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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

Aim: The aim of this study was to analyze the availability of plant proteins and their prediction for the future up to 2050 in Europe and Asia.
Materials and Methods: Data regarding plant proteins available, rain fall, temperature, CH_4, N_2O, income, price, farming lands, population, total production and stock variation were recorded and analised.
Results: The results analyzed 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.
Conclusion: It was concluded that rising trend in temperature lead 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.

Keywords: Plant-basedproteins, climate change, vegetables, sustainableconsumption, public policies

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Introduction

Global population growth, combined with the convergence of incomes and Western lifestyles (with high consumption of meat products), is calling into question the capacity of agriculture to meet the food needs of the 9.7 billion people who will inhabit the planet by 2050 (Voisin et *al*., 2013). The United Nations Environment Programme predicts that up to 25% of the world's food production will be lost by 2050 as a result of environmental degradation, particularly in developing countries (Gomiero et *al*., 2011). However, meeting these needs is of vital importance to all living beings. It is therefore important to have access to all types of nutrients for good health. In terms of protein requirements, international bodies, and the FAO (Food and Agriculture Organization of the United Nations) (FAO, 2002) recommend an intake of 0.83 g of protein per kg of body weight per day for an adult, and between 10 and 20% protein in the daily diet.

In the space of almost 50 years, there has been a clear change in overall consumption: in 1961, the average person consumed 61 grams of protein a day, 68% of which came from plant sources (Collin and Gohier, 2022). By 2013, this figure had risen to 81 grams, 40% of which came from animal sources, reflecting an increase in the overall consumption of both plant and animal proteins (Collin and Gohier, 2022). Not every human being has the privilege of satisfying this protein requirement. According to the FAO, 1/7 of the world's population suffers from hunger and 1 billion people have an inadequate protein intake (Chardigny, 2017).

Several prospective studies (Esnouf et *al*., 2011; BIPE, 2015) (TerresInovia, 2016) predict a major constraint on protein sources in the coming decades, which is not the case for carbohydrates or lipids. Indeed, as atmospheric CO2 levels rise, the protein content of crops will fall (Medek et *al*., 2017). Activities linked to food production are of great concern, since they are responsible for 30% of all greenhouse gas (GHG) emissions of human origin (Willett et *al*., 2019).

This phenomenon is set to worsen as the population increases and the need for energy increases, thereby exacerbating climate change. Climate change is causing adverse consequences for the environment and humans, including changes in rainfall, temperature, air quality, water levels and natural disasters, thereby jeopardizing food production (Field et *al*., 2014). This could have a significant impact on populations dependent on plant proteins, which are currently estimated at 76% of the world's population (Medek et *al*., 2017). According to this scenario, almost 150 million more people could be at risk of protein deficiency by 2050 (>1.5% of the projected population), as the protein content of rice, wheat, barley, and potato are all expected to fall by at least 6% (Medek et *al*., 2017).

Most plant proteins come from legumes (soya, beans, peas, chickpeas, lentils, etc.) and cereals (wheat, rice, etc.), but also tubers (such as potatoes) or leaves (leaf proteins from alfalfa), the level of consumption of which varies from country to country (Guéguen, Walrand et *al*., 2016). Lupins and potatoes are emerging sources (Guéguen, Walrand et *al*., 2016). Furthermore, sustainable intensification has appeared in the literature as a paradigm frequently referred to in agricultural production (Wezel et *al*., 2015). Plant proteins are certainly an opportunity to meet future global protein needs, using complementarity or associations with other traditional (animal products) or new (algae, insects) products (Chardigny, 2017). Partial substitution of animal proteins by plant proteins could make it possible to meet growing demand as part of the sustainable development of agricultural and food systems (Dorin et *al*., 2011, Willett et *al*., 2019).

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 (Collin and Gohier, 2022). What's more, vegetarianism is integrated into various religions, such as Hinduism and Buddhism (Lentz et *al*., 2018). Vegetarianism seems to be the most widespread selective diet in Western societies (Olabi et *al*., 2015; Radnitz et *al*., 2015).

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 (Miassi et *al*., 2022). Adopting a vegetarian or vegan diet has become common practice, both for ecological reasons and for health and well-being (Duboscq, 2019). 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 (Collin and Gohier, 2022).

However, it is important to consider that land conversion for agriculture is one of the largest emitters of GHGs within agricultural production (Foley et *al*., 2011; Peyraud, 2020). The conversion of tropical forest land alone contributes to 12% of annual anthropogenic CO_2 emissions, which represents 98% of CO_2 emissions due to land conversion (Foley et *al*., 2011). It will therefore be necessary to find practices that respect the environment in order to make the most of this advantage offered by crops in terms of protein supply. Efforts will therefore have to be made to ensure the availability of plant proteins while safeguarding the environment.

In 2016-2017, the demand for plant proteins amounted to around 27 million tonnes of crude protein in Europe. Europe's self-sufficiency rate varies greatly depending on the protein source (79% for rapeseed, 42% for sunflower and 5% for soya) (Collin and Gohier, 2022). As a result, Europe imports around 17 million tonnes of crude protein every year. As for Asia, a continent with strong demographic growth, Hinduism and Buddhism have a major influence on vegetarianism, led by China and India and impacting other countries on the continent (Mordor Intelligence, 2022). Demand for plant proteins will increase by 6.10% in 2028 (Mordor Intelligence, 2022). Given the importance of plant proteins in Europe and Asia and the challenges they will face in the future, these two continents were chosen for this study.

The general objective was to analyze the availability of plant proteins and their prediction for the future up to 2050 in Asia and Europe. Specifically, the first step was to take stock of changes in climate, demographics, cultivated areas and demand for plant proteins. Secondly, we identify the parameters determining the availability of plant proteins and, finally, to predict the impact of these parameters on the availability of plant proteins.

Materials and Methods

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 (Caillave et al., 2019). Asia is also recognised as a potential consumer, but also has a large agricultural production capacity (Neo, 2019). 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 (Mordor Intelligence, 2020). 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 (Qi et *al*., 2022). 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 (Mordor Intelligence, 2020). Asia's centuries-old agricultural history makes it fertile ground for the exploration of plant proteins, as it has a solid plant production base.

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 (Augère-Granier, 2020) 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) (Mordor Intelligence, 2022).

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.

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 (Tchaker, 2021). For Sultan et *al* (2015), 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 (Tchaker, 2021). 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 (Tchaker, 2021). This warming, accentuated by pollutants, has several harmful effects, in particular the disappearance of plant species (Tchaker, 2021).

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.

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 (FAO, 2017). Indeed, an increase in income allows access to protein sources, especially since, according to Kaabache (2019), the price of these proteins remains the main determinant of their consumption.

Social factors

Among the most decisive social factors, Caillave et al (2019) 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 a 30-year period (1990-2020) on the website of the Food and Agriculture Organization of the United Nations (FAO).

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 (FAO, 2023).

At the same time, the FAO states that most agricultural land is used to produce food for farm animals (Greenpeace, 2019). 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.

Analysis method

The chronological analysis of the various parameters listed above was carried out using time series analysis methods, which have the particularity, firstly, of tracing the evolution of variables over time. Secondly, they provide forecasts that can be used as a basis for crucial decisions (Sakli, 2016). To identify the determinants of protein availability at the level of individuals in different countries, structural equation modelling (SEM) based on the partial least squares method (commonly known as Partial Least Squares SEM (PLS-SEM)).

Indeed, structural equation modelling (SEM) uses a combination of factor analysis and regression. Regression in SEM is similar to classical linear regression, but is applied to relationships between latent factors (latent variables) rather than observed variables (Ravand and Baghaei, 2016). SEM thus allows the specification of regression equations that describe how latent factors are related to each other. These regression equations can also include regression coefficients that indicate the strength and direction of the relationships between the latent factors.

Compared to conventional statistical techniques such as regression, SEM is a more robust approach for testing substantive theories (Ravand and Baghaei, 2016). This approach is known for its compatibility with reality thanks to its simultaneous management of relationships between many variables (a). In addition, unlike regression, SEM takes measurement error into account, thus improving its accuracy (b) (Schumacker and Lomax, 2004).

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 (2014) 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.

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:

$$Y = XB + E \qquad (1)$$

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) (Jakobowicz, 2007). 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 (Jakobowicz, 2007). 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" (Jakobowicz, 2007).
The equations characterizing these two types of models are in the following form:
External models :

$$X_{kj} = \pi_{kj}\delta_k + \epsilon_{kj} \qquad (2)$$

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).
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 :

$$\delta_k = \sum_{i=\delta_i}^{\delta_k} \beta_{ki}\delta_i + \varepsilon_k \qquad (3)$$

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). It (path diagram) was showed the structural equation model used:

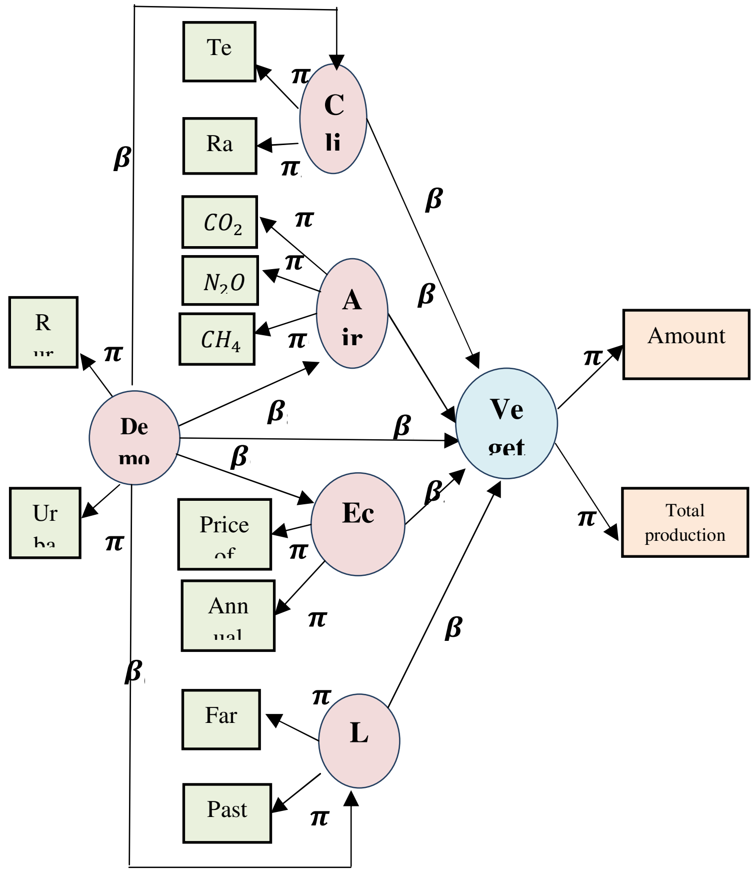

Fig 1: Path diagram showing the structural equation model

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 (Balah, 2018). 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:

$$Y_t = \sum_{j=0}^{\infty} \varphi_j \varepsilon_{t-j} \qquad (4)$$

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 (Sakli, 2016):

$$Y_{t+L} = \sum_{j=0}^{\infty} \varphi_j \varepsilon_{t+L-j} \qquad (5)$$

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.

Results and Discussion

Chronological development of the main parameters assessed

Chronological evolution of rainfall

The graph showed changes in rainfall over time in several countries, including France, Germany, Spain, Indonesia, China and Japan (Fig S1). 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 (2023), which notes extreme rainfall ranging from 600 mm to 2,000 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 (EEA, 2021).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 (EEA, 2021; Haylock et al., 2008).

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 (UN, 2019). This region is considered particularly vulnerable due to rising sea levels, leading to intense rainfall and extreme consequences for populations living at lower altitudes (UN, 2019). 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 (Tchaker, 2021).

Chronological evolution of temperature

The curve (Fig S2) represented 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 (2023), 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 (Planas, 2019).

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 (Meseguer-Ruiz et al., 2023; Chazarra-Bernab et al.; 2022; AEMET, 2022). Faced with excessive temperature rises in different countries, plants are faced with enormous risks, including climate-related diseases, deteriorating water supplies and soil acidification (IPCC, 2023). All these risks have a negative impact on food production, leading to a reduction in plant proteins.

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). The chronological evolution of the quantity of methane in the atmosphere of each country was recorded (Fig S3). It revealed a low quantity of this pollutant at European level, with a decreasing trend over time, particularly in France (3485kilotonnes 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 (Citepa, 2020).

However, methane emissions from the production and use of fossil fuels are much lower than those from agriculture (UN, 2022). The latter sources of production are therefore easier and cheaper to reduce, making them an urgent priority (Stern, 2020). Hence the birth of the "Oil and Gas Methane Partnership" (OGMP), the "zero pollution" action plan (2021) and the "Clean Air Outlook" programme (2022) (Stern, 2020; OGMP, 2020), 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 (Stern, 2020; Saunois et al., 2020).

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 (Qi et al., 2022). This crop is a real agricultural source of methane emissions (UN, 2022). 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. It showed the chronological evolution of the quantity of carbon dioxide (CO_2) emitted into the atmosphere in each country (Fig S4).

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 (González-Sánchez et al., 2012). 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 (OECD, 2020). This is also confirmed by Ali (2022), 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 (UN, 2022). 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 (UN, 2023). 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 (Ali et al., 2022; GIIGNL, 2021).

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.

Total population over time

It was illustrated the dynamics of the total population in the various countries between 1990 and 2020 (Fig S6). 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 (Bloom, 2020).

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 (Bloom, 2020). 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 (UN, 2022). 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 (UN, 2022). In addition to these factors, there are other factors such as the natural growth rate in each area or region outside the major cities (Cheshire and Magrini, 2006). Thus, the continuing increase in population in the various countries could be a determining factor in the shortfall in protein availability (Caillave et al., 2019). 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 (Bouzou, 2021).

Chronological evolution of the total agricultural and grazing area

The rate of occupation of agricultural land (areas occupied by agricultural production) and permanent and temporary grazing areas in the various countries was observed (Fig S7). 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 (Jouve, 2006). 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 (Jouve, 2006). Yet European countries are characterized above all by a high rate of urbanization (72%) and an increase in migration rates (UN, 2022).

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 (Qi et al., 2022) . 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 (Larrère, 2019). 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.

Chronological evolution of economic indicators

The dynamics of gross annual income per capita in each of the countries was considered (Fig S8). 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 3,700), 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 (INSEE, 2021). 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 (UNCTAD), 2021). 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.

Changes in the average annual price per tonne of plant protein in the six countries were observed (Fig S9). 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 (Cuq, 2018).

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 (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 (Mordor Intelligence, 2021). 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 (European Commission, 2018).

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.

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. It showed 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 (Porter, 2021). 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 (Clark et al., 2020).

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 (Qi et al., 2022). 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 100g of rice contains around 5.51 kilocalories (Ponka et al., 2016).

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 (Hopkins, 2023).

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 29.2g/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 4g in 2020 compared with the situation in 2010.

In Indonesia, availability has risen from 37g/person/day (2010) to 41g/person/day (2017), before dropping again to 37.6g/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 (Atlas, 2021).

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 47g per day per person (Fondation Louis Bonduelle, 2020). 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 (Biology and Agrosciences Scientific Department, 2021). 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 (Fondation Louis Bonduelle, 2020).

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 (Fondation Louis Bonduelle, 2020). It is true that cereals are currently the biggest contributors to the supply and satisfaction of protein requirements (Cuq, 2018). 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 (Fondation Louis Bonduelle, 2020).

Factors determining the availability of protein of plant origin

The results of estimating the effects of the various parameters (climatic, economic, land and demographic) using structural equation models (SEM) were observed (Fig 2). The results showed 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 (Miassi et al., 2022; Mordor Intelligence, 2021). 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 (Porter, 2021).

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 (UN, 2022). However, the expected effect of pollutants on availability is the opposite, as demonstrated by previous studies by Tchaker (2021) and the UN (2022). For Tchaker (2021), 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 (2022), 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 (Diallo et al., 2021), 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 (2002), 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 (Aiking, 2014). This is a fact that the FAO (2017) 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.

Prediction

The 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 (World Data, 2020). It is accepted that the minimum quantity of protein required per kg of body weight is 0.8 g/kg (Bilodeau, 2018). 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 (Balah, 2018). 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.

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 33g/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 50g/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 (World Data, 2020). This will be much more the case for those whose diets are based solely on plant-based products (Miassi et al., 2022).

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 (2019) 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 accessibility of proteins, 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 was an appropriate choice, especially when it considered 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 (Fondation Louis Bonduelle, 2020).

The results showed that climate change remained 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 (Meseguer-Ruiz and Cantos, 2023). However, the Mediterranean zone (represented here by Spain) and Indonesia are the most exposed to this increase in temperature (Chazarra-Bernabé et al., 2022).

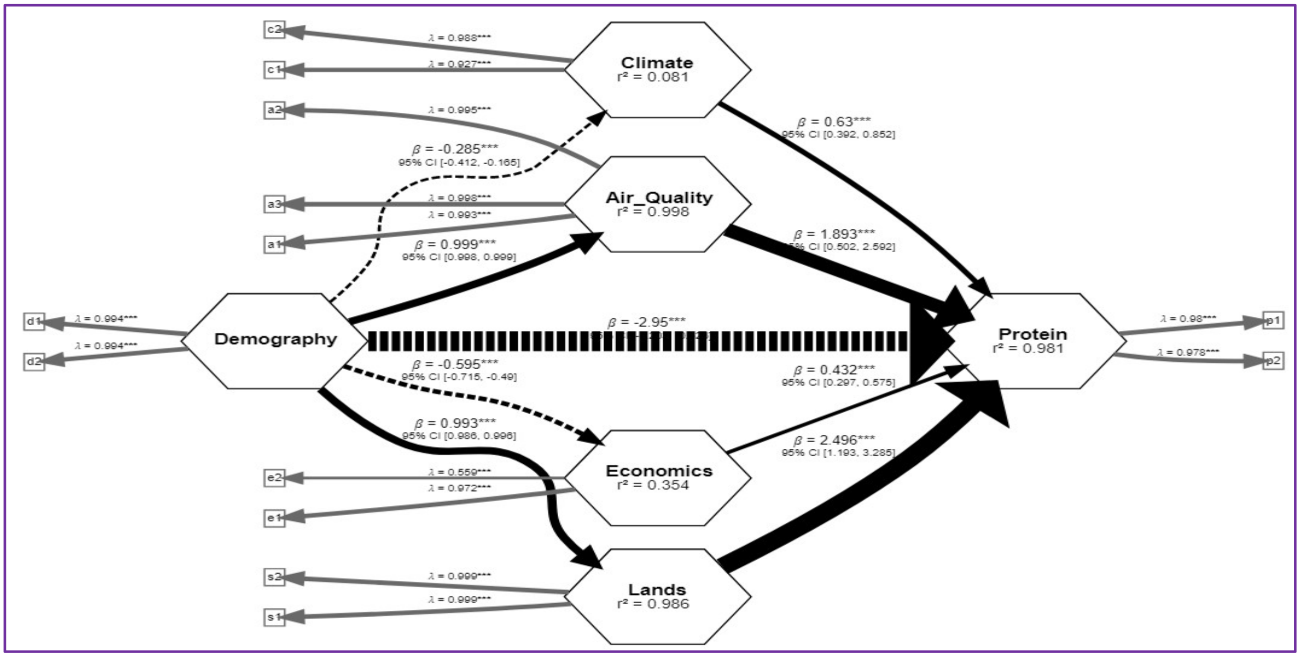

Fig 2: Main PLS effects on plant protein availability

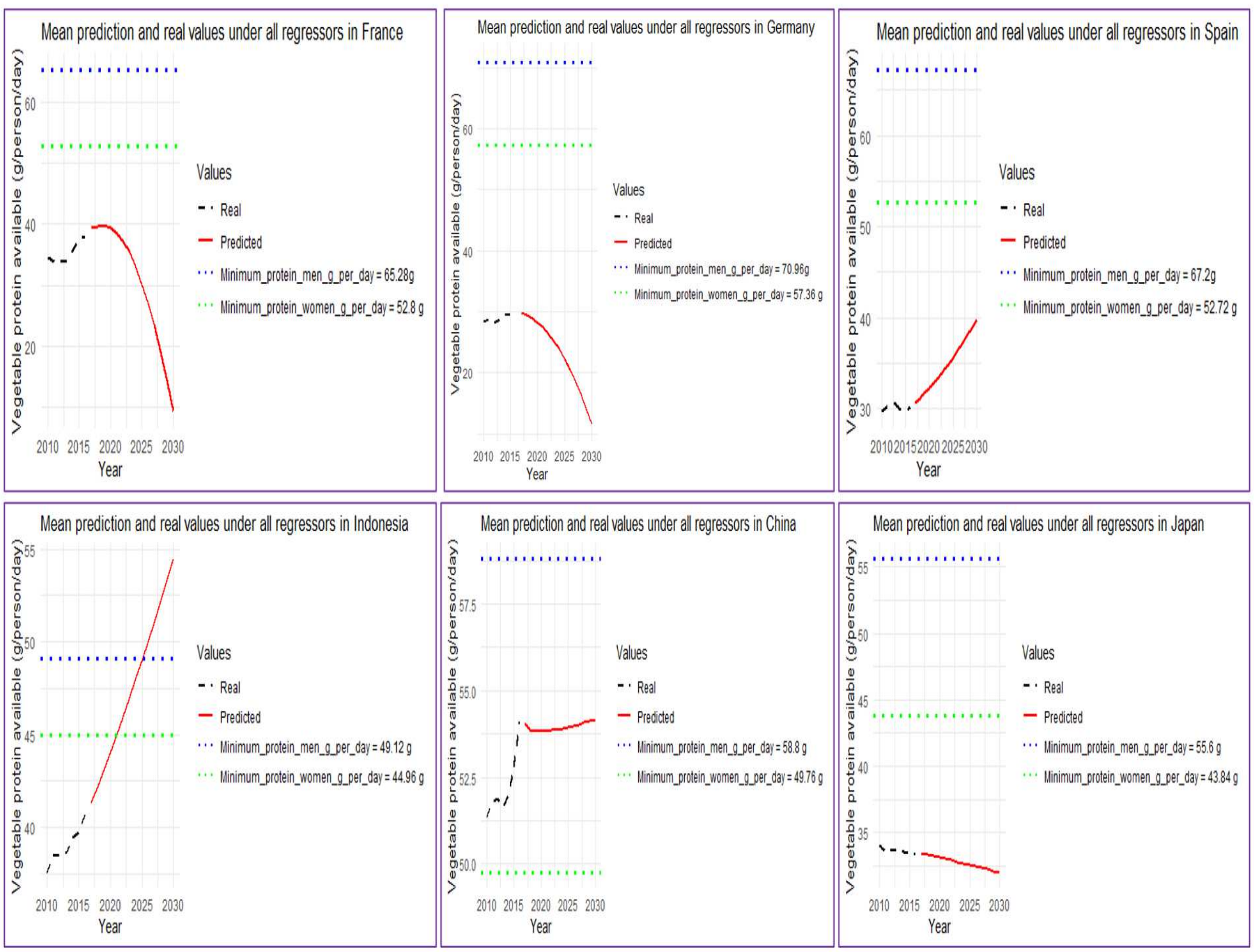

Fig 3: Annual forecasts for 2030 of the amount of plant protein available in each country

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 (Ali et al., 2022; Stern, 2020).

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 (FAO, 2023).

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 (UNCTAD, 2021). 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 (Rosental, 2009). 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 (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 (Clark et al., 2020).

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 (OECD/FAO, 2021).

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 (Miassi et al., 2022; Mordor Intelligence, 2021).

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 (Porter, 2021). 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 (2017), 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 (Diallo et al., 2021). Tchaker (2021) 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 (Greenpeace, 2019). 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 (PNNS, 2017).

Conclusions

It was concluded rising trend in temperature, an increase in atmospheric pollutants and in price of plant proteins, while the production of plant proteins and their availability at individual level showed 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 55g/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.

References

Aiking H (2014). Protein production: Planet, profit, plus people? The American Journal of Clinical Nutrition, 100, 483S-489S.

Ali I, Sun H, Tariq G, Ali H, Baz K, Mahmood H, Khan I and Yao J (2022). Asymmetric impact of coal and gas on carbon dioxide emission in six Asian countries: Using asymmetric and non-linear approach. Journal of Cleaner Production, 367: 132934.

Atlas Big (2021). World soybean production by country. Retrieved from https://www.atlasbig.com/(Accessed on July 29, 2023).

Augère-Granier M (2020). EPRS R: European Parliament Research Service, Research Service for Members. PE 652.044: 1-14.126.

Balah B (2018). Frontiers of use of monthly rainfall forecasting with the ARIMA model in agriculture. 1st International Seminar Agriculture 4.0: Le Génie Rural au service de l'Environnement, Algiers, Algeria. Hal Open Science: 1-6.

Bloom DE (2020). Demography can be a powerful driver of the process and pace of economic development. Finance and Development: 5-9.

Boucher O and Bessemoulin P (2002). Les besoins en observations pour la climatologie. Météo-France - Direction de la climatologie: 1-8.

Bouzou N (2021). Demography: why the (global) decline in the birth rate is a problem. Retrieved from https://www.europe1.fr/(Accessed on July 29, 2023).

Caillavet F, Fadhuile A and Nichèle V (2019). The evolution of animal product consumption in France: multiple challenges. INRA Prod. Anim. 32(2): 131-146.

Chazarra-Bernabé A, Lorenzo Mariño B, Romero Fresneda R and Moreno García JV (2022). Evolución de los climas de Köppen en España en el periodo 1951-2020. Notas técnicas de AEMET, 37.

Cheshire PC and Magrini S (2006). Population growth in large European cities: climate matters not only at the national level. Regional Studies 40: 23-37.

Citepa (2022). Methane: the Commission presents a proposal for a regulation to reduce emissions in the energy sector. Retrieved from https://www.citepa.org/fr/ (Accessed on July 30, 2023).

Clark G, Moonen T and Nunley J (2018). A history of our cities: Europe and its Urban development from 1970 to 2020: 1-56.

Cuq J (2018). Plant proteins as alternatives to animal proteins. How to increase their level of quality? Colloquiumorganised in partnership with the Académie des Sciences, Inscriptions et Belles-Lettres de Toulouse. Académie des Sciences et Lettres de Montpellier: 1-16.

European Commission (2018). Report from the commission to the council and the european parliament on the development of plant proteins in the european union. 757: 1-19.

FAO (2017). The future of food and agriculture - Trends and challenges. Rome, Italy: 1-180.

FAO (2023). Food and Agriculture Organization of the United Nations. Livestock and the environment. Retrieved from https://www.fao.org/livestock-environment/(Accessed on July 29, 2023).

Farm Europe (2017). Policy Briefing, Which EU strategy for plant proteins? CAP measures and developments in protein, oilseed and oilseed crops, What lessons? What directions? 1-17.

Foundations Louis Bonduelle (2020). How to help people in precarious situations while combating food waste. Retrieved from https://www.fondation-louisbonduelle.org/(Accessed on July 31, 2023).

GIIGNL Annual Report (2021). Who are the world's leading LNG exporters? Retrieved from https://www.connaissancedesenergies.org/(Accessed on July 30, 2023).

González-Sánchez EJ, Ordóñez-Fernández R, Carbonell-Bojollo R, Veroz-González O and Gil-Ribes JA (2012). Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture. Soil and Tillage Research, 122: 52-60.

Greenpeace (2019). Agriculture: Too much farmland is used for livestock farming in Europe. Retrieved from https://www.greenpeace.fr/espace-presse/(Accessed on July 31, 2023).

Hair JF, Ringle CM and Sarstedt M (2011). PLS-SEM: Indeed a silver bullet. Journal of Marketing Theory and Practice, 19: 139-15.

Hopkins R (2023). Major Rice Exporting and Importing Countries. Retrieved from https://fr.ripleybelieves.com/(Accessed on July 30, 2023).

Institut Nationale de la Statistique et des Etudes (INSEE), (2021). Historic fall in GDP, but resilience in household purchasing power. Les comptes de la nation, (1860): 1-4.

IPCC (2023). IPCC synthesis report: the risks are much higher than in previous forecasts. Climate change: observed changes. Synthesis reports. Retrieved from https://climat.be/ (Accessed on July 31, 2023).

Jakobowicz E (2007). Contributions to latent variable structural equationmodels. Mathematics [math]. Conservatoire national des arts et metiers. CNAM. French. fftel00207990v2f, 1-206

Jouve P (2006). Agrarian transition: population growth, anopportunity or a constraint? Afrique contemporaine, (217): 43-54.

Kaabache R (2019). Determinants and Incidence of animal protein consumption, the case of Algeria. Tributaries Journal, 3(2): 1-11.

Larrière C (2019). Nature in the city: a conversation between a philosopher and an architect. Retrieved from https://theconversation.com/de-la-nature-en-ville-conversation-entre-une-philosophe-et-un-architecte-110370.

Meseguer-Ruiz O and Olcina Cantos J (2023). Climate change in two Mediterranean climate areas (Spain and Chile): Evidences and projections. InvestigacionesGeográficas, (79): 9-31.

Météo France (2023). Extreme rainfall in mainland France. Retrieved from https://meteofrance.fr/actualite/presse/(Accessed on July 30, 2023).

Miassi YE, Dossa FK, Zannou O, Akdemir Ş, Koca I, Galanakis CM and Alamri AS (2022). Socio-cultural and economic factors affecting the choice of food diet in West Africa: a two-stage Heckman approach. Discover Food, 2(1): 16.

Mordor Intelligence (2020). Asia-Pacific Animal Protein Market Size, Sharing, Impact Of Covid-19 And Forecasts To 2029. Asia-Pacific Animal Protein Market (2016-2026). Retrieved from https://www.mordorintelligence.com/fr (Accessed on July 30, 2023).

Mordor Intelligence (2022). European plant protein market: growth, trends, impact of covid-19 and forecasts (2022-2027). Retrieved from https://www.mordorintelligence.com/fr (Accessed on July 30, 2023).

National Nutrition and Health Plan (PNNS), (2017). Retrieved from https://quoidansmonassiette.fr/pnns-2017-2021-revision-des-reperes-nutritionnels-pour-les-adultes/.

Neo P (2019). Protein powerhouse: Asia the 'Key protein market' by 2025 with China and India leading the charge. FoodNavigator. Retrieved from https://www.foodnavigator-asia.com/(Accessed on July 30, 2023).

OECD (2020). Commissariat général au développement durable, "L'empreinte carbone des Français reste stable", Datalab, January 2020, p. 3.

OECD/FAO (2021). "OECD-FAO Agricultural Outlook, OECD agricultural statistics (database). Retrieved from http://dx.doi.org/10.1787/agr-outl-data-fr.

Ponka R, Goudoum A, Tchungouelieu AC and Fokou E (2016). Nutritional evaluation of some ingredients used in the feed formulation of laying hens and pigs on a breeding farm in North-West Cameroon. International Journal of Biological and Chemical Sciences, 10(5): 2073-2080. http://dx.doi.org/10.4314/ijbcs.v10i5.11

Porter M (2021). Population explosion: causes, consequences, benefits, drawbacks. Retrieved from https://fr1.warbletoncouncil.org/(Accessed on July 31, 2023).

Qi Z, Zhou X, Tian L, Zhang H, Cai L and Tang F (2022). Distribution of mycotoxin-producing fungi in major rice production areas in China. Science Direct, Elsevier, 134: 108-572.

Ravand H and Baghaei P (2016). "Partial Least Squares Structural Equation Modeling with R," Practical Assessment, Research, and Evaluation: Vol. 21, Article 11. Retrieved from https://doi.org/10.72075/d2fa-qv48.

Rosenthal PA (2009). La biopolitique à l'épreuve de la croissance démographique mondiale, la vie des idées. Retrieved from https://www.researchgate.net/publication/(Accessed on July 31, 2023).

Schumacker RE and Lomax RG (2004). A Beginner's Guide to Structural Equation Modeling (2nd Ed). Lawrence Erlbaum Associates, Inc, Mahwah, NJ.

Scientific Biology and Agrosciences Department (2021). Proteins, water disturbances: 1-5.

Stern JP (2020). Methane emissions from natural gas and LNG imports: An increasingly urgent issue for the future of gas in Europe. OIES Paper: NG, No. 165, ISBN 978--1-78467-170-9, The Oxford Institute for Energy Studies, Oxford.

Sultan B, Roudier P and Traoré S (2015). The impacts of climate change on agricultural yields in West Africa. Marseille: IRD. ISBN 978-2-7099-2146-6.

Tchaker FZ (2021). Ecotoxicology and residue analysis. République Algérienne Démocratique et Populaire. Polycopie de cours. University of Médéa.

UN (2022). Five things you need to know about the greenhouse gases that are warming the planet. Retrieved from https://news.un.org/fr/story/2022/01/1124652.

UNCTAD (2021). United Nations Conference on Trade And Development (UNCTAD). World Investment Report. Investing in Sustainable Recovery: 4-280.

Worldwide data (2020). News, statistics and data from all European countries. Retrieved from www.donneesmondiales.com (Accessed on July 29, 2023).

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