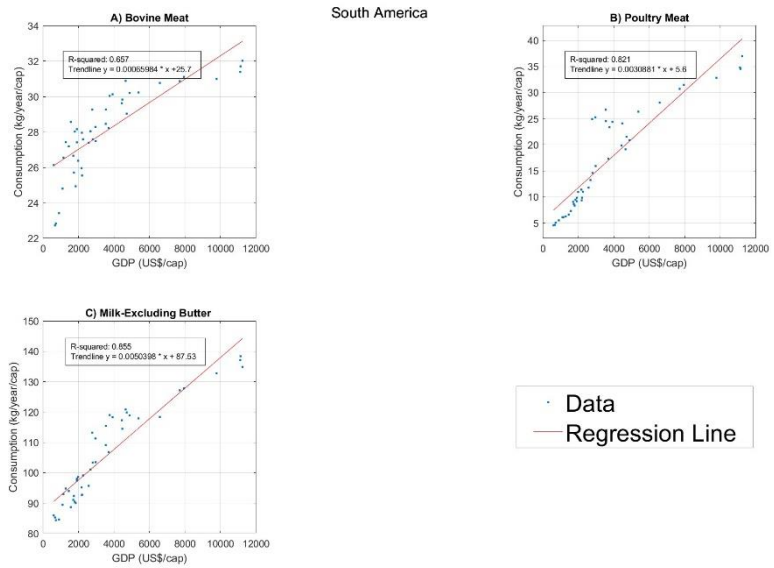

Figure 34 Linear regression of the trend of the three goods in relation to the average South American GDP.

Southern America presents a solid fit in milk and poultry meat regression. However, the bovine meat usage level seems to dissociate from the GDP trend reaching a limit value of consumption of 30 kg of bovine meat per year per capita. This comports to a medium R^2 value of 0.657. Poultry meat once again confirms its loyalty to the Bennett Law with a robust fit value of 0.821, while milk's linear regression output is R^2=0.855.

3.1.4 Europe

3.1.4.1 Eastern Europe

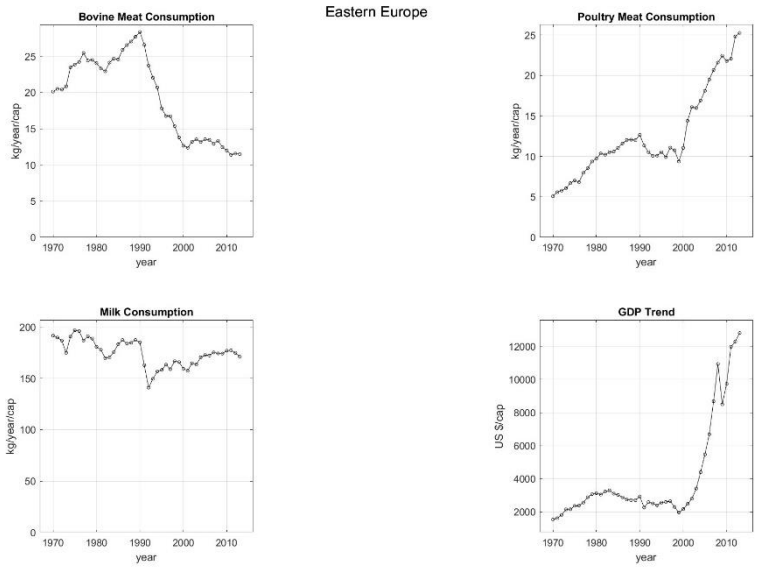

Figure 35 Eastern Europe trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Eastern Europe contains Moldova, Czechia, Poland, Romania, Russian Federation, Slovakia, USSR, Ukraine, Bulgaria, Czechoslovakia, Belarus, and Hungary.

GDP starts growing very rapidly starting from the '90s, even if the 2008 financial crisis hits, growth is directly proportional to the poultry meat consumption level. Meat usage level instead decreased in the 90's finding stability at around 12 kilos per capita in 2000. Eventually, all three goods experienced a consumption decrease after 1990 due to the economic crisis after URSS's dissolution.

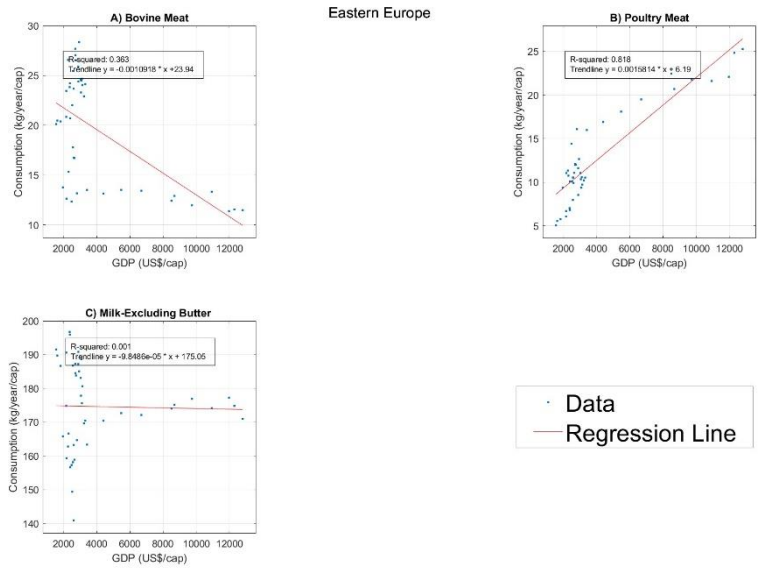

Figure 36 Linear regression of the trend of the three goods in relation to the average Eastern Europe GDP.

Except for the poultry meat graph, we can't draw any solid conclusions. Poultry meat shows a consistent R^2 of 0.818, and the bovine one R^2 value is equal to 0.363. Milk consumption-GDP correlation instead is the lowest we found as the R^2 value is 0.001.

3.1.4.2 Northern Europe

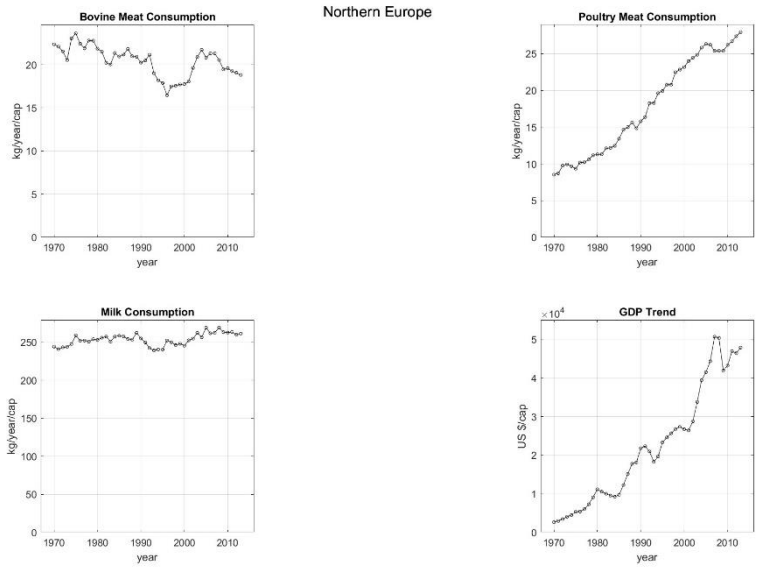

Figure 37 Northern Europe trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Northern Europe contains Ireland, Latvia, Lithuania, Norway, Sweden, the United Kingdom of Great Britain and Northern Ireland, Denmark, Estonia, Finland, and Iceland.

Milk and bovine meat usage levels stay quite steady at 250 and 20 kilograms respectively, while the poultry one rises as GDP increases.

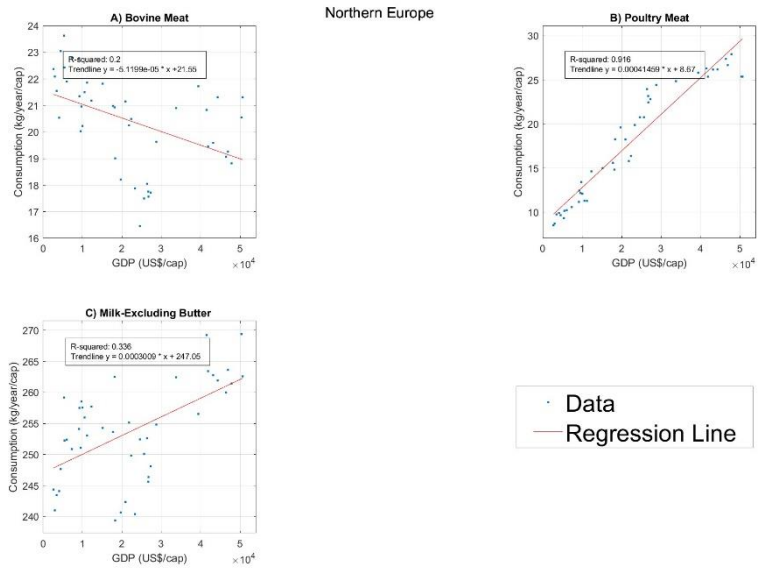

Figure 38 Linear regression of the trend of the three goods in relation to the average Northern Europe GDP.

As we discussed before milk and bovine meat linear regressions show scattered data all over the graph, giving respectively an output of R^2 =0.336 for milk and R^2=0.2 for bovine meat while poultry meat one presents a very precise fit of 0.916.

3.1.4.3 Western Europe

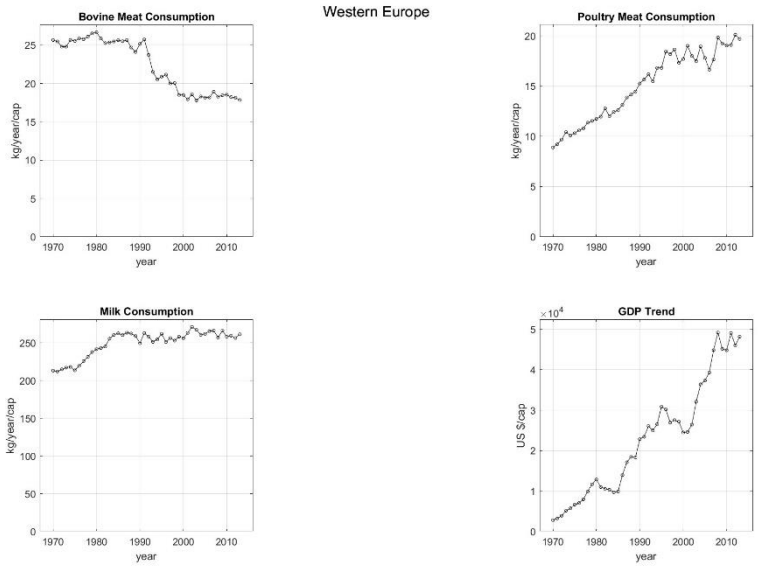

Figure 39 Western Europe trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

This region contains Austria, Belgium, Luxembourg, Netherlands, Switzerland, France, and Germany.

Poultry meat usage doubled during the years while milk one is finding stability at around 250 kilograms per year per capita. Bovine meat started to decrease in 1990. Despite some ups and downs, GDP has a positive trend.

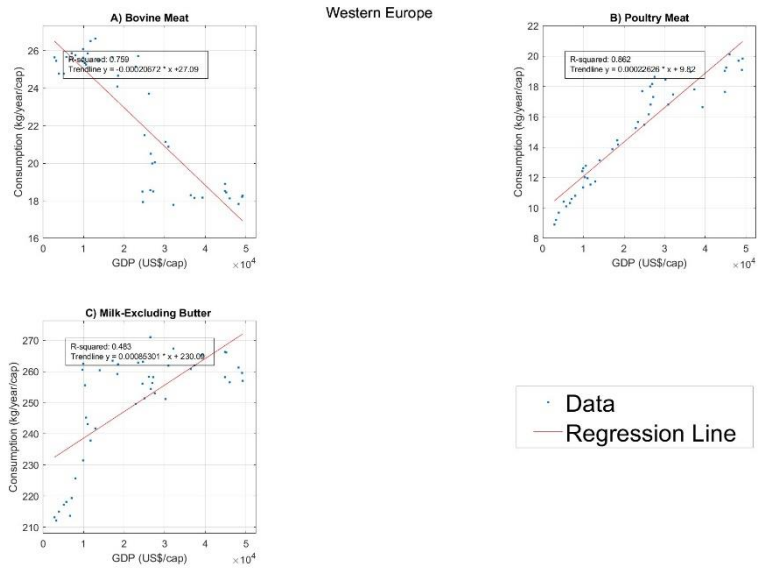

Figure 40 Linear regression of the trend of the three goods in relation to the average Western Europe GDP.

Both types of meat consumption display a solid fit, but the bovine line is downward while the poultry one is upward reflecting their consumption trend. In particular, panel A) shows an R-squared value of 0.759 while graph B) displays a fit of 0.862. Milk linear regression instead presents a medium result of 0.483.

3.1.4.4 Southern Europe

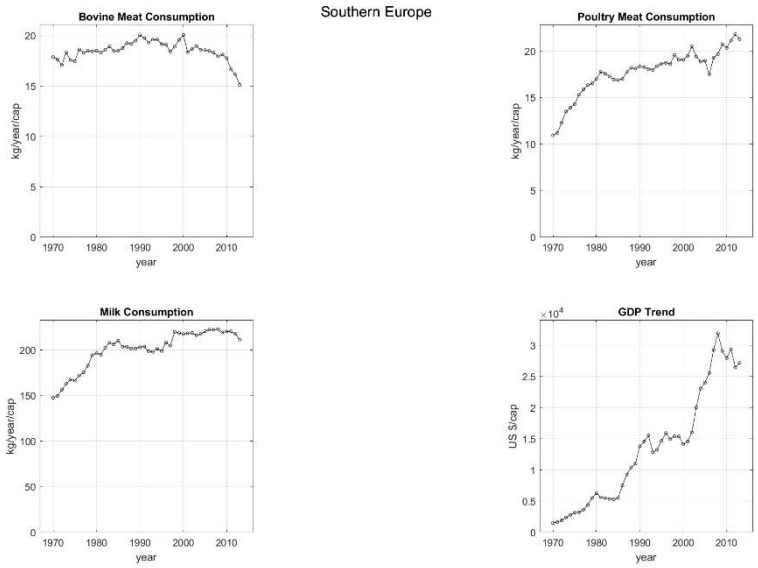

Figure 41 Southern Europe trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Southern Europe includes Italy, Malta, North Macedonia, Portugal, Serbia, Montenegro, Slovenia, Spain, Albania, Yugoslav SFR, Bosnia and Herzegovina, Greece, and Croatia.

Southern Europe plots results similar to the previous one.

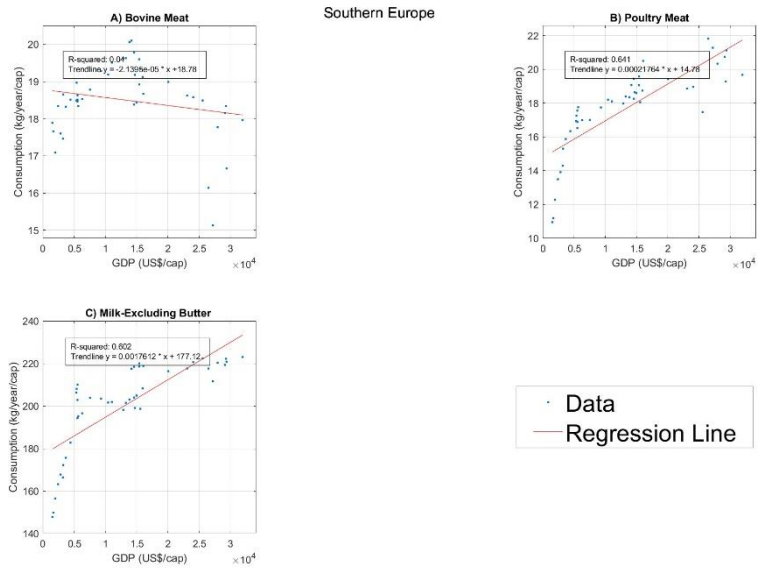

Figure 42 Linear regression of the trend of the three goods in relation to the average Southern Europe GDP.

As expected, the dispersion of data along the graphs results in scarce robustness in terms of statistics. Milk and poultry meat scatters are comparable even in the R^2 computation which is respectively 0.602 and 0.641. Concerning panel A) we can observe a fit value of 0.04, indicating no correlation between bovine meat consumption and the GDP level across the years.

3.1.5 Oceania

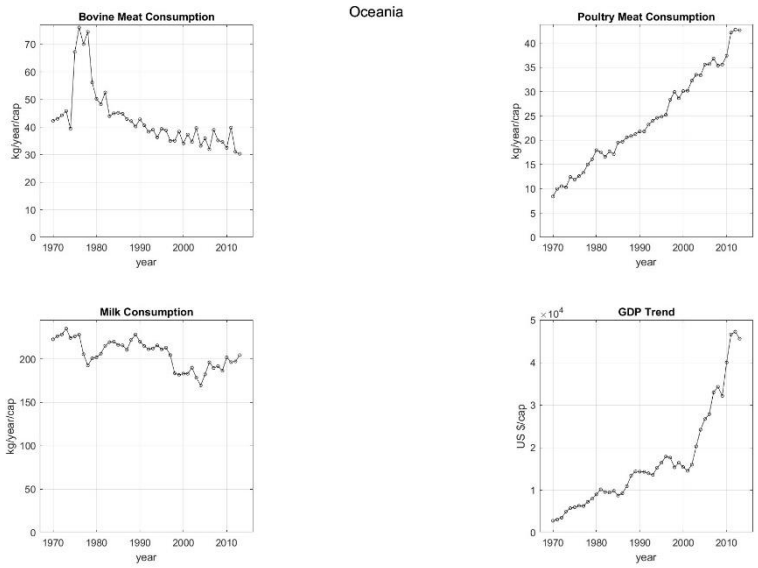

Figure 43 Oceania trend consumption of bovine meat, poultry meat and milk and GDP trend through the years.

Oceania contains Australia, New Caledonia, Vanuatu, New Zealand, Samoa Solomon Islands, Fiji, French Polynesia, and Kiribati.

The bovine meat consumption trendline presents an outlier during the 70s but overall, it is slightly decreasing over time. The milk line is steady at around 200 kg per year. GDP and poultry meat usage trends instead are increasing.

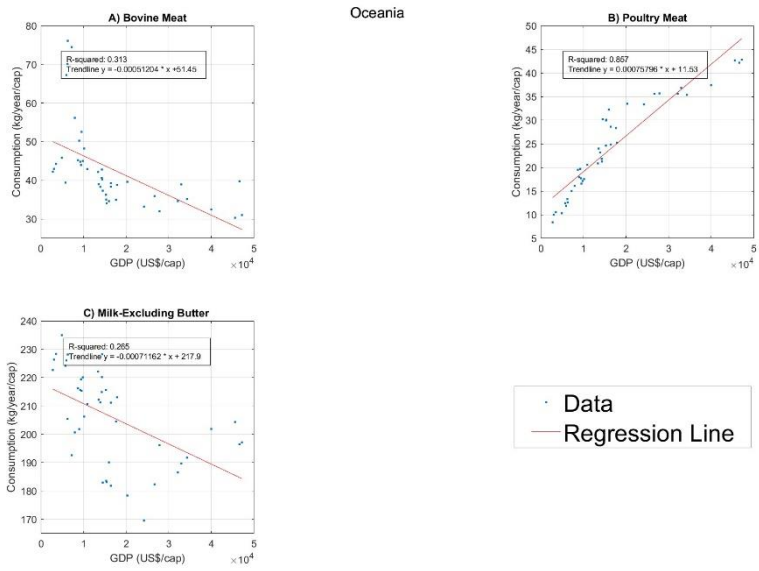

Figure 44 Oceania linear regression of the trend of the three goods in relation to the average region GDP.

Once again, the poultry meat regression is the most consistent with an R^2 value of 0.857. The bovine meat consumption doesn't strongly follow Benett's law showing an R^2 value of 0.313 and neither does milk consumption with 0.265.

3.1.6 Final Remarks

Below are three tables presenting the results of linear regressions between Gross Domestic Product (GDP), counted as average annual income per capita and the consumption of three types of goods: beef, poultry, and milk, counted as annual average kilograms consumed per capita. The data pertains to 18 world regions and covers the period from 1970 to 2013, except for Central Asia which covers only from 1990 to 2013, due to a lack of data in the FAO database.

Table 4 The following table encloses all the statistical data collected for bovine meat consumption, according to Bennett's law. Specifically, in the rows we find the subdivision of the macro areas of the globe into regions and in the columns respectively in order, the intercept of the regression line (beta zero), the angular

coefficient of the line (beta one), the correlation value of the two variables (R square) and finally the statistical reliability of the latter parameter(p-value).

BOVINE MEAT				
Region	β0 Value	β1 Value	R^2 Value	p-value
Northern Africa	5.54	0.0013	0.877	1.044×10^{-20} ***
Eastern Africa	6.66	-0.0020	0.164	0.4381 n.s
Middle Africa	7.23	-2.946×10^{-5}	0.014	0.0065 ***
Southern Africa	17.61	-0.0005	0.165	0.0061 ***
Western Africa	3.21	0.0005	0.25	5.557×10^{-4} ***
Central Asia	17.12	0.0009	0.452	6.107×10^{-4} ***
South-eastern Asia	2.46	0.0004	0.841	2.164×10^{-18} ***
Southern Asia	2.84	-0.0003	0.481	2.384×10^{-18} ***
Eastern Asia	0.55	0.0006	0.841	1.783×10^{-7} ***
Western Asia	4.68	0.0003	0.463	3.750×10^{-7} ***
Central America	9.84	0.0007	0.566	3.923×10^{-9}
Northern America	53.36	-0.0003	0.805	1.638×10^{-16} ***
South America	25.7	0.0007	0.657	2.649×10^{-11} ***
Eastern Europe	23.94	-0.0011	0.363	1.493×10^{-5} ***
Northern Europe	21.55	-5.12^{-5}	0.2	0.0023 ***
Western Europe	27.24	-0.0002	0.811	0.1913 ***
Southern Europe	19.48	-8.709^{-5}	0.245	1.466×10^{-14} ***
Oceania	51.45	-0.0005	0.462	7.904×10^{-5} ***

Table 5 The following table encloses all the statistical data collected for poultry meat consumption, according to Bennett's law. Specifically, in the rows we find the subdivision of the macro areas of the globe into regions and in the columns respectively in order, the intercept of the regression line (beta zero), the angular coefficient of the line (beta one), the correlation value of the two variables (R square) and finally the statistical reliability of the latter parameter(p-value).

POULTRY MEAT				
Region	β_0 Value	β_1 Value	R^2 Value	p-value
Northern Africa	1.22	0.0030	0.857	2.519×10^{-19} ***
Eastern Africa	1.54	0.0002	0.073	1.499×10^{-15} ***
Middle Africa	0.67	0.0047	0.784	0.0763 *
Southern Africa	1.07	0.0040	0.9	1.185×10^{-22} ***
Western Africa	1.33	0.0005	0.289	1.667×10^{-4} ***
Central Asia	1.48	0.0011	0.871	2.306×10^{-10} ***
South-eastern Asia	2.25	0.0028	0.915	3.051×10^{-22} ***
Southern Asia	0.16	0.0020	0.883	4.337×10^{-24} ***
Eastern Asia	1.17	0.0015	0.896	3.524×10^{-21} ***
Western Asia	6.23	0.0016	0.832	7.222×10^{-18} ***
Central America	0.13	0.0033	0.943	8.621×10^{-28} ***
Northern America	18.87	0.0007	0.918	1.988×10^{-24} ***
South America	5.6	0.0030	0.821	2.646×10^{-17} ***
Eastern Europe	6.19	0.0016	0.818	3.687×10^{-17} ***
Northern Europe	8.57	0.0004	0.916	3.570×10^{-24} ***

Western Europe	9.82	0.0002	0.862	6.873×10^{-11} ***
Southern Europe	14.78	0.0002	0.641	1.170×10^{-19} ***
Oceania	11.53	0.0008	0.857	2.485×10^{-19} ***

Table 6 The following table encloses all the statistical data collected for milk (excluding butter) consumption, according to Bennett's law. Specifically, in the rows we find the subdivision of the macro areas of the globe into regions and in the columns respectively in order, the intercept of the regression line (beta zero), the angular coefficient of the line (beta one), the correlation value of the two variables (R square) and finally the statistical reliability of the latter parameter(p-value).

MILK (EXCLUDING BUTTER)				
Region	β_0 Value	β_1 Value	R^2 Value	p-value
Northern Africa	43.46	0.0198	0.767	7.098×10^{-15} ***
Eastern Africa	23.48	0.0222	0.573	0.0207 **
Middle Africa	23.18	-0.0041	0.121	2.827×10^{-9} ***
Southern Africa	73.19	-0.0028	0.26	4.127×10^{-4} ***
Western Africa	12.65	0.0039	0.643	6.060×10^{-11}
Central Asia	145.16	0.0006	0.562	5.855×10^{-5} ***
South-eastern Asia	8.12	0.0028	0.83	1.019×10^{-21} ***
Southern Asia	39.75	0.0313	0.818	9.278×10^{-18} ***
Eastern Asia	5.28	0.0031	0.89	3.686×10^{-17} ***

Western Asia	117.1	-0.0009	0.049	0.147 n.s
Central America	84.18	0.0026	0.485	1.503×10^{-7} ***
Northern America	240.78	0.0002	0.329	4.633×10^{-5} ***
South America	87.53	0.0050	0.855	3.215×10^{-19} ***
Eastern Europe	158.53	9.84×10^{-5}	0.001	0.877 n.s
Northern Europe	247.05	0.0003	0.336	3.792×10^{-5} ***
Western Europe	230.09	0.0009	0.483	6.173×10^{-10} ***
Southern Europe	177.12	0.0017	0.602	1.689×10^{-7} ***
Oceania	217.9	-0.0007	0.265	3.494×10^{-4} ***

To draw any conclusions, we must select statistically significant results. To do so, we picked the elements in which we found a precise fit, specifically with an R-squared value major of 0.7. As stated before, we must check the integrity of the R^2 through the p-value. As explained above, p-values indicating greater robustness ($p<0.05$, indicated by ***) enhance the accuracy of the linear regression result.

3.2 Drivers of animal products' consumption as potential tipping element of the food system

The first column specifies the category of the tipping element, which can be technological, cultural, economic or scientific (Moberg et al., 2021). The second column presents the candidate tipping element. This section also specifies for which of the three goods (bovine, poultry meat and milk) the tipping element is acting. The direction of the tipping element is also defined: as positive or negative. Positive+ is when the tipping element enhances and continues the process/system of the good for which it adopts, promoting conditions of development and/or increase in resources. Negative- when the element influences the development of the process/system in which the good is located, to reduce its excessive consumption by finding alternatives and changing the consumer's choice. Finally, the last column describes a context in which the tipping element acts or a general context confirmed by data

Table 7 The following table collects different tipping points that we detected during data collection.

CATEGORY	CANDIDATE TIPPING ELEMENT	LITERATURE EXAMPLES	TIPPING ELEMENT CONTEXT
TECHNOLOGICAL	Artificial Meat (- negative) Bovine and poultry meat	Cultured meat holds promise as a sustainable and humane alternative to traditional meat production, with the potential to play a significant role in future food systems. Economic disadvantages and popularity are barriers that common sense has to overcome. (Bonny et al., 2017) (Li et al., 2023)	After Singapore, in June 2023, the US Department of Agriculture approved the production and commerce of cultured meat for two firms: Upside Food and Good Meat. Today artificial meat is being developed by more than 150 companies, totaling $896 million in 2022 alone.
	Technological Innovations	Technological advancements in	A key innovation was the scanning by computed

TECHNOLOGICAL	(+ positive) Bovine and poultry meat	production, distribution, and preservation make a wide variety of meats accessible and affordable to consumers. Additionally, innovations in cooking appliances simplify meat preparation, reducing time to cook and integrating meat into daily routines. This combination of convenience and technology ensures meat remains a convenient dietary option. (Kristensen et al., 2014) (Leroy & Degreef, 2015)	tomography CT of beef primal cuts offering highly precise measurements of total carcass composition with remarkable accuracy, in 2010. In the “chicken of tomorrow” case study we also highlighted the introduction of the first electrically heated incubator in 1923.
	UHT (+ positive) Milk	Thanks to UHT process consumers can access milk conveniently and store it for longer periods. UHT milk's extended shelf life reduces waste and allows for wider distribution, making milk more accessible to a broader population. (Krishna et al., 2021) (Muehlhoff et al., 2013a)	This process is largely used since the 70s and because UHT milk does not require refrigerated conditions, it has been able to spread even to countries where maintaining a cold environment for fresh milk is difficult and expensive.
	Dairy Industrialization (+positive) Milk	Dairy 4.0 technologies, including robotics, AI, and IoT, are transforming milk and dairy production from farm to table. These advancements promise increased automation and optimization, enhancing efficiency and product quality. (Hassoun et al., 2023) (Liu et al.,2018)	Over the last few years 3D printing of milk-based products are gaining popularity among researchers as well as food manufacturers.
CULTURAL	Globalization and Urbanization (+positive) Bovine and poultry meat	Globalization and urbanization have boosted animal product consumption by facilitating trade, providing diverse options, and catering to urban lifestyles.	As we saw in the Samoa case study and in the China case study, urbanization and globalization synergies were factors in changing diets through the

CULTURAL		(Mendez & Popkin, 2004) (Kansas University, 2011) (Dana Melby, 2011)	economy, trade and Western cultural influence.
	School milk scheme (+positive) Milk	The school milk scheme promotes milk consumption by providing subsidized or free milk to students, educating them about its nutritional benefits, and integrating it into school meal programs. This fosters milk consumption habits from a young age and aims for overall well-being. (Moberg et al., 2021) (European Commission Food Safety, 2024)	School Milk Scheme is present in different EU states and EU commissions budget this initiative with around 220 million € every year school. In Samoa, the government implemented such an approach to fight health concerns.
	Religion, beliefs and ethics (depends)	Religious festivals and customs also shape meat preferences and consumption through dietary laws and cultural practices, contributing to varied consumption patterns globally. (Kemper et al., 2023) (*Our World in Data*, 2023)	Over the last decade, the number of people choosing vegetarianism or veganism increased by around six times due to different reasons.
ECONOMICAL	Marketing Campaigns (+positive) Poultry meat Milk	Marketing campaigns can influence milk and poultry meat consumption by emphasizing health benefits, convenience, taste, and cultural appeal. (Poultry Development Review, 2013) (Muehlhoff et al., 2013b) (University of California, 2009)	'Got milk?' campaign, (U.S. 2004-2005) addressed as a 'weight loss' contributed to an increase in sales of television advertising by almost 100% in one year. Perdue campaign with the famous "It takes a tough man to make a tender chicken" made an incredible impact in the poultry market.
	Taxes and ban (- negative) Bovine and poultry meat Milk	Taxes influence product consumption by increasing prices, prompting consumers to seek cheaper	The Danish Tax on saturated fats in 2011 and the ban on chicken backs and turkey tails in Samoa (2007) influenced

ECONOMICAL		alternatives or healthier options. (Gren et al., 2019) (Huang, 2022) (Vallgårda et al., 2015)	consumer choice. This shift may reduce the overall consumption of taxed products and promote more sustainable solutions, such as a hypothetical tax on fresh milk would decrease its carbon footprint and encourage more sustainable alternatives.
SCIENTIFIC	Health consciousness (- negative for Bovine meat) (+ positive for poultry meat and milk) Bovine and poultry meat Milk	Increased health consciousness is shaping animal product consumption, with consumers opting for healthier alternatives, driven by concerns about cholesterol, saturated fats, antibiotics, and hormones, especially in meats. (Grundy et al., 2022) (Kansas State University Agricultural Experiment Station and Cooperative Extension Service, 2009)	Empirical research shows that when the consumer is more informed tends to make more sustainable choices. For example, when safety recalls came out in the United States in 2007, consumers substantially increased poultry demand at the expense of beef demand.
	Avian flu (-negative) Poultry meat	Avian flu is common due to its high contagiousness among birds, facilitated by factors such as direct contact, contaminated surfaces, and airborne transmission. Intensive farming practices and inadequate biosecurity measures further contribute to its prevalence. (W. Bruce Traill, 2006) (Kraipornsak, 2010)	Thailand, 2003/04 FAO estimated that more than 140 million birds died or were destroyed and many people died that accounted for the overall GDP loss as much as US$10 billion to US$15 billion.
	Artificial Breeding selection (+ positive) Bovine meat Poultry meat	In poultry, selective breeding enhances traits like growth rate, feed conversion efficiency, and disease resistance, leading to higher meat and egg yields.	Chicken of Tomorrow and further innovations highlight how the human impact can change the poultry meat industry.

SCIENTIFIC	Milk	Similarly, in bovine farming, genetic selection improves factors such as milk yield, carcass quality, and disease resilience, resulting in increased dairy and beef production. (David R. Laatsch, 2023) (Monteath, 2014) (Ahmed et al., 2023)	Also milk and bovine market had known a strong increase in effort to maximize yield in products.
	Modern feed formulations (+ positive) Poultry meat	Innovative feeding can boost efficiency in farming. Studies below show the importance of modern diets in developing countries can improve the size and productivity of chickens. (Alagawany et al., 2021) (Poultry Development Review, 2013)	A chicken in the 1950s was around 0.9 kilograms, now it can weigh over 4,2 kilograms, at the cost of having much more health problems.
	Lactose intolerance and dairy alternatives (-negative) Milk	Lactose-free dairy products have gained widespread health appeal globally as lactose intolerance afflicts more and more people, especially in Asia. Plant-based dairy alternative beverages market is increasing. (Dekker et al., 2019) (Schiano et al., 2020)	Lactose-free dairy is expected to reach a €9 billion turnover by 2022 and currently, 7.4% of the total milk market share is made up of plant-based alternative beverages, a number expected to more than double to 18.5% by 2023.

3.3 Case studies

3.3.1 China Case Study

We have elected to examine this case to elucidate various factors influencing the consumption of beef, particularly within the context of China. Over recent decades, this country has undergone a profound period of economic, demographic, and social transformation, rendering it a clear example of how structural dynamics changes can trigger bigger systems evolutions. This study aims to scrutinize how economic growth, concomitant with urbanization and globalization, interplay to shape consumer behaviours, as well as the dynamics of production and trade. Additionally, cultural and technological-scientific determinants will be explored for their contributory roles in this multifaceted process.

Chinese domestic beef consumption has increased substantially since 1980, although beef consumption growth remains low compared to pork and poultry consumption growth over the same period. With a population of 1.3 billion, a relatively small change in per capita consumption in China has an enormous impact on aggregate beef consumption. In 1970, just before economic reform was beginning to take place in China, annual per capita income was about $148 (Kansas University, 2011). Since the economic reform began in 1979, China's annual per capita income has increased to more than ten times the previous level. Urbanization continues to play a large role in shaping Chinese beef consumption habits. From 1997 to 2007, the proportion of urban Chinese residents increased from 32 to 45 % of the total population according to the 2008 Chinese Statistical Yearbook (Kansas University, 2011). Because urban and rural Chinese residents consume beef differently, urbanization has important implications. Urban residents tend to have more disposable income; seek more variety in food choices; eat out more often; and have different social and cultural attitudes, which makes them larger beef consumers. Increased income levels have led consumers away from a plant-based protein diet toward an animal-based protein diet. Food-away-

from-home consumption continues to rise, driven by higher income levels and the adoption of Western cultures and traditions. The trend of consuming more meats and fewer grains in China is amplified when consumers dine out. Chinese consumers are also more likely to consume higher quality beef when consuming beef outside the home, presumably due to food service establishments having better access to high-quality beef and refrigeration. Increases in income levels and food service establishments support increased beef consumption in China. Western-style restaurants are becoming prominent in China. McDonald's has nearly 1,100 outlets in China and plans to boost that number to 2,000 within the next three years. Yum! Brands Inc., which owns KFC and Pizza Hut, among other chains, is the largest Western-style fast-food group in China (Kansas University, 2011). Fast food dining is quickly being adopted into Chinese culture.

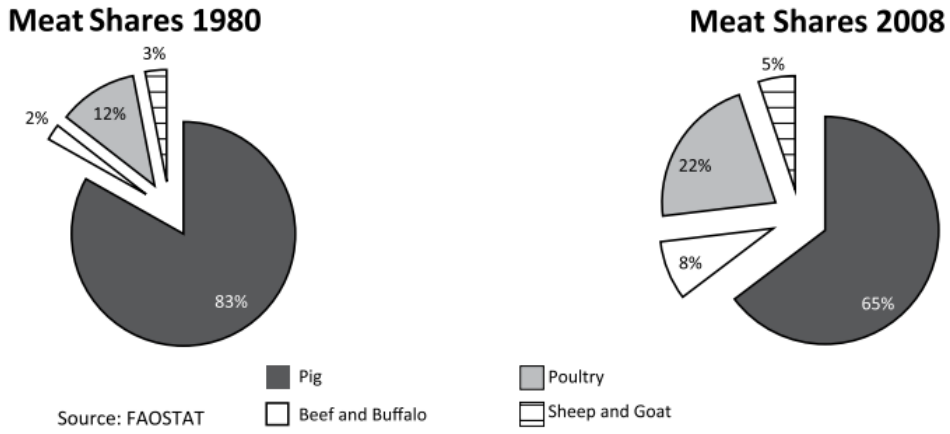

Figure 45 Meat consumption shares across the years in China. The left figure shows the subdivision of meat types in the country's consumption in 1980. The right one shows the same statistics in 2008. We can observe a significant increase in poultry, beef and buffalo meat, while pork meat consumption drops. This indicates how people's choices change towards a healthier and quality direction when income and conditions improve.

China's accession to the World Trade Organization (WTO) was conditional on China agreeing to significantly decrease tariffs specifically concerning agricultural goods. While some tariffs still exist, albeit at lower levels, a significant

impediment to trade has been nontariff barriers. When China was signed into the WTO, they agreed to adhere to the standardized import regulations as well as food safety standards set by the Sanitary and Phytosanitary Standards Commission and animal welfare and disease control standards implemented by the Codex Alimentarius Commission. China has reacted hastily to many of the disease outbreaks experienced around the world in the last 10 years and has often closed borders regardless of scientific confirmations (Mendez & Popkin, 2004). In other cases, China's regulations and import certifications have been so strict that the cost to import has outweighed the benefit. At the urging of the WTO and trade partners, China has taken steps to rectify the inconsistencies in import bans and regulations with several recent sweeping reforms such as the Food Safety Law in 2009 and tariff standardizations in the early 2000s.

3.3.2 Samoa Case Study

In this case study, we highlight how a small population like that of Samoa can undergo a dietary shift and a food transition. Once again, globalization and innovations in logistics and transportation play a pivotal role in trade and the ensuing socioeconomic factors that influence consumer choices. Additionally, we delve into the health consequences of the dietary change in the population, as well as the resulting effects and measures taken by the government of the country to mitigate the situation.

Shifts in the traditional Samoan diet began in the mid-twentieth century. Much of this change can be associated with World War II. With globalization and the Pacific's integration into the world economy an influx of imported goods began to increase and was only limited by availability and affordability. Many of these foods are highly processed, contain little nutritional value and are highly caloric. In comparison with their imported counterparts, traditional staples have negligible amounts of fat and higher amounts of dietary fiber. Lowering trade barriers, after Samoa's independence in 1962, led to an influx of inferior foods available, such as chicken backs and turkey tails. The concept of bans and taxes

has been pivotal in trade agreements in Samoan since the 1990 ban on chicken backs. Along with this reliance on imported food comes an increase in the levels of food insecurity in urban areas. People in these areas often do not have the space to maintain food gardens and thus rely more heavily on products available in stores and at market. With a more urbanized lifestyle people of all ages are increasingly sedentary. People now want a convenient lifestyle and everyone is on the go (Dana Melby, 2011). Urban dwellers consume fewer calories in a week than their rural counter parts but they have higher levels of body fat due to their more sedentary lifestyles. Preparing and cooking food outside was very active and involved the whole family. This allowed for family interaction and physical activity. Meal preparation is becoming more about ease and convenience. This desire for convenience results in more calories being consumed than expended. Also, people are overworking, or working outside the home and have less time for traditional food preparation. Local foods are sometimes viewed as lower class. More status is associated with being able to afford imported goods. The transition of Samoan diet from traditional to modern has led to increased rates of obesity and NCDs (non-communicable disease) in all age groups (World Health Organization, 2018). These rates are among the highest in the world and are continuing to rise. From 1961 until 2005 food imports to Samoa increased five times (Thow et al., 2017). The increase in food imports is demonstrative of the increasing rate of modernization in Samoa and the rising demand for these products. The prices of imported foods are often more competitive than local, poor quality, and require less work. Whereas, local pork and chicken are much better quality, healthier, in large steady supply but require labor and time to raise them. Turkey tails were banned in August 2007 after which three months notice were given for the ban to take hold (Thow et al., 2017). However, turkey tails could still be found in stores up until Christmas time 2007. By 2007, the average Samoan was consuming more than 44 pounds of turkey tails every year—a food that had been unknown there less than a century earlier (Dana Melby, 2011). That's nearly triple Americans' annual per capita turkey consumption. Obesity rates in the Pacific correlate directly to the rate of modernization. In more than ten pacific countries 50-90% of the population is overweight. In American Samoa 80% of women are obese(Dana Melby, 2011). Conducted studies found that half

of the population of Samoa aged 18–64 years was at high risk of developing an Non-Communicable Disease (NCD). Those classified as high risk had at least three of the five most common risk factors associated with NCDs: smoking, raised blood pressure, high body mass index, poor diet and low physical activity(World Health Organization, 2018).

The turkey tail ban did not result in revenue loss for Samoa. Responses to the ban were mixed; but, the ban did not seem to have major impacts on diet or shop proprietors. Chicken backs were banned for reasons very similar to the later ban on turkey tails. They contain little protein and high levels of fat and bone which renders them nutritionally insufficient. Under half of people surveyed in the study just switched to another comparably inexpensive cut of meat. One quarter of the people reported eating lower-fat meat or seafood as a result of the ban A number of surveys were conducted to better grasp what foods are eaten daily; how often fruits, vegetables, and snacks are eaten; and perceptions of health and food.

The bans were successful in decreasing the amount of fatty meat imported into Samoa and raising public awareness about the impacts of diet on health. WTO had concerns about the ban's effectiveness and possible discrimination against certain foods. In response, Samoa agreed to remove the ban but added health commitments in the WTO agreement. A study in 2015 provided recommendations, including fair taxes on all foods, considering health in farming, and making street food healthier. The Nutrition Center at the Ministry of Health (MOH) has taken a proactive approach to promoting and implementing nutrition education both in public settings and schools in Samoa. Among the various initiatives, preschools stand out for having the strictest nutrition guidelines as the inclusion of fruits and vegetables in school meals and a requirement for schools to maintain a garden on their premises. This garden must consist of at least six varieties of vegetables and two fruit trees (Dana Melby, 2011). The produce from these gardens is then utilized to prepare healthy meals, such as soups, for school lunches. This strategy ensures that children are provided with nutritious and locally sourced food options, promoting their overall health and well-being. Samoa government continued also taxing unhealthy foods, with an approach focused on fairness, scientific basis, and non-discrimination (Thow

et al., 2017). Additionally, the Samoan government, in partnership with the World Health Organization (WHO), launched the PEN Fa'a Samoa initiative in 2014(World Health Organization, 2018). This initiative focuses on prevention, early detection, and management of key NCDs like diabetes and cardiovascular diseases. The pilot program, implemented in seven villages, utilized local facilitators and healthcare workers to conduct screenings and assessments for NCD risk factors. Results were shared with the community in public meetings, and individuals identified as high-risk received personalized management plans. This initiative exemplifies a community-based approach to address Samoa's NCD crisis.

3.3.3 Denmark Case Study

With the rise of consciousness and information, people started to worry about health problems, such as obesity and related health issues, caused by unhealthy diets. To counter this trend, there was a growing awareness of the need for public regulations, including taxes, to incentivize healthier food choices. These taxes aim to internalize the external costs borne by society due to unhealthy diets and generate revenue for public spending or tax reductions. Several countries have implemented food taxes on items like sweetened beverages, ready-to-eat foods, sweets, and saturated fats. We chose the Danish case, as the first in its genre, to explain the critical importance of clarity among policy actors when defining taxes frameworks (Wright et al., 2017).

Denmark introduced a tax on saturated fat in food products in 2011, making it the first of its kind globally. However, this tax was repealed in 2012 before its effects could be fully assessed. Scientific studies have explored the potential impact of food taxes on dietary behaviour and health, primarily through model simulations and price elasticities. The results of these studies indicate that food taxes can influence dietary choices, particularly among lower socioeconomic groups, but the impact varies based on tax design and other factors (Jensen et al., 2016). The tax on saturated fat was introduced as part of a broader tax reform in Denmark in 2010. The reform aimed to reduce income tax rates and was financed

through increased taxes on energy, the environment, and health-related measures, including taxes on unhealthy products. Even if it is not the main reason, the Danish government also aimed to reinforce national coffers. Economic estimates speak of revenues of at least 200 million euros annually (Jensen et al., 2016). A unique aspect of this reform was the introduction of a tax on saturated fat in food products. It was implemented in response to Danish consumers' excessive consumption of saturated fat, which exceeded recommended daily energy intake levels. The tax was imposed on food manufacturers and importers, with the expectation that it would be reflected in consumer prices. Exemptions included drinking milk, food for export, animal fodder, and products from small enterprises. The tax was set at 16 Danish Krone (2,15 euros) per kilogram of saturated fat, with an additional value-added tax (VAT) of 25% targeting foods with more than 2.3% saturated fat (Klenert et al., 2023). The saturated fat tax came into effect on October 1, 2011, but it was repealed at the end of 2012, primarily due to political considerations. Fatty products like butter, margarine, cream, cheese, and meats were most affected by the tax due to their high saturated fat content. A study analyzed the effects of the tax on butter, margarine, and oils using household purchase data. It found a significant reduction in the consumption of butter and margarine. Taxing meat was complex due to the distribution and processing of meat in Denmark. Standardized coefficients for saturated fat content were used, and differentiated taxation based on fat content in specific meat cuts was allowed. The tax resulted in relatively higher price increases for fatty meat, potentially encouraging consumers to opt for leaner cuts. However, using the true fat content for taxation might have created even stronger incentives for healthier meat choices. Considering that Danes' average intake of saturated fat exceeds the recommended level by 40 % (Jensen et al., 2016), reductions in consumption of butter, margarine and similar products may be considered fairly small from a health perspective, albeit statistically significant. The results, however, also illustrate that the impacts of the tax have been somewhat complex. Budget effects and substitution effects between product varieties with different contents of saturated fat play an important role, whereas shifts in consumers' preferences following the introduction of the tax play a minor role. They also tend to suggest

positive health impacts on lower fat consumption, but also adverse health effects due to substitution effects on the intake of salt and of fruits and vegetables.

In summary, the Danish tax targeted excessive saturated fat consumption and was part of a tax reform designed to reduce income tax rates and promote healthier eating. The tax primarily affected the prices of fatty food products and had a notable impact on the consumption of butter and margarine. Taxing meat was intricate due to the meat distribution process in Denmark (Vallgårda et al., 2015). However, some analysis suggests that the main purpose of this tax was to increase public revenues as further research indicates the effectiveness of the tax in influencing consumer choices.

3.3.4 "Chicken of Tomorrow" Case Study

This case is one clear example of how artificial breeding and scientific innovations can boost the size and constitution of the chicken and therefore its market and consumption. A strong increase in inexpensive animal protein demand after World War II aroused the need for a bigger and more profitable chicken breed. U.S. farmers managed to achieve this goal by finding the "Chicken of Tomorrow". In 1925, there were more than six million farms in the United States, a stark contrast to the two million farms present today as more efficient intensive livestock farms manage to optimize production processes and specialize in one type of livestock.

Initially, farms primarily maintained small flocks of chickens for egg production, with meat being a secondary consideration. The beginning of innovation in chicken production can be traced back to 1923 with the introduction of the first electrically heated incubator (National Geographic, 2018). This marked a significant advancement as it relieved farmers from the burden of selecting and maintaining breeding stock. Additionally, it eliminated the need for hens to spend months of their short productive lives hatching eggs instead of laying more. With the advent of electrically heated incubators, farmers could now outsource these tasks to a new segment of the industry: thousands of hatcheries that shipped newborn chicks by mail. However, during and after World War II, there was a

growing demand for meat, leading to a desire for chickens with more substantial meat portions. In response to this demand, the USDA, in collaboration with industry stakeholders like Howard C. Pierce from A&P Food Stores, organized the Chicken of Tomorrow contest in 1948 (National Geographic, 2018). The aim was to breed chickens with larger, meatier bodies, specifically focusing on developing birds with thick breast meat and juicy dark meat in the drumsticks. The contest involved breeders from across the United States, who competed to create chickens that met these criteria. The winning entries showcased successful crossbreeds that combined traits from different chicken varieties to produce birds with superior meat qualities, producing a four-pound broiler in just 12 weeks while requiring only 12 pounds of feed (David R. Laatsch, 2023). Through advancements in technology such as controlled environment housing, precise prescription rations, and stringent biosecurity measures, today's chickens have further improved upon these metrics. Nowadays, it is common to produce a five-pound broiler in approximately 42 days while consuming less than 10 pounds of feed. As a result of these advancements and the increased efficiency of chicken production, the average American now consumes around 70 pounds of chicken per year, a significant increase compared to the amount consumed in 1950, which was five times lower (David R. Laatsch, 2023). The success of the Chicken of Tomorrow contest marked a significant shift in chicken breeding practices, reshaping the chicken industry, and leading to the dominance of hybrid breeds and the commodification of chicken genetics as proprietary intellectual property. The affordability and accessibility of poultry meat have been greatly enhanced by the concerted efforts of the poultry sector, along with advancements in technology and management practices across various domains such as poultry health, welfare, nutrition, and housing (Neeteson et al., 2023). Notably, significant progress in poultry breeding has played a crucial role in this transformation. The process of breeding expansion is expected to continue in trait development, increased data recording and automation efforts, and increasingly powerful statistical methods will further drive the reaching of breeding goals (*Poultry Development Review*, 2013). These novel opportunities enable the improvement of health and welfare, environmental impact and productivity at the same time.

4 Conclusions

In this research, we addressed the following key objectives: 1) to find correlations between dietary patterns and per-capita GDP, 2) to provide literatures to identify drivers of dietary shifts and 3) to analyze relevant case studies for evidence process of alimentary transition. In doing so we developed a statistical framework to provide evidence for Bennett's Law, we listed and categorized several elements that influence the consumption of beef, milk and poultry meat and through case studies, we explored some of these drivers in concrete and historical context. Urbanization and globalization in China and Samoa were key drivers in stimulating and facilitating dietary change, contributing to trade, availability of goods on shelves, and cultural influence. Residents of Samoa recognized turkey tail as a traditional food, while in China, the habit of eating out spread as the Western influences such as fast-food. In Denmark, a saturated fat tax, introduced for national health reasons but lasting only one year, succeeded in using the price elasticity of goods to change consumer choices and reduce saturated fat consumption. Scientific innovation and in particular artificial breeding have played a key role in poultry meat consumption, thanks to the "Chicken of Tomorrow" a contest that marked the beginning of development for methodologies with the aim of extrapolating maximum revenue from poultry.

However, among all these factors we can delineate a common ground that drives these processes to take hold, the monetary purpose. Following Bennett's Law, we then performed linear regressions between beef, poultry, and milk consumption and average annual income. The analysis was done by dividing the globe into 18 regions and running the calculation for each of them. We found that of the three study commodities, poultry consumption trend was the one showing the greatest fit of the Bennett's Law. This is because chicken is generally one of the cheapest sources of animal protein. For example, in Central America, poultry consumption can be explained by the per-capita GDP in a great way as demonstrated by the R^2 value of 0.94. As for milk and beef, they are subject to more factors and therefore the level of consumption deviates more from the Bennett's Law. In Southern

Europe, per capita beef consumption has been declining in recent years, even though the general economic level is rising, as well as in Middle Africa, probably suggesting a new phase of the nutrition transition (Mendez & Popkin, 2004).

Next, we explored the role of potential tipping elements candidates in a table by listing candidate elements divided into categories such as technological, cultural, economic and scientific (Moberg et al., 2021). This study presented tipping candidates that may have positive or negative implications in the development of the three kinds of foods examined so far. In these processes, evidenced by the literature, we highlighted how they could potentially influence the dynamics of tipping points and contribute to a sustainable food transition.

Our final output highlights the potential "positive" tipping elements as those drivers that would act as reinforcing feedback in food consumption, thus maintaining the system in its current status. We have defined "negative" tipping elements as the potential stopping drivers, which would be able to change the current patterns of food consumption.

These analyses have emphasized the importance of technological and scientific drivers in fostering production efficiency and thus cost, as well as how government and marketing tools such as taxes, bans, and advertising campaigns shape consumer choices. The historical episodes we have described tell of how changes in diets can take place, changing the dynamics of the modern food system.

The information gathered in this study can lay the foundation for the development of a more comprehensive and analytical framework of how to concretely implement a food transition by triggering tipping points and changing today's diets through social norms, policy interventions, and financial instruments.

Although several factors limit this work. The analysis is conducted for only three categories of food and the temporal break in their linear regressions (1970- 2013) does not allow us to conclude conditions today or in more recent years.

For these reasons, further investigation could develop a linear model that determines the consumption of certain products. This would provide more precision in determining the actual impact of each independent variable. Then, considering a specific geographic area would make the research homogeneous in that cultural and socioeconomic factors would be limited.

In conclusion, this investigation into the role of dietary shifts for sustainable food systems has illuminated crucial dynamics within the contemporary global food landscape. By examining historical records and contemporary calls for diet and food-system reform, we have identified key factors that contribute to the rapid uptake of new foods on a large scale within industrial food regimes. Our findings underscore the importance of technological innovation, collaborative efforts between governments, academia, and industry, as well as the influence of global food corporations and efficient supermarket chains in driving dietary transitions. Moreover, our exploration of tipping points within food systems emphasizes the interconnectedness of various factors, highlighting the need for holistic approaches to instigate positive transformations. Looking ahead, it is evident that achieving sustainable and equitable food systems will require alignment with diverse global systems of reference and the cultivation of multiplicative synergies among transformative visions. Overcoming self-fulfilling expectations and harnessing the potential of social norm changes will be critical for fostering widespread adoption of less damaging dietary behaviours. As we navigate these challenges, interdisciplinary collaboration and active communication will remain crucial, ensuring that we sign a direction towards a future where food systems are not only sustainable but also conducive to the well-being of both people and the planet.

Bibliography

Ahmed, R. H., Schmidtmann, C., Mugambe, J., & Thaller, G. (2023). Effects of the Breeding Strategy Beef-on-Dairy at Animal, Farm and Sector Levels. *Animals*, *13*(13), 2182. https://doi.org/10.3390/ani13132182

Alagawany, M., Elnesr, S. S., Farag, M. R., Tiwari, R., Yatoo, Mohd. I., Karthik, K., Michalak, I., & Dhama, K. (2021). Nutritional significance of amino acids, vitamins and minerals as nutraceuticals in poultry production and health – a comprehensive review. *Veterinary Quarterly*, *41*(1), 1–29. https://doi.org/10.1080/01652176.2020.1857887

Bonny, S. P. F., Gardner, G. E., Pethick, D. W., & Hocquette, J.-F. (2017). Artificial meat and the future of the meat industry. *Animal Production Science*, *57*(11), 2216. https://doi.org/10.1071/AN17307

Dana Melby. (2011). *" Gimme SAMOA That!": The Changing Diet in Samoa*.

David R. Laatsch. (2023). *The Chicken of Tomorrow*.

David Tàbara, J., Frantzeskaki, N., Hölscher, K., Pedde, S., Kok, K., Lamperti, F., Christensen, J. H., Jäger, J., & Berry, P. (2018). Positive tipping points in a rapidly warming world. *Current Opinion in Environmental Sustainability*, *31*, 120–129. https://doi.org/10.1016/j.cosust.2018.01.012

Davies, K. P., Gibney, E. R., & O'Sullivan, A. M. (2023). Moving towards more sustainable diets: Is there potential for a personalised approach in practice? *Journal of Human Nutrition and Dietetics*, *36*(6), 2256–2267. https://doi.org/10.1111/jhn.13218

Dekker, P., Koenders, D., & Bruins, M. (2019). Lactose-Free Dairy Products: Market Developments, Production, Nutrition and Health Benefits. *Nutrients*, *11*(3), 551. https://doi.org/10.3390/nu11030551

Durán-Sandoval, D., Durán-Romero, G., & López, A. M. (2021). Achieving the Food Security Strategy by Quantifying Food Loss and Waste. A Case Study of the Chinese Economy. *Sustainability*, *13*(21), 12259. https://doi.org/10.3390/su132112259

European Commission Food Safety. (2024).

FAO Statistics. (2024). https://www.fao.org/faostat/en/#data

FOLU Organization. (2019). *Growing Better: Ten Critical Transitions to Transform Food and Land Use*.

Gilles Billen, E. A. (2024). Beyond the Farm to Fork Strategy: Methodology for designing a European agro-ecological future. *15 January 2024*.

Godfray, H. C. J., Aveyard, P., Garnett, T., Hall, J. W., Key, T. J., Lorimer, J., Pierrehumbert, R. T., Scarborough, P., Springmann, M., & Jebb, S. A. (2018). Meat consumption, health, and the environment. *Science*, *361*(6399), eaam5324. https://doi.org/10.1126/science.aam5324

Gren, I.-M., Moberg, E., Säll, S., & Röös, E. (2019). Design of a climate tax on food consumption: Examples of tomatoes and beef in Sweden. *Journal of Cleaner Production*, *211*, 1576–1585. https://doi.org/10.1016/j.jclepro.2018.11.238

Grundy, E. A. C., Slattery, P., Saeri, A. K., Watkins, K., Houlden, T., Farr, N., Askin, H., Lee, J., Mintoft-Jones, A., Cyna, S., Dziegielewski, A., Gelber, R., Rowe, A., Mathur, M. B., Timmons, S., Zhao, K., Wilks, M., Peacock, J. R., Harris, J., … Zorker, M. (2022). Interventions that influence animal-

product consumption: A meta-review. *Future Foods*, *5*, 100111. https://doi.org/10.1016/j.fufo.2021.100111

Guyomard, H., Soler, L.-G., Détang-Dessendre, C., & Réquillart, V. (2023). The European Green Deal improves the sustainability of food systems but has uneven economic impacts on consumers and farmers. *Communications Earth & Environment*, *4*(1), 358. https://doi.org/10.1038/s43247-023-01019-6

Hassoun, A., Garcia-Garcia, G., Trollman, H., Jagtap, S., Parra-López, C., Cropotova, J., Bhat, Z., Centobelli, P., & Aït-Kaddour, A. (2023). Birth of dairy 4.0: Opportunities and challenges in adoption of fourth industrial revolution technologies in the production of milk and its derivatives. *Current Research in Food Science*, *7*, 100535. https://doi.org/10.1016/j.crfs.2023.100535

Huang, W. (2022). Demand for plant-based milk and effects of a carbon tax on fresh milk consumption in Sweden. *Economic Analysis and Policy*, *75*, 518–529. https://doi.org/10.1016/j.eap.2022.06.011

Jensen, J. D., Smed, S., Aarup, L., & Nielsen, E. (2016). Effects of the Danish saturated fat tax on the demand for meat and dairy products. *Public Health Nutrition*, *19*(17), 3085–3094. https://doi.org/10.1017/S1368980015002360

Kansas State University Agricultural Experiment Station and Cooperative Extension Service. (2009). *U.S. Beef Demand Drivers and Enhancement Opportunities*.

Kansas University. (2011). *Chinese Beef Consumption Trends: Implications for Future Trading Partners*.

Kemper, J. A., Benson-Rea, M., Young, J., & Seifert, M. (2023). Cutting down or eating up: Examining meat consumption, reduction, and sustainable food beliefs, attitudes, and behaviors. *Food Quality and Preference*, *104*, 104718. https://doi.org/10.1016/j.foodqual.2022.104718

Kenny Torrella. (2022). This is how much meat and dairy hurt the climate. *2022*.

Klenert, D., Funke, F., & Cai, M. (2023). Meat taxes in Europe can be designed to avoid overburdening low-income consumers. *Nature Food*, *4*(10), 894–901. https://doi.org/10.1038/s43016-023-00849-z

Kraipornsak, P. (2010). *The outbreak of avian influenza and chicken consumption in Thailand*.

Krishna, T. C., Najda, A., Bains, A., Tosif, M. M., Papliński, R., Kapłan, M., & Chawla, P. (2021). Influence of Ultra-Heat Treatment on Properties of Milk Proteins. *Polymers*, *13*(18), 3164. https://doi.org/10.3390/polym13183164

Kristensen, L., Støier, S., Würtz, J., & Hinrichsen, L. (2014). Trends in meat science and technology: The future looks bright, but the journey will be long. *Meat Science*, *98*(3), 322–329. https://doi.org/10.1016/j.meatsci.2014.06.023

Lehto, E., Korhonen, K., Muilu, T., & Konttinen, H. (2023). How do values relate to the consumption of meat and dairy products and their plant-based alternatives? *Food Quality and Preference*, *106*, 104804. https://doi.org/10.1016/j.foodqual.2022.104804

Leroy, F., & Degreef, F. (2015). Convenient meat and meat products. Societal and technological issues. *Appetite*, *94*, 40–46. https://doi.org/10.1016/j.appet.2015.01.022

Li, H., Van Loo, E. J., Trijp, H. C. M. V., Chen, J., & Bai, J. (2023). Will cultured meat be served on Chinese tables? A study of consumer attitudes and intentions about cultured meat in China. *Meat Science*, *197*, 109081. https://doi.org/10.1016/j.meatsci.2022.109081

Mendez, M. A., & Popkin, B. M. (2004). *Globalization, Urbanization and Nutritional Change in the Developing World*. *1*(2).

Moberg, E., Allison, E. H., Harl, H. K., Arbow, T., Almaraz, M., Dixon, J., Scarborough, C., Skinner, T., Rasmussen, L. V., Salter, A., Lei, X. G., & Halpern, B. S. (2021). Combined innovations in public policy, the private sector and culture can drive sustainability transitions in food systems. *Nature Food*, *2*(4), 282–290. https://doi.org/10.1038/s43016-021-00261-5

Monteath, C. (2014). *Steps to sustainable livestock*.

Muehlhoff, E., Bennett, A., & McMahon, D. (2013a). *Milk and dairy products in human nutrition*. FAO.

Muehlhoff, E., Bennett, A., & McMahon, D. (2013b). *Milk and dairy products in human nutrition*. FAO.

National Geographic. (2018). *The Surprising Origin of Chicken as a Dietary Staple*.

Neeteson, A.-M., Avendaño, S., Koerhuis, A., Duggan, B., Souza, E., Mason, J., Ralph, J., Rohlf, P., Burnside, T., Kranis, A., & Bailey, R. (2023). Evolutions in Commercial Meat Poultry Breeding. *Animals*, *13*(19), 3150. https://doi.org/10.3390/ani13193150

Nyborg, K., Anderies, J. M., Dannenberg, A., Lindahl, T., Schill, C., Schlüter, M., Adger, W. N., Arrow, K. J., Barrett, S., Carpenter, S., Chapin, F. S., Crépin,

A.-S., Daily, G., Ehrlich, P., Folke, C., Jager, W., Kautsky, N., Levin, S. A., Madsen, O. J., … De Zeeuw, A. (2016). Social norms as solutions. *Science*, *354*(6308), 42–43. https://doi.org/10.1126/science.aaf8317

Our World in Data. (2023).

Poultry development review. (2013). Food and Agriculture Organization of the United Nations.

Schiano, A. N., Harwood, W. S., Gerard, P. D., & Drake, M. A. (2020). Consumer perception of the sustainability of dairy products and plant-based dairy alternatives. *Journal of Dairy Science*, *103*(12), 11228–11243. https://doi.org/10.3168/jds.2020-18406

Semba, R. D., De Pee, S., Kim, B., McKenzie, S., Nachman, K., & Bloem, M. W. (2020). Adoption of the 'planetary health diet' has different impacts on countries' greenhouse gas emissions. *Nature Food*, *1*(8), 481–484. https://doi.org/10.1038/s43016-020-0128-4

Systemiq. (2023). *The Breakthrough effect: How to trigger a cascade of tipping points to accelerate the net zero strategy*.

Thow, A. M., Reeve, E., Naseri, T., Martyn, T., & Bollars, C. (2017). Food supply, nutrition and trade policy: Reversal of an import ban on turkey tails. *Bulletin of the World Health Organization*, *95*(10), 723–725. https://doi.org/10.2471/BLT.17.192468

Tuninetti, M., Ridolfi, L., & Laio, F. (2022). Compliance with EAT–Lancet dietary guidelines would reduce global water footprint but increase it for 40% of the world population. *Nature Food*, *3*(2), 143–151. https://doi.org/10.1038/s43016-021-00452-0

University of California. (2009). *Got Milk Advertising Strategy*.

Vallgårda, S., Holm, L., & Jensen, J. D. (2015). The Danish tax on saturated fat: Why it did not survive. *European Journal of Clinical Nutrition*, *69*(2), Article 2. https://doi.org/10.1038/ejcn.2014.224

Van Der Ploeg, F. (2016). Reacting to multiple tipping points. *Nature Climate Change*, *6*(5), 442–443. https://doi.org/10.1038/nclimate2962

W. Bruce Traill, A. E. L. (2006). *Risk perception and chicken consumption in the avian flu age – a consumer behaviour study on food safety information*.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Majele Sibanda, L., … Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, *393*(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Winkelmann, R., Donges, J. F., Smith, E. K., Milkoreit, M., Eder, C., Heitzig, J., Katsanidou, A., Wiedermann, M., Wunderling, N., & Lenton, T. M. (2022). Social tipping processes towards climate action: A conceptual framework. *Ecological Economics*, *192*, 107242. https://doi.org/10.1016/j.ecolecon.2021.107242

World Health Organization. (2018). *Samoa, Engaging people for healt promotion*.

Wright, A., Smith, K. E., & Hellowell, M. (2017). Policy lessons from health taxes: A systematic review of empirical studies. *BMC Public Health*, *17*(1), 583. https://doi.org/10.1186/s12889-017-4497-z

Ringrazio la Professoressa Marta Tuninetti e l'Ingegnere Vittorio Giordano per avermi supportato con entusiasmo e dedizione durante il lavoro per questo documento.

Ringrazio le persone a me amate, i miei amici, le persone che mi hanno fatto crescere.

Ringrazio Valeria che è stata al mio fianco sempre.

Ringrazio infine la mia famiglia, il mio nido, in tutto e per tutto.