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Plant Proteins Availability in Europe and Asia: A Causality Analysis of Climate, Demographics, and Economic Factors

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ABSTRACT: The article examines the availability of plant-based proteins in Europe and Asia, considering the challenges posed by climate, demographics, and economics. The availability of these proteins is crucial given the growing impact of climate, economic, and social variables. Indeed, these factors play a decisive role in the production and accessibility of plant-based proteins across countries. The study employed a causality analysis method using regression models to determine the relative impact of these factors on protein availability. Two indicators were prioritized: total national production and the daily accessible quantity per person. This approach made it possible to construct hypothetical trajectories, showcasing the interrelations between the different variables. The results show that the availability of plant-based proteins varies across regions. Factors such as rising temperatures, increasing pollutants, and rising prices of plant proteins are particularly concerning. In this context, legumes appear as a promising alternative. They offer resilience against climatic variations while being an excellent protein source. The findings also encourage rethinking our consumption. Meat, with its significant ecological footprint, should see its consumption decrease in favor of plant-based proteins, ensuring a more sustainable diet. To facilitate this transition, the importance of appropriate public policies and incentives for producing and consuming plant proteins is emphasized.

Keywords: Plant-based proteins; Climate change; Vegetables; Sustainable consumption; Public policies

1. Introduction

Global population growth, the convergence of incomes and Western lifestyles jeopardize the capacity of agriculture to feed the 9.7 billion people predicted by 2050 [1]. According to the United Nations Environment Program, up to 25% of global food production could be lost by 2050 due to environmental degradation, particularly in developing countries [2]. Despite these challenges, meeting these dietary needs is crucial for all living beings, highlighting the importance of varied access to essential nutrients, including protein, with FAO recommendations setting an intake of 0.83 g of protein per kg of body weight per day for adults [3].

Furthermore, not all human beings have the privilege of satisfying this need for protein. According to the FAO, 1/7 of the world's population suffers from hunger and 1 billion people have insufficient protein intake [4]. Indeed, despite increased investment in agricultural research, almost one in seven people suffer from chronic malnutrition, highlighting the shortcomings of the current food system [5]. Also, severe acute malnutrition, characterized by an insufficiency or loss of body weight in relation to height, particularly affects children, with a mortality risk 11 times higher than those who are not malnourished [6]. These severe forms of protein shortage are exacerbated by factors such as the lack of access of the poorest to food resources, inefficiencies in production and losses during storage, processing, as well as food waste [7].

Several prospective studies [8–10] predict a major constraint on protein sources in the coming decades, which is not the case for carbohydrates or lipids. Indeed, as atmospheric CO_2 levels rise, the protein content of crops will fall [11]. Activities linked to food production are of great concern, since they are responsible for 30% of all greenhouse gas (GHG) emissions of human origin [12].

The accentuation of climate change, linked to population growth and increased energy needs, is expected to further seriously endanger the environment and food production. This situation could expose the 76% of the world population dependent on plant proteins to the risk of protein deficiency [11–13]. By 2050, nearly 150 million more people could face protein insufficiency, with an expected decline of at least 6% in protein content in key crops such as rice, wheat, barley and potato [11].

The diversity of plant protein sources, such as legumes, cereals, tubers and leaves, varies from one country to another [14]. Lupins and potatoes are also emerging as promising sources [14]. The notion of sustainable intensification is frequently addressed in the agricultural literature, highlighting the potential of plant proteins to meet future global needs, in complement or association with other traditional or emerging products [4–15]. By considering a partial replacement of animal proteins with plant proteins, it is possible to meet growing demand in the context of the sustainable development of agricultural and food systems [12–16].

The transition to a diet based increasingly on plant proteins and animal meat substitutes is inevitable. From the consumer's point of view, this transition seems very cost-effective: the cost of plant proteins compared with animal proteins is significantly lower [17]. What's more, vegetarianism is integrated into various religions, such as Hinduism and Buddhism [18]. Vegetarianism seems to be the most widespread selective diet in Western societies [19,20].

More and more people are choosing to adopt a diet that departs from the traditional Western way of eating and to migrate towards a more plant-based diet, which is increasingly developed in certain countries such as India [21]. Adopting a vegetarian or vegan diet has become common practice, both for ecological reasons and for health and well-being [22]. However, animal proteins provide the body with a greater protein intake, so it is necessary to consume the right plant proteins, and in the right quantities, to meet all the needs of the human body [17].

However, agricultural land conversion is emerging as a major source of greenhouse gas emissions [23,24]. Converted tropical forest lands contribute 12% of annual CO_2 emissions, accounting for 98% of emissions linked to this conversion [23]. Thus, environmentally friendly practices are crucial to maximize the benefits of crops in terms of protein intake, requiring efforts to guarantee the availability of plant proteins while preserving the ecosystem [23,24].

In 2016–2017, Europe demanded around 27 million tonnes of plant proteins, but its self-sufficiency varies (79% for rapeseed, 42% for sunflower, 5% for soya) [17], leading to the import of 17 million tonnes. In Asia, influenced by Hinduism and Buddhism, vegetarianism, promoted by China and India, is influencing other countries [25], with a forecast 6.10% increase in demand in plant proteins by 2028 [25]. These two continents were chosen for this study because of the anticipated challenges.

The overall objective was to analyze the future availability of plant proteins in Asia and Europe until 2050. To do this, we examined the evolution of climate, demographics, cultivated areas and protein demand plants. Next, we identified the crucial parameters and projected their impact on plant protein availability.

2. Methodology

2.1. Justification for the Choice of Asia and Europe

Europe is known as a potential consumer of proteins, with an estimated consumption rate of 150% of recommended intakes, based on FAO assessments [26]. Asia is also recognised as a potential consumer, but also has a large agricultural production capacity [27]. Hence the choice of these two continents in this study.

Regarding the target countries, the choice was also based on the level of protein consumption in the various countries. In Asia, China, Japan and Indonesia are recognised as major markets for plant proteins [28]. Moreover, these countries, particularly China, are known for their impressive agricultural heritage, with a long tradition of crops that are essentially rich in protein, such as rice and peas [29]. This makes these countries the continent's leading markets for plant proteins due to the increasing prevalence of health disorders such as obesity, attributed to a growing trend towards vegan diets [28]. Asia's centuries-old agricultural history makes it fertile ground for the exploration of plant proteins, as it has a solid plant production base.

However, the plant-based meat market in Asia is still in its development phase, with low acceptance of plant-based meat products among consumers in Beijing, illustrated by a study by Wang et al. [30]. This reluctance is explained by a low familiarity with plant-based meat, as observed by Zhang et al. [31] and Liu et al. [32]. The latter reveal a lack of knowledge of new alternative proteins, particularly proteins of plant origin, and opposition of 22% and 9.6% respectively to its adoption. This information confirms the barriers related to the availability and acceptance of plant proteins in Asia, reinforcing the need to focus future assessment of plant protein availability on this region.

In Europe, France, Germany and Spain are the three countries considered. Their selection is linked to the fact that between them they produce more than half of all animal proteins [33] and form an integral part of the large European vegetable protein markets (soya protein, wheat protein, pea protein, rice protein, oat protein and other types) [25].

2.2. Data Collected and Collection Methods

To gain a better understanding of the dynamics surrounding the availability of proteins of plant origin, a range of data has been collected and analyzed. These include climatic, economic, and social data (Table 1).

2.2.1. Climatic Factors

The climatic data recognized as determining the availability of proteins of plant origin are mainly precipitation, temperature, and atmospheric pollutants. Indeed, the high variability of precipitation and excessively high temperature has a significant impact on the agricultural production sector [34]. For Sultan et al. [35], agriculture is the human activity most dependent on these climate variations. These two climate parameters were collected over 30 years (1990–2020) on the World Bank website.

In addition to rainfall and temperature, which influence agricultural production, other climatic parameters such as atmospheric pollutants are the most frequently cited [34]. These pollutants include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are the main contributors to the greenhouse gas phenomenon, leading directly to global warming, characterized by an increase in temperature [34]. This warming, accentuated by pollutants, has several harmful effects, in particular the disappearance of plant species [34].

The data characterizing these parameters was collected over a 30-year period (1990–2020) on the Food and Agriculture Organization of the United Nations (FAO) website.

2.2.2. Economic Factors

The evolution and disparity around protein consumption is also linked to several economic factors, including the standard of living characterized by the average income of the population [36]. Indeed, an increase in income allows access to protein sources, especially since the price of these proteins remains the main determinant of their consumption [37]. For this, the gross national income per capita and the average annual price of a tonne of protein were collected over the same 30-year period (1990–2020) on the website of the United Nations Food and Agriculture Organization. Food and Agriculture (FAO).

2.2.3. Social Factors

Among the most decisive social factors, Caillave et al. [26] attribute first place to strong demographic growth, accentuating demand around the availability of proteins. These data, including average annual income, average annual price of plant proteins and total annual population, were collected over 30 years (1990–2020) on the website of the Food and Agriculture Organization of the United Nations (FAO).

2.2.4. Other Factors

In addition to the various factors highlighted above, the study also took into account other parameters such as land use for both agriculture and grazing (both permanent and temporary), especially in a context where the link between agriculture and animal production (livestock farming) no longer needs to be demonstrated. Livestock farming is seen as a key driver of sustainable development in agriculture, especially in terms of its ability to reduce the environmental impact on the soil through the contribution of organic manure from animals [38].

At the same time, the FAO states that most agricultural land is used to produce food for farm animals [39]. Regarding the indicators for assessing the availability of proteins of plant origin, data relating to total production (tonnes), changes in stocks (tonnes) and the availability of proteins at the level of individuals per day (g/person/day) have been collected on the FAO website for the period available on this site (2010–2020).

These various added factors were analyzed in the present study with the aim of assessing their respective influence on the consumption of proteins of animal origin.

Table 1. Summary of parameters used in this study to assess plant protein availability.

Variables	Description	Sources	Expected Effects	Authors
Dependent variable				
Plant proteins available	Amount of plant protein accessible or available to an individual per day (g/person/day)	FAO		**Variable of interest**
Independent variables				
Rainfall	Annual rainfall (mm)	World Bank	+	[34,35]
Temperature	Average annual temperature (°C)	World Bank	-	[34,35]
CH_4	The quantity of methane (kilotonnes) in the atmosphere	FAO	-	[34]
N_2O	The quantity of nitrous oxide (kilotonnes) in the atmosphere	FAO	-	[34,40]
Income	Gross annual per capita income (USD)	FAO	+	[36,37]
Price	Average annual price per tonne of animal protein (USD/tonne)	FAO	-	[26,37]
Farming lands	Total area of farmland (hectares)	FAO	+	[38,39]
Population	Total population	FAO	-	[41,42]
Total production protein	Total annual quantity of protein produced nationally (tonnes)	FAO	+	Considered just another indicator of availability
Stock variation	Quantity of stored protein available after consumption and sales	FAO	+	Considered just another indicator of availability

3. Analysis Method

The time series analysis of parameters was carried out using time series analysis methods, allowing the evolution of variables to be traced over time and providing useful forecasts [43]. To identify the determinants of protein availability at the individual level in various countries, structural equation modeling (SEM) was employed, based on partial least squares (PLS-SEM). This approach, combining factor analysis and regression, specifies regression equations describing the relationships between latent factors, providing greater precision through the simultaneous management of relationships between many variables and the consideration of measurement error [44,45].

This is the case in the present study, where the data collected covers several periods and several variables simultaneously in each of the six countries studied. PLS-SEM is a non-parametric method and therefore makes no distributional assumptions. This has led to its use in several studies, as Hair et al. [46] point out. The latter report that the use of PLS-SEM has increased exponentially in a variety of disciplines. This is because of its distinctive methodological features which make this approach even more popular.

To do this, this technique was applied to test the relative importance of climatic variables (temperature, rainfall, pollutants), economic variables (gross income per capita, price of plant proteins), social variables (population density in rural and urban areas) and other variables (area of farmland, area of grazing land) on the availability of plant proteins (total production on a national scale, quantity available per day per individual). To achieve this, the study began by constructing all the hypothetical trajectories that express causality between the variables mentioned.

In this study, as also shown in Figure 1, the response variable is the availability of plant protein, characterised by two key indicators: total production on a national scale (in tonnes), and the quantity available per day per individual (g/person/day). The study is based on the hypotheses that climate change (temperature, precipitation, atmospheric pollutants), demographics (rural and urban population density), changes in land use (agricultural and grazing) and economic fluctuations (price of plant protein per tonne, gross annual income per capita) can have a direct impact on plant protein availability indicators.

The influence of demographics on the various parameters was also assessed in order to highlight the indirect role played by the social factor (population density) on the dependent variable indicators. Mathematically, PLS is an extension of multiple linear regression and, as in multiple linear regression, the main aim of PLS is to construct a linear model whose general form is as follows:

$$Y = XB + E \tag{1}$$

where

- Y is a matrix of n observations by m response variables,
- X is a matrix of n observations by p predictor variables (design),
- B is a matrix of regression coefficients p by m, and E is the error term of the model of the same dimension as Y.

Furthermore, for the purposes of this study, the reflective approach was used to express the relationship between latent variables (which cannot be measured directly) and their manifests (indicators used to measure the latent variable) [47]. This approach, which has been adopted in most uses of structural equation models with latent variables, assumes that each manifest variable is linked to its latent variable by a simple regression [47]. The relationships between each latent variable and its manifests are referred to as the "external model", while the relationships between latent variables are referred to as the "internal model" [47].

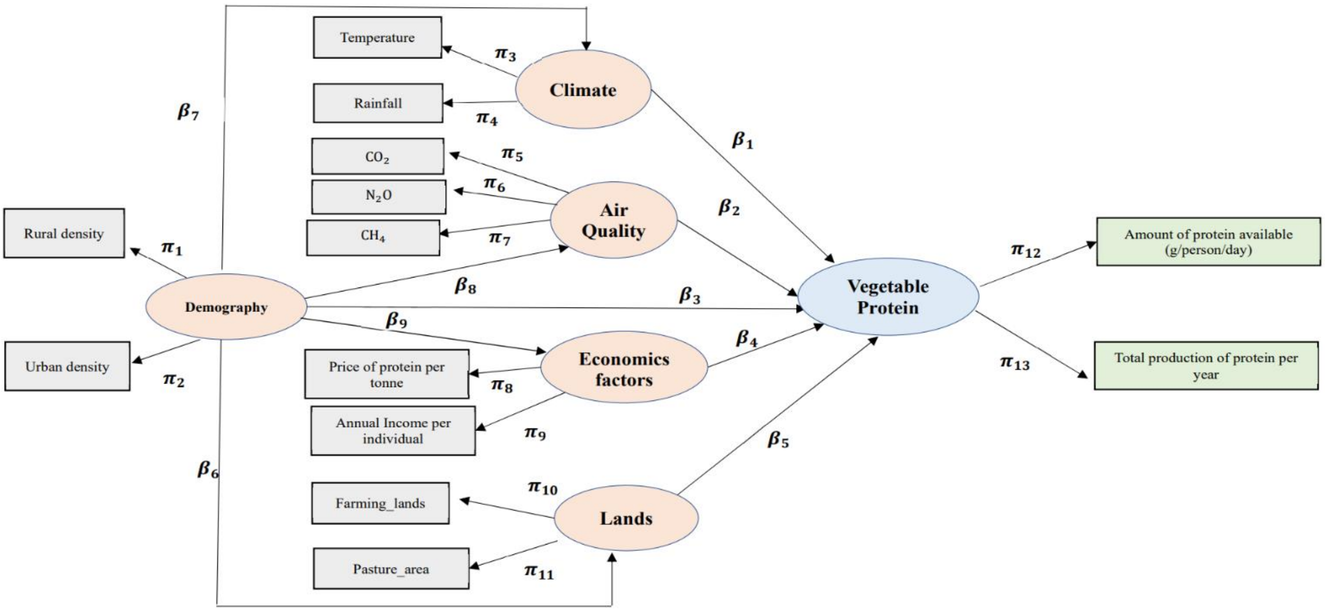

Figure 1. Path diagram showing the structural equation model.

The equations characterizing these two types of models are in the following form:

External models:

$$X_{kj} = \pi_{kj}\delta_k + \epsilon_{kj} \tag{2}$$

where X_{kj} is the vector associated with the *j*th manifest variable of the latent variable δ_k; π_{kj} is a structural coefficient (loading) associated with X_{kj} and ϵ_{kj} is an error term (measurement errors of the manifest variables).

In this case, we are talking about the relationships between each parameter and its own measurement indicators: climate and its indicators (temperature, rainfall), air quality and its indicators (atmospheric pollutants), economies and their indicators (prices and income), demographics and its indicators (rural and urban population density), land use and its indicators (agricultural and grazing areas), and availability of plant protein and its indicators (availability per person per day and total quantity produced nationally).

Internal models:

$$\delta_k = \sum_{i=\delta_i}^{\delta_k} \beta_{ki}\,\delta_i + \varepsilon_k \tag{3}$$

where β_{ki} is the structural coefficient associated with the relationship between the variables δ_k and δ_i and ε_k is an error term associated with the endogenous latent variable δ_k.

Here, we are looking at the direct relationships between the latent variables (climate, air quality, demographics, economy, land use) and the latent response variable (protein availability). Figure 1 (path diagram) shows the structural equation model used:

Robustness assessment tests of the PLS-SEM model were thoroughly carried out, covering key indicators such as Cronbach's alpha (α), composite reliability (rhoC), indicator reliability (rhoA), and discriminant validity.

The forecasts were made using the Auto Regressive Integrated Moving Average (ARIMA) method, considered to be one of the best performing forecasting methods when dealing with time series data as in this case [48]. Indeed, to determine the parameters (*p*, *q*) respectively describing the order of the autoregressive component (*p*) and the moving average component (*q*), the partial (PAFC) and simple (AFC) autocorrelation functions have were used in accordance with recommendations in the literature [43]. The choice of values of p and q was based on the analysis of the correlograms of these functions. When multiple levels of correlation were observed in these functions, degrees of p and q commonly used in practice, generally between 2 and 3 at most, were considered, as suggested by previous studies [43]. As for the parameter "d", it represents the number of differentiations carried out to guarantee the stationarity of each series, thus indicating the number of iterations of the differential calculation carried out. The equations used to make these forecasts are as follows:

Let Y_t be the ARIMA time series of an explanatory variable X_t written as a linear transfer function of a noise series:

$$Y_t = \sum_{j=0}^{\infty} \varphi_j \, \varepsilon_{t-j} \tag{4}$$

To obtain a forecast Y_{t+L} (where L denotes a following year or a lag) of the explanatory variable X the following equation was used [43]:

$$Y_{t+L} = \sum_{j=0}^{\infty} \varphi_j \, \varepsilon_{t+L-j} \tag{5}$$

These various analyses were carried out using R software version 4.3.0 and Excel was used to enter the data obtained from our two sources (World Bank and FAO website).

4. Results

4.1. Chronological Development of the Main Parameters Assessed

4.1.1. Chronological Evolution of Rainfall

The graph in Figure S1(see Supplementary Files) shows changes in rainfall over time in several countries, including France, Germany, Spain, Indonesia, China and Japan. An analysis of the graphs for the three European countries (France, Germany and Spain) shows almost identical fluctuations between 1990 and 2020.

The curve showing the average annual change in rainfall indicates a slight increase in rainfall in France, from 866 mm in 1990 to 928 mm in 2020, and in Spain, from 571 mm in 1990 to 684 mm in 2020. By contrast, the situation appears to be stable in Germany, where rainfall has remained constant, varying from 848 mm in 1990 to 824 mm in 2020.

However, although there is a variation in trends within these countries, average annual rainfall remains highest in France, followed by Germany, and finally Spain, which has the lowest value. This has also been noted by Météo-France [49], which notes extreme rainfall ranging from 600 mm to 2000 mm in the countries of north-western Europe, including France.

In addition, the European Environment Agency (EEA) also points out that most precipitation studies have shown a trend towards wetter conditions in northern Europe throughout the 20th century [50]. On the other hand, the European Environment Agency reports a gradual decrease in rainfall in certain specific parts of southern Europe, without explicitly mentioning whether Spain is included in these regions. This decrease, estimated at around 90 mm per decade, may not therefore affect Spain.

Furthermore, the stability observed in Germany is in line with the results of other previous studies based on E-OBS data. These studies conclude that average annual precipitation on a European scale has not changed significantly since 1960 [50,51].

As far as the Asian countries are concerned, a variable trend in rainfall is also observed within each country (Indonesia, Japan, China); this translates into an increasing trend in rainfall in Indonesia and Japan, and a gradual decrease in China. Indeed, the results of the graph indicate that the rate of precipitation is much higher in Indonesia (2914 mm in 1990 to 3594 mm in 2020) than in the other two countries. This is followed by Japan, which shows a slight increase from around 1810 mm in 1990 to 1918 mm in 2020. In contrast to the increasing trends in Indonesia and Japan, China shows a decreasing trend, from 903 mm in 1990 to 833 mm in 2020.

These results observed in European countries are consistent with those observed in Asian countries, highlighting geographical differences in rainfall over the last thirty years. The United Nations (UN) also highlights this spatial variation and classifies the South-East Asian region as the most exposed to the threats of climate change, both on an Asian and global scale [52]. This region is considered particularly vulnerable due to rising sea levels, leading to intense rainfall and extreme consequences for populations living at lower altitudes [52]. This vulnerability to precipitation could be a determining factor in the availability of plant proteins, especially when we remember that agricultural production is highly dependent on climatic variations [34].

4.1.2. Chronological Evolution of Temperature

The curve shown in Figure S2 (See Supplementary Files) represents the chronological evolution of temperature in the countries selected for the study. The curve shows irregular oscillations across the different countries. The temperature curves clearly and significantly show an upward trend, irrespective of the country or continent. These results are in line with the conclusions of the IPCC [53], which confirms that global warming is marked by a significant increase in temperatures due to human activities in recent decades. From this perspective, these temperature rises are contributing to the global warming observed on a planetary scale.

However, the annual averages for this parameter also reveal geographical differences like those observed in the case of rainfall. Indonesia has the highest temperatures, ranging from 25 °C (1990) to around 26 °C (2020). This further reinforces the UN's ranking (2019), which places Indonesia at the top of the list of countries most vulnerable to climate change, characterized by rising sea levels and extreme warming conditions.

Nevertheless, Spain has the highest average annual temperatures in Europe, at around 15 °C (2020). This is because Spain is part of the Mediterranean region, which, according to the Intergovernmental Panel on Climate Change (IPCC) (2019; 2018), remains particularly vulnerable to the effects of climate change, with more adverse socio-economic consequences than other regions of the world.

These conclusions are also supported by recent studies that highlight the specific features of the Mediterranean area in terms of temperatures and the general increase in global warming [54,55]. This global warming directly threatens the production of plant proteins by accentuating water scarcity due to increased evapotranspiration. Increases in temperature, shown in Figure S2, generate risks such as climate-related diseases, deterioration of water supplies and soil acidification, all detrimental to food production, leading to a decline in plant proteins [53].

4.1.3. Chronological Evolution of Air Pollutants

In-depth analysis of air pollutants in a study focused on assessing plant protein availability is necessary. By examining the concentrations of these pollutants in the selected countries, it is easier to perceive emerging trends for each pollutant, and to determine which pollutants could significantly influence the availability of plant proteins.

The main pollutants considered in this study are methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). Figure S3 (See Supplementary Files) shows the chronological evolution of the quantity of methane in the atmosphere of each country. It reveals a low quantity of this pollutant at European level, with a decreasing trend over time, particularly in France (3485 kilotonnes in 1990 to 2847 kilotonnes in 2020) and Germany (6045 kilotonnes in 1990 to 2525 kilotonnes in 2020). In Spain, there has been a slight increase from 2000 kilotonnes (1990) to 2100 kilotonnes (2020). Furthermore, the decrease observed in European countries such as France and Germany may be due to the action plans drawn up by the European Commission to reduce methane emissions on the European continent, which consider that emissions produced within the continent are negligible compared with those imported into it [56].

However, methane emissions from the production and use of fossil fuels are much lower than those from agriculture [57]. The latter sources of production are therefore easier and cheaper to reduce, making them an urgent priority [58]. Hence the birth of the "Oil and Gas Methane Partnership" (OGMP), the "zero pollution" action plan (2021) and the "Clean Air Outlook" programme (2022) [58], all of which are working to reduce the amount of natural gas produced on the continent.

In Asian countries, particularly Japan, the situation is like that in France and Germany, with a gradual decline in the total quantity of this pollutant over the period 1990 to 2020. On the other hand, there has been a sharp increase in the amount of methane in China, from 42,010 kilotonnes in 1990 to 68,969 kilotonnes in 2020, followed by Indonesia with 11,551 kilotonnes in 1990 and 16,887 kilotonnes in 2020. These are the findings of scientists who have carried out similar studies. For example, China leads the list of countries with the highest increases in fossil fuel emissions [58,59].

This can be explained by the fact that China is ranked as the world's leading producer and consumer of rice, contributing 28% of global production according to the Food and Agriculture Organization of the United Nations [60]. This crop is a real agricultural source of methane emissions [57]. Considering the contribution of this pollutant to the problem of global warming, this indirectly makes CH_4 one of the factors that could encourage the reduction of plants, in particular plant proteins. The influence of this pollutant on plant proteins could be considerable in countries such as China and Indonesia, where CH_4 is increasing exponentially every year. Figure S4 (See Supplementary Files) shows the chronological evolution of the quantity of carbon dioxide (CO_2) emitted into the atmosphere in each country.

The curves representing the quantity of carbon dioxide emitted into the atmosphere between 1990 and 2020 show fluctuations similar to those observed for methane. There is a downward trend in CO_2 emissions in Germany and France, as in the case of methane, and an upward trend in Spain: 226,340 kilotonnes in 1990 and 288,357 kilotonnes in 2020. These fluctuations in CO_2 emissions reflect the different sensitivities of countries to climate issues. The increase in carbon dioxide emissions in Spain can be partly explained by the fact that the country is one of the European nations that is not meeting its reduction commitments under the Kyoto Protocol [61]. This non-compliance with the international agreement may therefore contribute to the upward trend in emissions of this pollutant in the country.

On the other hand, according to the results, CO_2 emissions are increasing considerably in Asian countries. In fact, this is what the Organization for Economic Co-operation and Development (OECD) has shown by classifying China as the world's leading exporter of CO_2 [62]. This is also confirmed by Ali [63], who points out that the Asian continent is strongly dominated by booming industries. Industry remains the main source of greenhouse gas emissions, including CO_2, due to its heavy reliance on fossil fuels [57]. This growing trend in CO_2 in Asia can be clearly understood in the light of gas and energy consumption through the continent's rapidly expanding industrialization. Like CH_4 , the contribution of CO_2 to global warming makes this pollutant one of the factors contributing to the disappearance of protein-rich plant species. As a result, its influence on plant proteins could be more pronounced in Asian countries and in Spain, where CO_2 is increasing significantly over time.

Changes in nitrous oxide (N_2O) over time show fluctuations similar to those observed for the pollutants CH_4 and CO_2 (Figure S5). In the three European countries, France, Germany and Spain, there is a downward trend in the concentration of N_2O in the environment. The quantity of this pollutant has fallen from 220 kilotonnes in 1990 to around 140 kilotonnes in 2020 for France and Germany, and from 87 kilotonnes in 1990 to less than 85 kilotonnes in 2020 for Spain.

However, the situation is different in Asian countries, particularly Indonesia and China. In these countries, nitrous oxide emissions have increased over the observation period (1990 and 2020). This trend can be attributed in part to their role as major exporters of natural gas and main consumers of this energy for industrial purposes, resulting in massive emissions of this pollutant that is harmful to the environment [63,64].

The results of this study highlight geographical variations and interactions that extend across different continents for different climatic parameters, including rainfall, temperature and the quantity of atmospheric pollutants such as CH_4, CO_2 and N_2O. Asian areas seem to be facing more severe situations than European countries. The results of this study highlight the spatial variability of climatic parameters, including rainfall, temperature and the concentration of atmospheric pollutants such as CH_4, CO_2 and N_2O. This variability extends over different geographical regions and involves different parts of the world, including intercontinental areas. Indeed, the increase in these different pollutants in different countries, particularly in Asian areas, could be a determining factor in the availability of plant proteins.

4.1.4. Total Population over Time

Figure S6 (See Supplementary Files) illustrates the dynamics of the total population in the various countries between 1990 and 2020. Overall, there has been a steady increase in the number of inhabitants per country, except for Japan, which has seen a significant decrease in its population between 2010 and 2020. This decline in Japan's population could be attributed to the phenomenon of population ageing, which is largely dominant in Japan, with 28% of the population aged 65 and over, three times the world average [65].

This truly explains the decline in population density that Japan has experienced from 2010 to 2020, since 50% of the population is over 48.4 years old (median age), considered to be the highest in the world [65]. Despite this, the general trends show an increase in population in the various countries studied over the last thirty years.

This demographic trend observed in most of the countries considered remains a global phenomenon, with an estimated growth rate of over 200% between 1950 and 2022 [57]. This unbridled population growth over the last two centuries is associated above all with improvements in living standards, but also with the gradual increase in human lifespan and growing urbanization [57]. In addition to these factors, there are other factors such as the natural growth rate in each area or region outside the major cities [66]. Thus, the continuing increase in population in the various countries could be a determining factor in the shortfall in protein availability [26]. However, in some European and Asian countries, it is the falling birth rate and the dominance of older individuals that are the most important concerns [67].

4.1.5. Chronological Evolution of the Total Agricultural and Grazing Area

Figure S7 (See Supplementary Files) shows the rate of occupation of agricultural land (areas occupied by agricultural production) and permanent and temporary grazing areas in the various countries. In this context, permanent grazing refers to the constant use of the same natural area by livestock, while temporary grazing refers to the periodic exploitation of specific areas by animals to allow regeneration of the pastures used.

An analysis of this figure shows a gradual reduction in the area allocated to agricultural production in European countries. In France, agricultural production has fallen from 30.5 million hectares (1990) to less than 28.5 million hectares (2020). In Germany, the decrease is also real, from 18 million hectares (1990) to 16.5 million (2020), and finally in Spain, the total agricultural area has fallen from 30.4 million hectares to 26.14 million hectares.

However, population growth in Europe should normally have led to an expansion of agricultural land in these countries. This is because population growth is a key factor in food demand and, consequently, in the expansion of arable land [68]. In this case, however, population growth is accompanied by an increase in the level of urbanization. The non-confirmation of these results can be justified by the fact that the authors essentially emphasize the rural layer as the predominant element in the increase in agricultural land [68]. Yet European countries are characterized above all by a high rate of urbanization (72%) and an increase in migration rates [57].

In Asia, analysis of the graphs shows a gradual increase in farmland, particularly in Indonesia and China. This can be attributed to the ability of these countries to increase their production levels, particularly China, which has long been considered the world's leading rice exporter, contributing 28% of global production [29]. On the other hand, in Japan, where an ageing population predominates, there has been a gradual decline in the area of farmland.

In terms of both permanent and temporary grazing areas, there has been an increasing trend over time in the different countries. These results bear witness to the enthusiasm of Europeans and Asians alike for urban grazing [69]. This reduction in the area allocated to agricultural production in Europe could have an impact on the availability of plant proteins in the region, as it could reduce the space available for growing protein-rich plants.

4.1.6. Chronological Evolution of Economic Indicators

Figure S8 (See Supplementary Files) shows the dynamics of gross annual income per capita in each of the countries considered. Analysis of these figures shows a gradual increase in gross income per capita in the various countries. Specifically, in 2020, the average annual income in France has almost doubled compared with the situation in 1990 (i.e. from USD 22,500 to USD 41,563). In the other two European countries, the situation is virtually the same, with trends ranging from USD 22,500 (1990) to USD 48,000 (2020) in Germany and Spain, where income has risen from USD 13,600 (1990) to more than USD 27,000 (2020).

In Asia, the situation is no different in terms of the trends seen in European countries, especially Japan, where purchasing power is as high as in the three European countries. In other Asian countries, including Indonesia and China, people's incomes are also changing considerably over time. In Indonesia, for example, there will be a 400% increase in 2020 compared with 1990 (USD 694 to USD 3700), and in China, per capita income will have risen from USD 400 in 1990 to around USD 10,000 in 2020.

For Gelb and Diofasi (2016), these increases can be associated not only with an increase in wages but also with an increase in the relative prices of goods. This is also stated by the Institute National of Statistics and Studies (INSEE) (2021), when it attributes to these increases in income the rise in the cost of health services in recent years, characterized by the emergence of pandemics [70]. For others, these increases reflect foreign direct investment (FDI) flows, which are taking place mainly in Asian regions (United Nations Conference on Trade and Development [71]. The gradual increase in gross per capita income observed in European and Asian countries could have an impact on the availability of plant proteins. This is for the simple reason that this increase is likely to influence eating habits and consumption choices, particularly by promoting access to varied sources of plant proteins.

Figure S9 (See Supplementary Files) shows changes in the average annual price per tonne of plant protein in the six countries. Analysis of the figure shows an increasing trend in the price of a tonne of plant protein between 1990 and 2020 in the various countries of Europe and Asia. This is precisely the average price of a tonne of protein from legume seeds (lupins, beans, lentils, chickpeas and many others), oilseeds (soya, sunflower, rapeseed and groundnuts, etc.) and cereals (wheat, millet, oats, rice), all considered to be the main sources of protein from plant sources [72].

In France, a tonne of these foods was valued at around $200 in 2000, before rising sharply to over $400 between 2010 and 2015 - double the price 20 years ago. In Germany, the increase has been greater, rising from around $400 (1990) to around $900 (2020), a rate of around 125%. The situation is similar in Spain, where prices have risen from USD 300 (1990) to over USD 650 (2020).

The same trends can be seen in Asia, particularly in Indonesia and Japan, where prices have doubled over the last 30 years (1990–2020). The general rise in the price of these plant proteins is associated with strong demand for protein-rich plant products. Faced with very high rates of self-sufficiency (up to 79% for certain protein sources such as rapeseed), these countries, particularly those in Europe, import more than 17 million tonnes of crude protein each year from several other countries such as Brazil, Argentina, and the United States [73] (European Commission, 2018).

This interest in these proteins is mainly linked to the allergies that consumers are developing towards animal proteins, leading them to substitute meat with vegan proteins, which ultimately stimulates their market with a gradual increase in prices on a global scale [25]. For example, it is stated that the market for meat and dairy substitutes is particularly promising, with annual growth rates of 14% and 11% respectively [73].

Furthermore, the increase in average annual prices per tonne of plant proteins observed in Europe and Asia suggests an increase in the costs associated with these protein sources. This trend could potentially influence the availability and accessibility of plant proteins, which in turn could have an impact on consumer food choices and demand for vegan products, thereby stimulating the plant protein market.

4.1.7. Evolution of Protein Availability Indicators in Each Country

The growing trend in the price of plant proteins has been associated with an imbalance between demand and supply of these proteins of plant origin in most of the target countries. Figure S9 (See Supplementary Files) shows a chronological projection of the quantity of production (in tonnes) and the variation in stocks of plant proteins (tonnes) to assess the supply in each of the different countries.

In fact, there has been a downward trend in the production and stock of plant proteins in three of the six countries considered. These are France, Germany, and Japan. From around 39 million tonnes (2010), France has seen a gradual decline to a production estimated at around 35.5 million tonnes in 2020, a drop of more than 9% over the last ten years.

In Germany, FAO data also indicate a drop of more than 17% in the level of plant protein production over the last ten years, and in Japan a drop of more than 8% over the same period. These decreases observed in these different countries also follow the gradual decline in agricultural production areas previously highlighted in the three countries. Some associate this decline with the depletion of agricultural land, especially given the demographic explosion that has long been considered responsible for the pressure on natural resources such as land [74]. On the other hand, for some, the decline in production areas in countries such as France and Germany is justified more by the increase in the rate of urbanization, estimated at 72% of the EU population; a problem that is fueled above all by the migration of the agricultural (rural) population to urban areas [75].

Moreover, in Asia, and more particularly in China, production levels have changed considerably over time, with an estimated increase of more than 24% in recent years (i.e. 1,015,939,000 tonnes of plant proteins in 2010 compared with 1,260,523,000 tonnes in 2020). A very slight increase (3%) has also been observed in Indonesia. These results are far from surprising, especially when one considers China's global status in terms of agricultural production, especially rice, where China remains the leading reference with a 28% share of world production [29]. This massive production of rice in China and other Asian countries contributes significantly to increasing the availability of plant proteins for their populations. This is simply because 100 g of rice contains around 5.51 kilocalories [76].

These different findings mean that countries such as France, Germany and Japan are ranked as those that rely most heavily on imports to meet their plant protein needs, especially with their production levels continuing to fall over time. Farm Europe (2017) highlighted this plant protein gap, pointing out that Europe relies on imports of protein crops and oilcake from third countries for up to 70% of this deficit. At the same time, countries such as Indonesia and especially China are increasing their export volumes in line with their growing production volumes. This explains the decline in plant protein stocks in China, a country considered to be a potential rice exporter [77].

Figure 2 simultaneously shows changes in the availability of protein of plant origin (g/person/day) and the rate of availability at individual level in the various countries. Following the fall in production and the increase in population density, per capita availability is gradually falling in Germany. From 28.5g/person/day in 2010, per capita availability will fall to less than 26g/person/day in 2020. This decline can also be seen in Japan, where from more than 34g/person/day (2010), Japanese people will have less than 33g/person/day in 2020.

In Spain, despite changes in production levels, an analysis of changes in availability per person shows a slight decrease over time. Estimated at around 29. 8g/person/day in 2010, the availability of plant-based proteins will be around 29.2 g/person/day in 2020. In other Asian countries (China and Indonesia) and in Europe (France), on the other hand, the general trend in plant protein availability per person is upwards, especially in China, where there will be an increase of more than 4 g in 2020 compared with the situation in 2010.

In Indonesia, availability has risen from 37 g/person/day (2010) to 41 g/person/day (2017), before dropping again to 37.6 g/person/day in 2020. In France, the amount of protein available per person per day has increased from 34 g/person/day (1990) to 38 g/person/day (2016). By 2020, this quantity had fallen again, to 36 g/person/day. This slight increase in the availability of plant proteins in France has been made possible by its soya production. France ranks 18th in the world with around 400,292 tonnes of this potential source of protein per year [78].

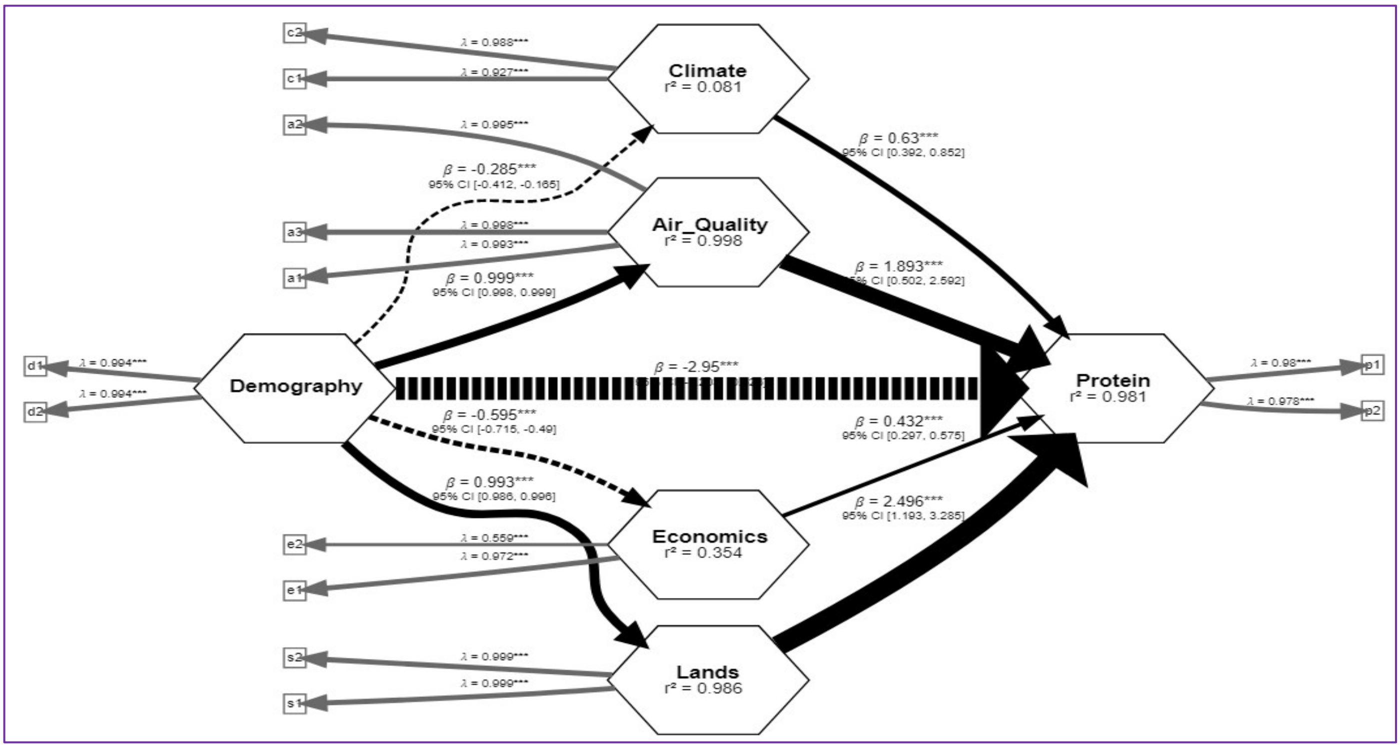

Figure 2. Main PLS effects on plant protein availability.

However, Asian countries have shown greater availability of plant proteins than European countries, which still express a lower level of accessibility. This deficit in plant proteins has been highlighted by Farm Europe (2017), which states that Europe is 70% dependent on imports of protein crops and oilcakes from third countries. With regard to the speed of availability characterizing the rate at which the quantity of plant proteins is accessible to each individual in these different countries, the data revealed several findings. In Germany, the annual rate of access to plant proteins fell considerably in 2019 (−12.77%) and 2020 (−1.67%), indicating a low level of accessibility to plant proteins over the years.

Similarly, in Spain, although the figures have also varied, the speed of accessibility has shown a downward trend, with mostly negative values: 2013 (−0.03%); 2014 (−1.9%); 2015 (−0.5%); 2017 (−0.46%) and then in 2019 (−3.98%). In France, the situation is the same, with a gradual decline in access to plant proteins over time, from −2.4% (2011) to −4.08% (2019). On the other hand, in Indonesia, although the rate of accessibility was initially positive (2.44% in 2011 to 1.17% in 2017), it continued to fall gradually, becoming negative from 2018 (−1.89%) to 2020 (−2.23%). Furthermore, although the evolution of this speed shows an upward trend in China and Japan, it remains negative in 2020, at −0.03% (China) and −0.95% (Japan) respectively.

These results indicate that in these countries, as in the rest of the world, the proportion of plant proteins consumed remains insufficient, especially in the European countries considered, where average availability is still below the world average, estimated at 47 g per day per person [79]. According to the FAO, this situation is set to become even more critical soon, with a forecast 40% increase in global demand for proteins by 2030 and even more by 2050. In other words, between now and 2050, given the rapid growth in the world's population, the major challenge will be to guarantee the availability and optimal use of current food resources to achieve this objective [79].

Furthermore, with the depletion of certain aquatic reservoirs, the gradual reduction in the space available for livestock farming, and a dietary pattern that favours above all the consumption of proteins of animal origin (meat, fish, poultry, eggs, etc.), pulses are increasingly recommended [79]. It is true that cereals are currently the biggest contributors to the supply and satisfaction of protein requirements [72]. Nevertheless, the choice of legumes is justified by their dual advantage as a significant source of protein and their adaptability to drought conditions and marginal environments, while being more accessible and economical, especially in light of climate change [79].

4.2. Factors Determining the Availability of Protein of Plant Origin

Figure 2 shows the results of estimating the effects of the various parameters (climatic, economic, land and demographic) using structural equation models (SEM). Tests to evaluate the robustness of the PLS model carried out were thoroughly carried out, covering key indicators such as Cronbach's alpha (α), composite reliability (rhoC), indicator reliability (rhoA), and validity. discriminating. All results far exceeded the recommended thresholds, thus confirming the reliability and validity of the PLS-SEM model specified in this study.

The results in the figure shows that 98.1% of the variation in plant protein availability at the level of individuals in the different observation countries is explained by the variables considered in the model. In fact, the quantity of plant protein available to an individual per day (g/person/day) and total production within these different countries are significantly influenced by all these parameters, which are: precipitation (c1), temperature (c2), CH_4 (a1), CO_2 (a2), N_2O (a3), gross per capita income (e1), average annual tonne price (e2), area of agricultural land (s1), area of grazing land (s2), rural population density (d1) and urban population density (d2).

The main results obtained show that only demography has a negative influence on all the plant protein availability indicators considered. This negative influence could be attributed to the fact that a high population density increases the population's demand, especially with the advent of the vegetarian diet, essentially due to the allergies that consumers develop to animal proteins [21–25]. For others, population growth is increasing the pressure on resources, particularly agricultural land, thereby reducing their production capacity, particularly in terms of yields of agricultural products that are essentially rich in protein, such as cereals [74].

This explains the positive effect of agricultural land use on the availability of plant proteins at the individual level. For example, the model shows that an increase of one hectare in the area under protein-rich crops increases the amount of protein available per day per individual by more than 2.49g (at the level of the various countries). This is what Farm Europe (2017) notes for the availability of protein peas (soya) and rapeseed meal protein, which doubled between 2004 and 2017 in the countries of the European Union following an increase in the area under rapeseed meal production.

However, the positive influence of atmospheric pollutants on plant protein availability indicators may be associated with the fact that the emission of these various pollutants comes from agricultural production, especially from the use of fertilisers and organic manure and their runoff into the soil [57]. However, the expected effect of pollutants on availability is the opposite, as demonstrated by previous studies by Tchaker [34] and the UN [57]. For Tchaker [34], global warming is under the influence of pollutants and is encouraging the disappearance of both plant and animal species. This conclusion is supported by the UN [57], which states that greenhouse gas emissions must be halved by 2030 to limit global warming to 1.5 °C above pre-industrial levels by the end of the century.

Similarly, although most studies have highlighted the negative impact of climate parameter variability on agricultural production, particularly temperature increases over time [80], the model results show a positive effect of these climate parameters on the availability of plant proteins.

These opposing effects can be attributed to the simultaneous measurement of two availability indicators or parameters (total production and availability per day per person). It can also be attributed to the observation period considered in this study, i.e., 10 years (2010–2020), given the data available from the FAO. Furthermore, according to Boucher and Bessemoulin [81], from a scientific point of view, the real single effect of a climatic parameter such as temperature, precipitation or atmospheric pollutants can only be observed after a period of thirty (30) years.

Finally, with regard to economic factors, it also emerges that price and income have a positive influence on indicators of plant protein availability. This seems logical, in the sense that it is recognized that over-consumption of protein remains a fundamental characteristic of developed countries, as in the EU, where consumption is twice as high as the recommended intake set by the FAO [82]. This is a fact that the FAO [36] attributes above all to the importance of their purchasing power, characterized by high incomes, enabling them to consume 40% more than low- or middle-income countries. Taken together, these effects largely explain the variability observed in the availability of plant protein at the individual level in different countries.

4.3. Prediction

Figure 3 shows the annual forecasts up to 2030 of the quantity of vegetable protein that would be available for an individual in the various countries under the influence of the main parameters (precipitation, temperature, CH_4, CO_2, N_2O, the price of a tonne of protein, agricultural area, population density, total protein production and stock variation) identified. To these graphs are added two other values characterizing the minimum quantity of protein required by men and women in each country, according to their average weight in 2021 [83]. It is accepted that the minimum quantity of protein required per kg of body weight is 0.8 g/kg [84]. Based on the average weights of men and women in each country, the minimum amount of protein contained in the bodies of the inhabitants of these countries was estimated and added to the various prediction graphs.

The ARIMA method, considered to be the most appropriate for data following time series, was used to make the various forecasts [48]. At European country level, analysis of the results of the prediction of the amount of plant protein that would be available to an individual shows a decreasing trend over time, particularly in France and Germany, where by 2030, forecasts indicate a gradual reduction to 10 g/person/day of plant protein. In Spain, on the other hand, forecasts suggest an increase in the amount of protein consumed by individuals to 40 g/person/day. Nevertheless, in these various European countries, including Spain, the amount of plant protein available to individuals will remain insufficient to meet the protein needs of the inhabitants of these countries.

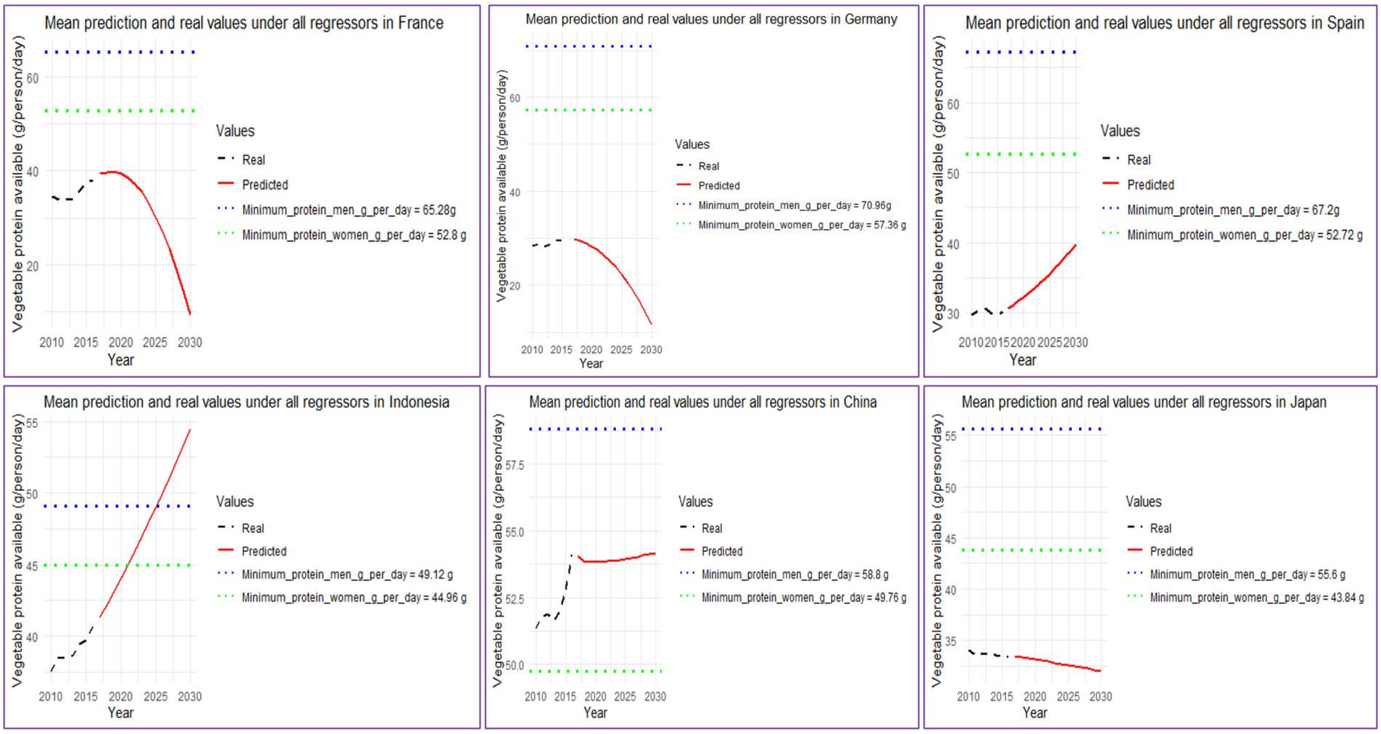

Figure 3. Annual forecasts for 2030 of the quantity of plant protein available by country.

In Asia, especially Japan, forecasts are moving in the same direction, with a gradual reduction over time in the amount of plant protein available to each individual. The model predicts a decrease to below 33 g/person/day for each Japanese. Although China will see a slight increase in the amount of plant protein available between now and 2030, only women will remain satisfied, with a minimum protein requirement estimated at 50 g/person/day. Chinese men, on the other hand, will continue to suffer from a total lack of protein, with a minimum requirement estimated at almost 58 g/day/person, given their body weight.

As for Indonesia, the model predicts an increase to 55 g/person/day for everyone in 2030. Of all the countries, only Indonesia shows satisfaction from 2020 onwards, with availability of up to 55 g/person/day, compared with a requirement of 45 g/day and 49.12 g/day for women and men respectively.

From these results, with the current level of production in each country, it is obvious that eating only plant proteins in these different countries will not enable individuals, particularly men, with greater needs given their higher body weights to meet their plant protein requirements [83]. This will be much more the case for those whose diets are based solely on plant-based products [21].

Faced with such increases in protein requirements in different countries, particularly in France, Germany, and Japan, where the quantity available per person is gradually decreasing, it is imperative to first find a suitable method of combining animal and plant protein production to make the most of these two potential sources of protein. With this in mind, Greenpeace [39] states that it would be interesting to propose innovative and sustainable systems to livestock farmers and agri-farmers to enable them to work together to increase their respective production.

To improve the accessibility of proteins, the French National Nutrition and Health Plan (PNNS) (2017) suggests promoting the consumption of legumes as a source of vegetable protein (at least two portions per week, i.e., 200g). This is an appropriate choice, especially when we consider that, in addition to being an important source of protein, pulses are more accessible in terms of cost and are much more adaptable to climatic hazards [79].

5. Discussion

The results of this study show that climate change remains a worrying phenomenon in both Europe and Asia. Analysis of climate data, particularly temperature data, showed a considerable upward trend, the main source of global warming. For some, this increase in temperature over time is the consequence of human activities in previous years [54]. However, the Mediterranean zone (represented here by Spain) and Indonesia are the most exposed to this increase in temperature [55]. Apart from temperature, the study also showed an increase in atmospheric pollutants such as CH_4, CO_2 and N_2O, particularly in Asian countries where not only is the industrial sector increasingly developed but agriculture is also booming [58–63].

Analysis of the economic factors linked to plant proteins has shown an increase in gross national income per capita and in the price of these proteins. These increases also reflect the improvement in the purchasing power of the population within each country. This improvement in prices over time is mainly associated with the influence of the increase in demand for these proteins in countries with low levels of agricultural production, such as those in Europe, which are obliged to import as much as possible to meet galloping demand, especially in the face of various health problems [38].

However, this can also be attributed to the improvement in gross national incomes in the various countries, which is also improving their purchasing power, mainly because of the health services and major investments that are increasingly being made [85]. Indeed, based on these various improvements, countries such as France, Indonesia and China are also succeeding in maintaining the increase in the quantity of plant protein available in terms of the quantity accessible daily per individual compared with the other three countries (Germany, Spain, and Japan).

However, in addition to these variables, there are others, notably population density, for which analyses confirm the persistence of the demographic explosion in recent years [86]. The effect of this demographic growth is to intensify pressure on resources such as agricultural land, especially in Asia, where China remains a benchmark for rice production [29] (Qi et al., 2022). In Europe, this growth is more likely to lead to an increase in the rate of urbanization, which is already considered to be sufficiently high, at 72% of the EU population [75].

From a nutritional point of view, the influence of this demographic change can be seen in the different countries, with a slowdown in the rate at which the quantity of these proteins of plant origin has become available over the last thirty years. This slowdown is associated with the imbalance between supply and demand for these proteins, where the former (supply) remains below the latter (demand), which will continue to grow significantly over time [62].

The SEM results showed a significant influence of climatic, demographic and economic parameters, including agricultural area, on availability indicators such as the quantity of plant protein available per person per day (g/person/day) and total production. The most notable is the negative impact of demographics (rural and urban population density), especially due to the increase in demand for these proteins over the years. Indeed, demand for plant proteins is gradually increasing as population density rises and people's eating habits evolve towards a vegetarian diet [21–25].

This strong preference for plant proteins at the expense of animal proteins (sources of allergies for some consumers) considerably limits their availability each year. This is due to the gradual reduction in viable production areas for cereals, which are the real sources of plant proteins [74]. This result has been confirmed by the model through the significant influence of agricultural land use on the availability of plant proteins. These results are also confirmed by Farm Europe (2017), which notes a significant increase in protein from rapeseed and pea oilcake as a result of an increase in the area under these crops. The results also show a positive effect of economic factors (prices and income) on the availability of plant proteins. This finding confirms those of the FAO [36], which stresses that protein over-consumption is mainly observed in developed countries where populations have greater purchasing power.

However, the positive influence of climatic parameters observed contrasts with other previous results which, on the other hand, demonstrate a negative effect of the variability of climatic parameters on agricultural production, in particular the increase in temperature over time [80]. Tchaker [34] has focused instead on the disappearance of protein-rich plant species under the influence of global warming, encouraged by atmospheric pollutants.

Forecasts based on ARIMA indicate a decreasing trend in the availability of plant proteins over the next ten years (in several countries, notably France, Germany, and Japan). In the other three countries (Spain, Indonesia, and Japan), although the forecasts show an increase in the availability of these proteins, comparisons with the threshold values for their requirements in terms of minimum protein quantities in the body show that proteins of plant origin alone are far from being able to satisfy the needs of individuals in each of these countries, except for Indonesia. The situation is even more worrying in countries where availability will gradually decline over time.

To remedy this situation, which is characterized by a shortage of proteins of plant origin, cooperation between livestock farmers would be extremely useful, especially by setting up innovative and sustainable systems involving livestock farmers and farmers with the aim of providing access to proteins (both animal and plant) in quantity [39]. Others suggest focusing instead on promoting leguminous crops such as soya, which are essentially rich in protein and capable of withstanding the problems of climate instability [86].

6. Conclusions

In conclusion, this study highlights the impact of climate change, population growth and economic factors in assessing the availability of plant proteins in various European and Asian countries. The results show a rising trend in temperature, an increase in atmospheric pollutants and in the price of plant proteins, while the production of plant proteins and their availability at individual level show varying trends from one country to another. On the other hand, Asian countries are experiencing a significant increase in atmospheric pollutants due to industrialization and intensive agricultural development, which may have consequences for the availability of plant proteins.

Demographic pressures, growing demand for plant proteins and the reduction in viable production areas for cereals are contributing to a gradual decline in the availability of plant proteins in certain European countries such as France, Germany, and Spain. Prediction models suggest that the availability of plant proteins will continue to decline in certain European countries (France and Germany), while other Asian countries could see a moderate (China) or considerable (Indonesia) increase. Indeed, by 2030, forecasts indicate a gradual reduction to 10g/person/day of plant protein in France and Germany.

In Asia, only Indonesia could meet the needs of its population, estimated at 55 g/person/day. However, it is important to note that the projected availability remains insufficient to meet the nutritional needs of the population, particularly in developing countries where demand for plant proteins is constantly increasing. In order to address this major concern, collaboration between livestock farmers and farmers offers the prospect of establishing innovative and sustainable farming systems, promoting balanced access to proteins of animal and plant origin. An additional sustainable strategy could be to encourage the cultivation of protein-rich legumes, such as soya, to increase the availability of plant proteins while building resilience to climate change.

In short, the availability of plant proteins is a major challenge in a context of climate change, population growth and economic development. Concerted and sustainable measures are needed to ensure adequate availability of these proteins, which are essential to the nutrition and health of populations. Awareness of the importance of plant proteins and their promotion should be among the priorities of national and international food policies to meet this global challenge.

Supplementary Materials

The supporting information can be found at: https://www.sciepublish.com/article/pii/109.

Data Availability Statement

The data supporting the reported results are available as supplementary files and can be obtained on reasonable request.

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Ethics Statement

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Informed Consent Statement

Not applicable.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests.

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