REVIEW

Human-nature interaction approached from a bibliometric analysis of Malthus and Boserup

April 2024

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ABSTRACT

The theoretical framework of Complex Adaptive Systems allows modeling human-environment interactions that are constantly evolving and have implications for sustainability. The aim of this paper is to identify which approach, Malthusian or Boserupian, has served as a reference in contemporary studies on the human-environment relationship. We carried out a systematic review of the scientific literature building upon the seminal works of Malthus and Boserup. The scientific papers were collected from the Scopus database. Three sets of data were used: a set in which Malthus appears in the References, another for Boserup in the References, and a set with references to both Malthus and Boserup. Data were analyzed with the bibliometric software Bibliometrix. The results show the contribution of both authors to contemporary scientific studies on climate change, food security, waste management, among others. Boserup stands out for her contribution to agricultural land use and international agricultural policies after the Second World War, whereas Malthus addresses broader themes linked to human development, considering aspects such as wealth, poverty, human nature, and happiness. As regards the human-environment relationship, i.e., linking the aspects of sustainability, the Malthusian approach is perceived as being closer to the strong sustainability, to ecological economics, subjects linked to the work of Georgescu-Roegen. In Boserup, it is closer to weak sustainability, reflected in international economic policies. The implications of this research include the impact of climatic alterations on diets, which requires considering the mathematical contributions, bifurcations, and tipping points that will ultimately impact human development on Earth. The reading of Malthus' work seems to be relevant for studies addressing contemporary population (society) issues. The originality of our study lies in the identification of contemporary topics in human-environment relations that are grounded in the works of Malthus and Boserup, suggesting that Malthus' seminal work has served as a reference for a wide range of sustainability issues.

Keywords: sustainability, models, complexity.

RESUMEN

El referencial teórico de los Sistemas Adaptativos Complejos permite modelar las interacciones hombre-ambiente que están en constante evolución y tienen implicancias en la sustentabilidad. El objetivo del trabajo es identificar qué abordaje, Malthusiano o Boserupiano, ha servido de referencia en los estudios contemporáneos sobre la relación hombre-ambiente. La metodología del trabajo consistió en la revisión sistemática de la literatura científica de los trabajos seminales de Malthus y Boserup como referencia. Los documentos científicos fueron recolectados de la base de datos de Scopus. Se utilizaron tres conjuntos de documentos: Malthus, Boserup y Malthus, y Boserup. El análisis de los datos fue realizado con el desarrollo de un software de bibliometría (Bibliometrix). En los resultados, se apre-

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https://doi.org/10.58149/fv2q-8f24

cia la contribución de ambos autores en el ámbito científico contemporáneo, ligado al cambio climático, la seguridad alimentaria, la gestión de residuos, entre otros. En Boserup se destaca, la contribución sobre el uso del suelo agrícola y las políticas agrícolas internacionales posteriores a la Segunda Guerra Mundial. En Malthus se vislumbran aspectos más amplios ligados al desarrollo humano, considerando aspectos como riqueza, pobreza, naturaleza humana, felicidad. Con respecto a la relación hombre-ambiente, vinculando los aspectos de la sustentabilidad, se percibe el abordaje Malthusiano más próximo a la sustentabilidad fuerte, a la economía ecológica, a los aportes de Georgescu-Roegen. En Boserup es más próximo a la sustentabilidad débil, reflejado en las políticas económicas internacionales. En las implicancias de esta investigación, se encuentran las incidencias de las alteraciones climáticas en las dietas, para lo cual se debe tener en consideración las contribuciones matemáticas, las bifurcaciones y puntos de inflexión que terminarán impactando en el desarrollo humano en el planeta Tierra. La lectura de la obra de Malthus pareciera ser relevante para los estudios que se proponen tratar las cuestiones contemporáneas relativas a la población (sociedad). La originalidad del estudio se encuentra en haber identificado los tópicos contemporáneos en las relaciones hombre-ambiente que encuentran fundamentación en las obras de Malthus y Boserup, sugiriendo que el trabajo seminal de Malthus ha servido de referencia para una amplitud de temas relacionados a la sustentabilidad.

Palabras-clave: *sustentabilidad, modelos, complejidad.*

INTRODUCTION

The ability of agriculture to support growing populations has been a concern for generations and remains a high priority in the global policy agenda (Rosegrant and Cline, 2003). The eradication of poverty and hunger was included as one of the United Nations Millennium Development Goals adopted in 2000. One of the goals was to halve the proportion of people suffering from hunger between 1990 and 2015 (World Bank Group, 2003).

The problems of today's society are complex. Climate change, social inequality, and environmental degradation are complex systems, that are far from balanced, and interconnected in various ways. Climate change is influenced by human activity, natural cycles, and feedback loops. Social inequality is affected by a wide range of factors, including economic policies, social structures, and cultural norms. Environmental degradation is influenced by human activity, natural cycles, and feedback loops. It is also a system far from equilibrium since it constantly changes and adapts to new conditions.

Evolutionary studies on the interactions between humans and the environment have a long history. In socio-ecological coevolution, a systemic perspective of feedback between human and environmental systems is provided by Jørgensen *et al.* (2023) and Søgaard Jørgensen *et al.* (2020). Sustainability implies taking into consideration the development of both present and future generations. According to Folke *et al*. (2021) and Jørgensen *et al*. (2023), interconnected industrialized societies are the primary drivers of change in the Earth system, a period known as the Anthropocene. Although the beginning of the Anthropocene is under debate, many scientists trace it back to the Industrial Revolution at the end of the 18th century, when industrial mass production began to have a significant impact on the environment.

Turner and Fischer-Kowalski (2010) analyze environment-human interactions through the contributions of Malthus and, especially, the ideas of Ester Boserup. Nogueira *et al*. (2021) link this new era with the critical theory related to sustainability and social organization systems of business schools. The relevance of environmental governance, involving socio-ecological relationships and management, is highlighted to understand the Anthropocene dynamics better (Schill *et al*., 2019).

When discussing the relationship between population growth and resource availability throughout history, we can focus on two contradictory seminal theories, -that of Malthus and that of Boserup. While Malthus argued that population tends to increase geometrically while resources increase arithmetically, leading to scarcity crises and the need for population controls, Boserup argues that population pressure stimulates innovation and technological development, leading to the intensification of agriculture and the adoption of new practices to ensure survival.

Both authors explained human evolution and the link with nature on the basis of only two variables (food and population), and how they were related, i.e. which one influenced the other. That is, if food influences population as proposed by Malthus, or if population influences food, as argued by Boserup. However, scientific progress in different fields continued to advance knowledge on the relationship between these two variables, adding others and new inter-relationships, leading to the partitioning or emergence of different areas or scientific disciplines. Therefore, scientific progress leads us to take into consideration the Complexity Theory, in which there are several interrelated systems.

One way of identifying the different systems is through the approach of Complex Adaptive Systems (CAS), which encompasses both living systems and social systems which develop in the biosphere and require a continuous process of energy and material conversion to preserve their identity and express their functions (Mayumi and Giampietro, 2019).

The Complex Adaptive Systems (CAS) approach allows modeling a constantly changing human behavior in connection with the sustainability of territories: the diversity and individuality of the system components (human, plant, animal); the local interactions among the elements that create emergent patterns, which in turn shape the interactions; and constant change and coevolution resulting from feedback or processes like learning that favor certain types of behaviors or dynamics which affect the functioning of the system (Schill *et al*., 2019).

The CAS approach allows linking and capturing the interactions between the behaviors of various individuals, interacting within their broader socio-cultural contexts and the biosphere in which they are embedded. In attempting to understand some

of the intricate interrelationships in the biosphere, specifically human population growth and resources, the works of Malthus (1798) and Boserup (1965) can be considered.

In the initial stages of the complex systems approach, the seminal works of Malthus and Boserup considered the interactions between population, food, and technology. Scientific research has led to a huge advancement of knowledge, leading to increased specialization within particular fields, which in some cases interferes with identifying the general, interdisciplinary interactions, which may be as relevant as the specific interactions within each field.

Taking into account this increased complexity of the systems and their interactions, we posed a question to try and capture the general interactions, -namely which of these authors, Malthus or Boserup, has provided the basis for evaluating and discussing contemporary problems about population and food production considering the human-environment relationship. The same object of study, analyzed from the perspective of another approach or paradigm, could provide answers to contemporary problems. Thus, two opposite views on two variables so relevant to human evolution as food and population could provide, at different times, rigorous scientific pathways for human development. Therefore, the objective of this work is to identify which approach, Malthusian or Boserupian, has been the most influential in contemporary studies on the relationship between humans and the environment.

LITERATURE REVIEW

Malthus and Ricardo believed that populations tended to stabilize at levels where the natural price of labor prevailed, a principle that Ricardo called the Iron Law of Wages. Spangenberg *et al*. (2002) model addresses the relationship between economic growth and environmental impact, which has sparked debate between those who advocate growth, citing the phenomenon of the environmental Kuznets curve, and those who disagree, citing the limits to growth. The discussion on the connection between wages, economic growth, and environment continues to the present, as in Rêgo and de Godoi (2022), who analyze land rent theories and compare them with data about the price of Brazilian rural land for the last 30 years.

Malthus (1766–1834) argued that population increased exponentially (he called it 'geometrically'), while food production increased linearly, or arithmetically. Those mismatches between population growth and resources would inevitably lead to what he called 'positive checks', *i.e.*, crises like wars, emigration, and famines (Malthus, 1798). As a result, population size would decrease to a sustainable level. Technology in Malthus' theory is assumed to be an independent external factor (Egger *et al*., 2020).

Malthus' work was partly motivated by Godwin's earlier publication *An Inquiry into the Nature and Progress of Rent*. In Malthus' work, there is an enquiry into the perfectibility of man and society which has been largely neglected. He also inquires into social classes, into the tendency of the laws of poverty to defeat their own purpose, into the progress of the human mind and various aspects of inequality in society (Malthus, 1798).

More than 150 years after Malthus, Ester Boserup (1910-1999) published *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure* in 1965 (Boserup, 1965). Population growth became the independent variable. Boserup developed concepts to explain how population density and land use influence each other in this context of agricultural technologies, thus contradicting Malthus. In addition, she studied the relationship between the dynamics of population, technology and land use in different societies. Her contributions were of great relevance to the UN Economic Commission for Europe (1947-1965) on agricultural trade policy.

The endogeneity of the techno-managerial strategies of agriculture in Boserup's thesis was about innovation in agricultural technology in general. She argued, though, that industrial technology did not apply to subsistence producers because the difference between the relative labor costs of labor-based foods and industrial-based foods hampered adoption. However, this was not included explicitly in her thesis (Turner and Fischer-Kowalski, 2010). Her ideas were heard and explored by the leading institutions involved in agricultural and rural development, including the World Bank (Codjoe and Bilsborrow, 2011; Headey and Jayne, 2014; Peura, 2013; Walshe, 2010).

She argued that the behavior of subsistence producers differed from that of commercial producers. The behavior of subsistence farmers, guided by household consumption needs rather than by market demand, was aimed at minimizing the risk of household needs, not at maximizing profits, which in turn affected land distribution, labor, and land improvements. They would change or explore innovations for the known technical-managerial practices only if compelled by changes in the labor-land dynamics. According to Boserup, small subsistence farmers depend entirely on their demographic dynamics and require techno-managerial assistance to intensify production.

Boserup contributed to agricultural development in general, especially considering Europe, China, and India, among others. In Latin America, her ideas can be found in the programs of the Green Revolution in the 1960's and 70's, which involved the development of new varieties of high-yielding crops, the use of chemical fertilizers and pesticides, and the expansion of irrigation systems. However, Boserup's ideas on agricultural development and population pressure have had a complex and controversial impact in Latin America.

Latin America and the Caribbean make up one of the most unequal regions in the world, having one of the lowest levels of intergenerational mobility in the different dimensions of well-being. This deep-rooted high inequality has become an inertial phenomenon transmitted from generation to generation. The flip side of this phenomenon, low intergenerational mobility, is not only related to equity, but also to other central aspects of the region's development, such as growth and political-institutional stability. The socioeconomic status of the families of origin strongly conditions labor participation, unemployment, wages and informality of workers in Latin America and the Caribbean. Differences in labor outcomes according to the socioeconomic status of families are observed even among workers with the same level of education and skills, and they are particularly severe for women (Berniell and De La Mata, 2022).

The views on inequality in development have been mostly influenced by the mainstream economic theory rather than by developmentalism theories. Neoclassical economic growth theories hold that scientific and technological innovation and revolution can improve production efficiency and promote social progress and economic development in situations where production factors are limited (Grossman and Helpman, 1989; Pang *et al*., 2022; Solow, 1956). Neoclassical economists have rejected the Malthusian view, resolving it through the claim that resource depletion is due to the lack of optimal resource man-

agement institutions with a long time horizon, and through the central role of technological progress in alleviating resource constraints (Decker and Reuveny, 2005).

Both models (Malthusian and Boserupian) have been subject to review and criticism, because none of them takes into account parallel political developments that affected land distribution and property rights. Rather, they were constructed within a limited geopolitical and historical context (Soby, 2017). According to Lambin *et al*. (2001), neither population nor poverty alone can account for land cover change worldwide. Instead, land cover changes are driven by people's responses to economic opportunities, mediated by institutional factors. Opportunities and constraints for new land uses are created by local and national markets and policies. Global forces become the main determinants of land use change, as they amplify or attenuate local factors.

There have been debates about agricultural policies, social inequality, and the environmental sustainability of Green Revolution programs for their emphasis on large-scale industrialized agriculture and their impacts on small farmers and the environment. Some critics argued that these programs exacerbated social and economic inequalities (advantage of large producers to adopt new technologies and benefit from scaling technologies; loss of employment in the countryside and the consequent migration of farmers to the cities; social inequality; loss of culture and traditional agricultural practices) and contributed to environmental degradation by soil erosion and loss of biodiversity (Shiva, 2001; Altieri, 2001; Folch, 1998; Barrera, 2012).

The scientific progress achieved in the last decades, which has increased complexity by integrating human and environmental dimensions over time, makes it necessary to use models of sustainable transitions. Sustainability Transitions (STs) models originate from changes that affect the life-support systems of our planet, such as population growth and socio-technical and economic development. According to Geels *et al*. (2016), these transitions occur over a generation or more (50 or 100 years). They are not deterministic, in the sense that they are interconnected changes that occur in different areas, such as technology, the economy, institutions, ecology, culture, and belief systems.

Complexity is an attribute of systems made up of diverse and interdependent agents that constantly influence and adapt to internal or external stresses (Holland, 1995). As the levels of diversity, adaptability, connectivity, and mutual dependence of systems increase, they enter "the edge of chaos", or a region of emergent complexity (Boisot and McKelvey, 2010). Remaining in this intermediate state, these systems never reach a permanent equilibrium, but neither do they collapse. Increasing stresses above a certain threshold can lead to chaotic behavior, sensitive to initial conditions with relevant amplifications (Benbya *et al*., 2020).

Vivien *et al*. (2019) propose three types of sustainability. The first, strong sustainability, is based on ecological economics, and considers degrowth, the biosphere and the contributions of Georgescu-Roegen (1975). The second, weak sustainability, is based on economic science driven by biotechnology, the defense of property rights, and the definition of OECD (2009); finally, very weak sustainability, which is based on a biomass-based economy replacing fossil fuels (Langeveld *et al*., 2010; Sanders, 2012; E.C., 2012).

Although research into socio-technical transitions says little about social sustainability (*e.g*., inequality, poverty, working conditions), research into the justice and the distributive consequences of transitions to sustainability is emerging (Geels, 2019; Jenkins *et al*., 2018; Sareen Haarstad, 2018). The high number of elements which emerge when the interrelations between adaptive systems are analyzed (leaving aside the consideration of only a few variables, as in the work of Malthus and Boserup) leads us to consider the human-nature interaction as a community inserted in the biosphere in which there is feedback, self-organization, and the existence of non-linearity.

Malthus (1798) was the first to observe geometric population growth, and he developed a model to simulate the exponential growth of populations, known as the Malthusian exponential growth model. Later, Verhulst formulated the logistic model of population growth in 1838. According to Das & Gupta (2011), the next major breakthrough in population dynamics was presented by Lotka (1925) and Vito-Volterra (1926). For the first-time, they presented differential equations of the predator-prey type (trophic interaction model). The predator-prey model is one of the most common types of population models used to describe interactions between various species (Alebraheem, 2023). Properties of complex sociotechnical systems such as non-linearity, self-organization, coevolution, and bifurcations inevitably lead to unpredictable states.

The CAS approach can enhance our understanding of the dynamics of the Anthropocene by capturing non-linear interactions, fast and slow variables, contextual changes, the generation of multiple attractors and changing patterns in social norms, which can lead to the emergence of new forms of governance, and the evolution of socio-ecological relations and management (Schill *et al*., 2019). It highlights the relevance of environmental governance, and the evolution of socio-ecological relations and management to better understand the dynamics of the Anthropocene.

The interactions between agents create outcomes that are greater than the sum of the behaviors of individual agents, a phenomenon called emergence (Fraser and Greenhalgh, 2001). According to Valentine *et al*. (2022), previous research has shown that "fairness in assessment is a nonlinear phenomenon that arises from interactions among its components and functions like a complex adaptive system".

The evolution from a linear approach with few variables to a complex one with several variables, as a consequence of scientific progress, can be efficiently addressed with CAS. For example, Folke *et al*. (2021) identify central inflection elements in the regulation of the state of the planet and interactions between them, which could mean serious cascading effects for humanity and even challenge planetary stability. Human well-being is being challenged by ocean acidification, deoxygenation, tropical cyclones, ocean heat waves, and sea level rise. Folke *et al*. show the effects of societal inequality and its actions (perceptions and justice, aspirations, market conceptions) on the biosphere, and the impacts of the biosphere on inequality through gradual environmental change and environmental shocks.

A relevant work of the 1970s is *The Limits to Growth* by Meadows *et al*. (1972), which could be akin to the ideas of Malthus in terms of technological and socio-political problems, although Meadows considered technological advances. The work describes the different moments of development of countries. For example, the development of the countries of the Northern Hemisphere would be followed by the Latin American countries, and finally, these would favor the development of Africa.

Motesharrei *et al*. (2014) developed a dynamic model[1] of the human population, concluding that collapse can be avoided by reaching a steady state at maximum carrying capacity if the depletion rate of nature is reduced to a sustainable level and resources are distributed equitably. Turchin *et al*. (2022) confirm that increasing agricultural productivity is necessary but insufficient to explain rising social complexity. They highlight a combination of increasing agricultural productivity and invention/adoption of military technologies.

According to Beard *et al*. (2023), the structural demographic theory is based on Malthus' theory, with subsequent adjustments by Boserup and Tainter. These later theories provide frameworks compatible with the nature of a complex system such as a society. A society is complex when it exhibits a certain degree of stratification and social differentiation; specialization of economic functions and occupations at the individual, group and territorial level; centralized control, that is, elites that regulate and integrate economic and political activity; regimentation and control of behavior (*e.g*., rule of law); investment in cultural assets (*e.g*., monumental architecture, literary and artistic creation, etc.); information flow between individuals (*e.g*., education), between economic and political groups, and between centralized structures and the periphery; trade and redistribution of resources; the general coordination and organization of people and groups; and a single political unit that integrates an extended territory (Rees *et al*., 2023).

Among the main risks reported by the World Economic Forum (2023), there is the possibility of erosion of social cohesion and social polarization. In this regard, it is relevant to consider the work of Adanu (2023), who postulates that population density higher than 2,293 people per square kilometer increases violent conflicts, with institutional quality being relevant. Reducing violent conflict requires at least three things: maintaining population density below 2,293 people per square kilometer, investing in institutional quality improvements, and increasing income.

Agricultural productivity is related to the society that is responsible for its development. Borgerhoff Mulder et al. (2009) showed that intergenerational transmission of wealth and wealth inequality is substantial in agricultural, pastoral, and small-scale societies. They estimated the degree of intergenerational transmission of three different types of wealth (material, embodied, and relational). In their work on social capital and inequality, they argue that social networks and norms can create unequal access to opportunities and resources, leading to persistent inequality. Bowles and Gintis (2002) showed that the main channel of transmission of socioeconomic status across generations is wealth.

The problems of the market system can be summed up in the distribution of income, but the system itself determines the distribution of income only in the sense of preserving the *status quo* (Arrow, 1971). Schumpeter established that employers do not exercise asymmetric powers over their employees, an idea which became a fundamental principle of economic theory (Schumpeter 1934). Bowles and Carlin (2020) and Aghion *et al*. (2020) have criticized neoclassical economic theory on the basis of its failure to consider social behavior and institutions. Glick and Lozada (2021) state that the original fundamental principle of law and economics is that legal decisions should be based on maximizing efficiency. However, in the judicial system, there are always winners and losers.

Adams (2019) analyzes the debate on wages and the proper relationship between work and remuneration, drawing upon concepts of economic theory and on a genealogical analysis of legal concepts. His research shows how this debate has, over time, conditioned the use of concepts such as "wage", "salary", and "remuneration" in legislation and case law on deductions. According to the author, "the legal concept of the 'wage' is closely related to the economic idea of the wage as the price of a commodity, while the legal concepts of 'salary' and 'remuneration' are more closely analogous to the economic idea of the wage as the cost of subsistence". He stresses that the blurred use of these concepts in courts and the tendency of courts to acknowledge that the employer has the power to withhold wages in case of breach of contract by the worker can unveil much about the implicit assumptions underlying court decisions and how they have shaped the law.

Inequality does not follow a deterministic pathway. In a sense, both Marx and Kuznets were wrong. There are powerful forces that push alternatively in the direction of increasing or decreasing inequality. The predominance of one or the other depends on the institutions and policies that societies choose to adopt (Piketty and Saez, 2014). Piketty and Rendall (2022) argue that the rise of neoliberalism and the decline of social democracy in recent decades have increased inequality and propose a set of policies aimed at reducing the concentration of wealth and promoting more inclusive growth.

Egger *et al*. (2020) stress the importance of recognizing and diversifying the principles which guide social behavior (for example, susceptibility to technological progress or government subsidies). They also highlight that, despite their fundamental differences, both the Malthusian and Boserupian models have strengths and provide information about the population and the land use dynamics of a rural region in an industrial society. The authors also point out that emigration must be a central element of models applying the theories of Boserup and Malthus to the peripheral regions of contemporary industrialized societies.

Rasmussen *et al*. (2018) address the knowledge gap on how agricultural intensification affects both ecosystem services and human well-being in low- and middle-income countries. In general, they conclude that agricultural intensification rarely leads to simultaneous positive ecosystem service and well-being outcomes. This is particularly the case when ecosystem services other than food supply are taken into consideration.

Eppinga *et al*. (2023) developed a model based on Malthus and Boserup to study environmental change and ecosystem functioning in transitions of socioecological systems. The authors contend that a sustainable management of socio-ecological systems requires an understanding of how anthropogenic climate and land use change can alter the interactions between human societies and the ecosystem processes on which they depend. Their work extends previous stylized model approaches, which considered relatively isolated social-ecological systems, by incorporating urbanization and considering how larger populations may become less dependent on local ecosystem processes through natural resource imports from large-scale systems located elsewhere. This expansion was based on a previous conceptual framework suggesting that societies can be strongly dependent on local ecosystem processes (*i.e*., reside in a green loop), or be less dependent by importing natural resources from elsewhere (*i.e*., reside in a red loop). In their analysis of the viability and stability of local socio-ecological system states across a wide range of environmental and so-

[1] Based on the prey-predator model of (*Lotka,* 1925; Volterra, 1926).

cioeconomic conditions, they observed dynamics consistent with green-loop- and red-loop-dominated societies comprising alternate stable socioecological states.

The IPCC report recognizes the interdependence of climate, ecosystems, biodiversity and human societies, the value of diverse forms of knowledge, and the close links between climate change and human societies (IPCC, 2023). In recent years, the world has faced dramatic changes due to the occurrence of multiple crises in a short period, including climate change, the COVID-19 pandemic, and the Russian-Ukrainian war. Although different, these consecutive crises share common characteristics (*e.g.*, systemic shocks and a non-stationary nature) and impacts (*e.g.*, disruption of markets and supply chains), raising questions about security, food safety, and sustainability (Galanakis, 2023).

Large-scale involuntary migration is ranked fifth in the World Economic Forum's global risk report for the medium term (ten years from now). In this report, extreme weather events and natural disasters appear in the first positions. Failure to mitigate and adapt to climate change is in first place for the medium term (World Economic Forum, 2023).

MATERIALS AND METHOD

A systematic review is a form of research that uses the literature on a topic as a data source. Uman (2011) describes the steps involved in conducting a systematic review: define the review question, decide on the exclusion and inclusion criteria, develop a search strategy, select the studies according to the inclusion/exclusion criteria, extract the data, assess the study quality, analyze and interpret the results, and communicate the findings.

In this work, bibliometric data were analyzed with the Biblioshiny interface for the Bibliometrix package in R Studio programming language, which allows the analysis of literature in a scientific field, topic or subject of interest. This program processes bibliometric data using statistical rules, word count laws, co-citation counts, bibliographic linkage, keyword co-occurrence and other techniques (Aria & Cuccurullo, 2017).

Data collection

We chose Scopus as it is the largest database of abstracts and citations of scientific literature. The documents were retrieved on May 5 2023, using the search keys "Malthus" and "Boserup." The research examined the occurrence of both terms in titles, abstracts and keywords of articles. The Scopus base returned 29 documents. First, we read the titles, abstracts, and metadata in the screening process. Then, we performed a content analysis, which confirmed that all articles belonged to the study field. Thus, 29 documents were included in the analyses using Bibliometrix[2].

Another search conducted on Scopus for the occurrence of "Malthus T. R." in the References section yielded 4,510 results. After processing, it was found that 98 documents were duplicates, resulting in a database of 4,412 unique documents citing Malthus. Lastly, a search on Scopus for the words "Boserup E." in the References section yielded 6,575 documents, with 147 duplicates excluded, resulting in a database of 6,428 unique documents citing Boserup.

Therefore, three databases were collected: one with documents that contain both Malthus and Boserup in titles, abstracts and keywords, and two other databases, one containing references to Malthus and the other to Boserup (table 1).

Description	Malthus in References	Boserup in References	Malthus and Boserup in Title-Abstract-Keyword
Timespan	1970:2023	1970:2023	1982:2023
Sources (Journals, Books, etc)	2,970	3,104	29
Documents	4,412	6,428	29
Annual Growth Rate %	5	5.41	0
Average citations per doc	25.45	31.43	19.52
References	686,024	850,657	1,458
Keywords Plus (ID)	6,883	6,589	149
Authors	6,266	9,162	53
Single-authored docs	2,619	3,519	17
Co-Authors per Doc	1.83	2	1.86
International co-authorships %	0	0.09334	10.34
Article	2,321	4,016	25
Book	937	888	1
Book chapter	557	916	1
Conference paper	129	76	0
Review	380	440	2

Table 1. Databases

[2] For further explanation, see Aria and Cuccurullo, 2017.

The largest number of documents was retrieved for the references to Boserup, and the timespan changes when considering the selection of both authors mentioned together, giving 29 documents between 1982 and 2023.

Data analysis

The three databases were analyzed with Bibliometrix. Only the database containing the 29 documents in which both authors are mentioned in title, abstract and keywords were analyzed, reading the abstract and the whole article.

Bibliometrix builds thematic maps on the basis of key words, which allows detecting and visualizing conceptual subdomains. The algorithm uses co-word and h-index indicators to create a thematic map in a two-dimensional strategy diagram (Aria and Cuccurullo, 2017; Cobo *et al*., 2015). Biblioshiny calculates the relationship that a network of words establishes with other networks of words, distributing the themes according to centrality and density: motor themes: important and well-developed themes for structuring a research field; niche themes: very specialized and peripheral themes; emerging or declining themes: low density and centrality themes to the research field; and basic themes: basic, general, and transversal themes to the research field.

We used data in KeyWords Plus to generate the thematic map and set three parameters to maintain the richness of information without impairing map readability. KeyWords Plus is of great interest for bibliometric purposes, as it uses a database algorithm which extracts terms from the titles of articles cited in a document.

We used the clustering algorithm Walktrap[3] to build the map for the 250 most frequent keywords, considering only KeyWords Plus terms with a minimum frequency of three occurrences.

RESULTS AND DISCUSSION

In the first part of the results, we present the findings of the analysis performed by Bibliometrix on the 29 documents in which Malthus and Boserup appear together, and our full content analysis. In the second part, we present the results of the analysis of references to Malthus and Boserup, performed mainly by Bibliometrix.

Malthus and Boserup together

Bibliometric analysis of the 29 documents with co-occurrence of Malthus and Boserup in Title, Abstract, Keyword sections

The 29 documents returned by Scopus were treated and analyzed by the R Bibliometrix package running on R Studio software.

The first most cited document was *Induced intensification: Agricultural change in Bangladesh with implications for Malthus and Boserup* by Turner II and Shajaat Ali (1996), which is cited in 152 documents in connection with agricultural intensification. In this work, in which both Malthus and Boserup coexist, Turner II and Shajaat carried out a test among 265 households in 6 villages in Bangladesh to measure the level of agricultural change, considering variations in the behavior of small-holders. The second most frequently cited document, with 124 citations, is *A theory of preindustrial population dynamics: Demography, economy, and well-being in Malthusian systems* by Wood (1998), in which changes in well-being are modeled under a fixed system of food production and in the face of changes in subsistence conditions. The third is *Adaptation to land constraints: Is Africa different?* by Headey and Jayne (2014), which examines adaptation to falling land-labor ratios using a comprehensive theoretical framework in which households faced with binding land constraints can respond in three ways: intensifying agricultural production, diversifying out of agriculture, and reducing fertility rates, with 81 citations.

The most cited words in the co-occurrence network for the 29 documents (figure 1) that include both authors are “population growth”, linked to “economic development” and “developing country”; and “population dynamics”, linked to “population” and “social sciences”. Then, three other less relevant networks appear. One which links “Malthusian theory” with “Africa”, another network on “population pressure” with “farming system” and

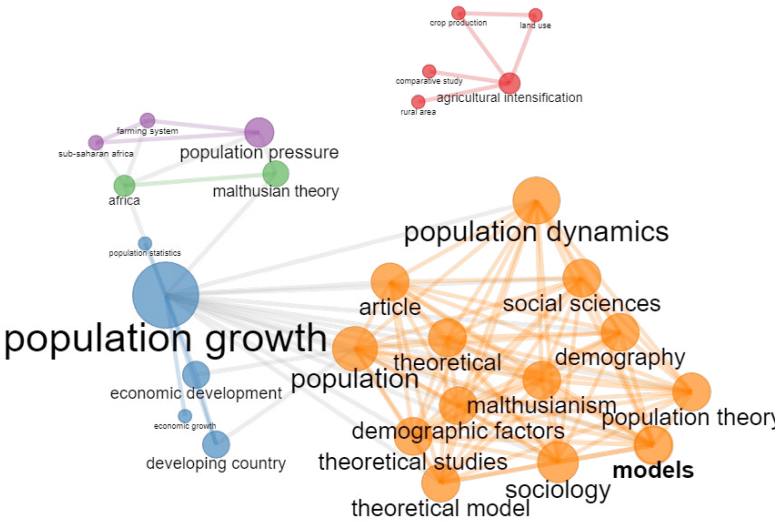

Figure 1. Co-occurrence network (Malthus and Boserup). Source: prepared by the authors.

[3] One of the most popular algorithms for community identification.

"Africa" and, finally, another network far from the others that links "agricultural intensification" with "land use", "rural areas", "comparative studies" and "crop production". From this figure, it is possible to see the incidence of the contributions of Malthus in the first three most relevant networks and the incidence of Boserup in the "agricultural intensification" and in the first on "economic development" networks.

In 19 of the 29 papers that include both Malthus and Boserup, we found models with great heterogeneity of variables and diversity of applications. The paper by Çelik *et al*. (2023) is related to the work of Bu *et al*. (2022) on how population migration affects carbon emissions in China. Another recent paper by Tomiyama *et al*. (2020) was cited by Banerjee *et al*. (2023) on the topic of hydrolysis, bioconversion of ethanol related to carbon flux and biorefinery residues. Çelik is cited in another paper by Wijerathna-Yapa and Pathirana (2022) on sustainable agri-food systems to address climate change and food security.

Content analysis of the documents with references to Boserup and Malthus in Title, Abstract, and Keywords

The documents were thoroughly read and the information was organized according to the following criteria:

- **According to location**: Pryor and Maurer (1982) in pre-capitalist economies; Levi (1985) in India, Bangladesh, Pakistan and all Africa; Blanchet (1989) in developing and developed countries; Turner II and Shajaat Ali (1996) in Bangladesh; Marquette (1997) in developing regions, more specifically, in sub-Saharan Africa; Lom (1999) in developing countries such as Senegal; Cochet (2004) ancient agrarian systems and in central Africa; Henley (2005) in Asia; Demont *et al*. (2007) in northern Coˆte d'Ivoire; Codjoe and Bilsborrow (2011) in Ghana; Headey and Jayne (2014) in Africa; Ervin and López-Carr (2017) in Latin America; Palliere (2018) in Sierra Leone; Jahel *et al*. (2018) in West Burkina Faso; Hadush *et al*. (2019) in Ethiopia; Egger *et al*. (2020) in Austria; Çelik *et al*. (2023) in middle-income countries (Russia, Thailand, Iran, Lebanon, Türkiye, Malaysia, Côte d'Ivoire, Peru, Ukraine, Jordan, Argentina, Mexico, India, Pakistan, Bangladesh, Uzbekistan, Kazakhstan, South Africa, Colombia, Nigeria) and upper-income countries (USA, France, Greece, Denmark, Germany, Canada, Austria, the Netherlands, Poland, Australia, Japan, Finland, United Kingdom, Spain, Israel, Belgium, Norway, Italy, Switzerland, Sweden).
- **According to the period:** Artzrouni and Komlos (1985) from the Neolithic to the Industrial Revolution; Turner II and Shajaat Ali (1996) from 1950 to the present; Henley (2005) pre-industrial; Demont *et al*. (2007) between 1995 and 1998; Codjoe and Bilsborrow (2011) between 2001 and 2002; Headey and Jayne (2014) from 1970 to 2000; Birchenall (2016) in the modern and pre-modern era; Ervin and López-Carr (2017) between 1970 and 2010; Ashmore (2018) various historical periods; Jahel *et al*. (2018) from 1960 to 2015; Egger *et al*. (2020) from 1961 to 2011; Çelik *et al*. (2023) from 2010 to 2019.
- **Theoretical**: Bonneuil (1994) theoretical model on population and technological change; Bonneuil, (1997) mathematical notions of equilibrium in dynamic systems theory and in game theory to show how social forms are generated by individual interactions; Wood (1998) changes in well-being are modeled under a fixed system of food production and in the face of changes in subsistence conditions; Weyland (2006) contradicted Malthus, but considered social and moral analyses; Walshe (2010) teaching strategies on sustainability; Peura (2013) considers macro level theories for understanding the urge for reform as well as the process of societal change both in general terms, and, more specifically, within the energy sector; Fürnkranz-Prskawetz (2015) theory on population and environmental impact; Soby (2017) new development model may incorporate elements of both Neo-Malthusian and Boserupian economic-demographic models; Ashmore (2018) theoretical on political ecology; Tomiyama *et al*. (2020) exploring through simulation how famine occurs in both individual villages and groups of villages is a powerful tool for understanding the qualitative dynamics of human population capacity; Price and Feldmeyer (2012), though an empirical model, analyze migration movements as the explanatory variable and CO_2 emission as the dependent variable. They also consider the environmental pollution in high- and middle-income countries that receive high levels of immigrants.
- **According to the variables considered**: Bonneuil (1994); Marquette (1997); Wood (1998), Cochet, (2004), Henley (2005); Codjoe and Bilsborrow (2011); Peura (2013); Headey and Jayne (2014); Hadush *et al*. (2019) and Egger *et al*. (2020) would be more linked to Boserup; on the other hand, the documents close to Malthus would be: Bonneuil (1997); Wood (1998); Weyland (2006); Peura (2013); Hadush *et al*. (2019); Egger *et al*. (2020); Tomiyama *et al*. (2020). Finally, Turner II and Shajaat Ali (1996); Hadush *et al*. (2019) make explicit the coexistence of Malthus and Boserup's analyses.

  As a synthesis of the review of the works in which both authors are cited, five relevant points were identified: 1) population growth *vs*. food; 2) resources (inputs, materials) linked to ecological economics; 3) technology-driven productivity; 4) land ownership; 5) references to Boserup are more limited to land use and international policies after World War II Codjoe and Bilsborrow (2011); Headey and Jayne (2014); Egger *et al*. (2020). On the other hand, Malthus is cited in broader analyses including diverse factors, such as the perfection of man, social classes, happiness, Godwin's error, wealth and poverty, the theory of mind, human nature and morality.

Comparison of topics in documents citing Malthus and Boserup separately

In Malthus, the H impact appears in the top positions in the journals *Ecological Economics, Plos Ones, Population and Environment,* and *Sustainability,* among others. On Boserup's side, the first place is occupied by the journal *World Development* followed by *Human Ecology* and *American Anthropologist*.

When considering the main journals, it can be seen how Malthus's publications would be more linked to the strong sustainability proposed by Vivien (2009), who highlights the approach of "strong sustainability" or "type I bioeconomy", linked to the works of Georgescu-Roegen (1975, 1978), studied in ecological economics. On the other hand, documents citing Boserup are more linked to the approach of "weak sustainability" or "type II bioeconomy" as defined by the OECD for economies driven by industrial biotechnology; and to "very weak sustainability", or "type III bioeconomy" Langeveld *et al*. (2010); European Commission (2012) in connection with biomass-based economies.

Therefore, in the journal *World Development,* Boserup would be aligned with weak or very weak sustainability.

Regarding the keywords, in Malthus, they are linked to more global concepts, such as climate change, evolution, fertility, population dynamics. Conversely, keywords in Boserup are more related to land use, agriculture, poverty, and economic growth.

Topical trend 1970-2023

Between 1970 and 2023, topics in Malthus evolved from social status, migration and demography to coevolution, fear effect, Covid-19, and carbon sequestration. Over the same period, topics in Boserup shifted from politics, socioeconomics, and fertility to waste management, demographic interviews, and sustainable development goals. In the 1980s, works shared topical trends, but in the following decades there would be great divergence, with works citing Malthus addressing broad factors such as population, human development, and those citing Boserup focusing on land use and international development policies.

In order to analyze the trends of the topics from 1970 to the present, a graph was plotted from 2000 to 2023 to show the relevant aspects of references to Malthus (figure 2) and Boserup (figure 3) by decade.

An analysis of the thematic trends in references to either author by decade shows marked differences and few similarities. In the 1980s, Malthus is cited in connection with topics such as social class, historical survey and parity, whereas Boserup is cited in relation to population characteristics, human resources, and agricultural workers. The only term on which they agree is "history of medicine". If we consider that the variables food and population were relevant for both authors, the association with the history of medicine was relevant in this decade.

In Malthus' references, the topic "history of medicine" appears in Sen (1981), who notes that famine occurs in situations of moderate to good food availability, without a significant decrease in the *per capita* food supply. On the other hand, Boserup is cited in Galloway (1988), a research on basic patterns of price variation in relation to fertility, mortality and nuptiality in pre-industrial Europe.

In the 1990s, trends emerged in references to Malthus on topics such as population, environment, Wales, and remarkably, "man-environment relationship". Boserup was cited in relation to population dynamics, demography and spatial distribution, among others. Words shared by both authors in this decade are "developed countries", "developing countries", "socio-economic factors".

In the 2000s, Malthus is cited in relation to demography, migration, social aspects, and Boserup in connection with Africa, population growth, and international cooperation. Common words include Africa, world, Asia, and environmental degradation. In this decade, Boserup is cited in connection with "nature-society relations", which would be related to the content that emerged as a trend for Malthus in the previous decade, "man-environment relationship".

As regards the socioeconomic aspect, both authors are cited in connection with poverty with greater emphasis in the mid-2000s. Among recent works, Sullivan and Hickel (2023) evaluated real wages, human height and mortality in Europe, Latin America, sub-Saharan Africa, South Asia and China, using empirical indicators of human welfare. The researchers emphasize that it is unlikely that 90% of the human population lived in extreme poverty before the 19th century, except during periods of severe social dislocation, such as famines and wars, and that the rise of capitalism caused a dramatic deterioration of human welfare. Conversely, Ghosh *et al*. (2022) examine the main drivers of poverty in Birbhum district (India), identifying

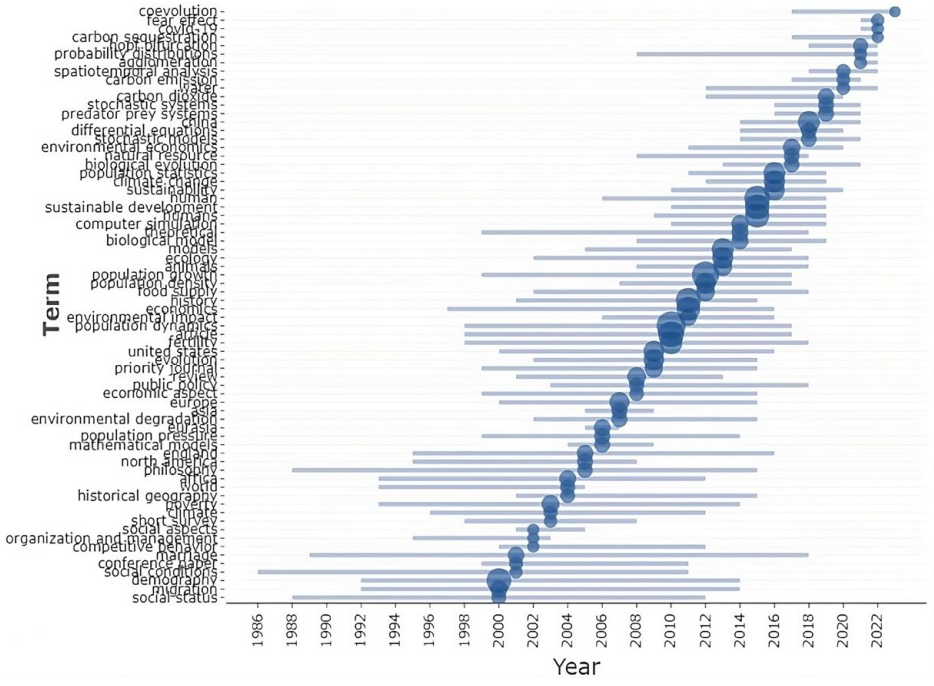

Figure 2. Topical trend 2000-23 in references to Malthus. Source: prepared by the authors.

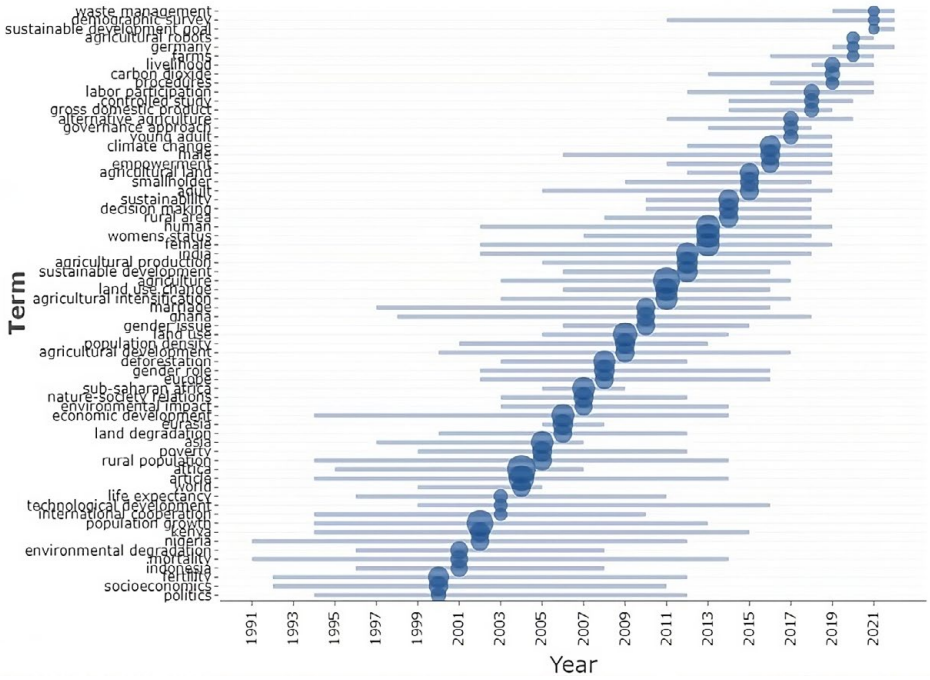

Figure 3. Topical trend 2000-23 in references to Boserup. Source: prepared by the authors.

ten parameters as significant drivers of poverty, six of which are physical, namely slope, elevation, drainage density, frequency of waterlogging, soil texture, and rainfall. The remaining four socio-cultural and economic parameters are literacy, major market center, population growth, and road density. The factor analysis shows that, in terms of their eigenvalue, the five essential factors are agro-climatic, infrastructural and educational, hydrological, demographic, and edaphological.

In the 2010s, Malthus appeared in papers on population dynamics, history, and biological evolution, while Boserup was cited in connection with agriculture, female status, female, agricultural intensification, and gross domestic production. Both authors frequently appear in connection with human, climate change, and sustainability. In the case of Malthus, he is cited in topics such as stochastic models, differential equations that would be linked to simulation models. In the references to Malthus in connection with population dynamics, for example, there is an article by Zhang *et al*. (2011) on causal relationships between climate change and large-scale human crises, in which strong temporal correlations were established between climate change and social crises in the past. They conclude that climate change was the ultimate cause of social crisis, and that the climate-induced economic slowdown was the direct cause of large-scale human crises in pr-industrial Europe.

In the 2020s, references to Malthus are associated with elements of CAS: spatio-temporal analysis, carbon emissions, Hopf bifurcation, and coevolution; whereas Boserup is mentioned in relation to agricultural robots, farms, waste management, and sustainable development goals. In this short three-year period of the 2020s, there are no words in common. Linked to carbon sequestration is a paper by Mohankumar *et al*. (2023) on the sustainability of fertilizer use in a district in India. A book by Horne (2023), *What Is Promoting Human Extinction? Contributions to Political Science,* deals with carbon flux research. Funded by DARPA (Defense Advanced Research Projects Agency), the book describes selected important events that threaten human civilization. Some are more subtle than others, such as identity politics and culture, compared to global warming and the population explosion. In general, experts in various fields agree that increasing complexity, incompetence, and population stress are the main drivers of environmental degradation, resource depletion, and increasingly frequent and violent conflicts. Each of these also has devastating effects. Each problem is directly or indirectly interrelated with the others, but all arise from destructive competition and a socioeconomic order based on growth and production. The funding of this book by DARPA is in line with the interesting results of Turchin *et al*. (2022), which relate agricultural productivity to the growth of social complexity and war conflicts between States.

Schroder *et al*. (2023) investigate the intersection of landscape, household and community through a multi-scale analysis of households using the Gini index and a regional-scale analysis of near-continuous LiDAR data inside and outside previously documented pre-Hispanic Maya settlements. The index is another way to study how social and economic variability from household to community level intersects with diverse ecological patterns. In Salas-Rojo and Rodríguez (2022), the relationship between inheritances received and the distribution of wealth (financial, non-financial, and total) is explored in four developed countries: the United States, Canada, Italy, and Spain. Using machine-learning methods, they found that inheritances explain more than 60% of wealth inequality in the United States and Spain (using the Gini coefficient), and more than 40% in Italy and Canada. Including parental education as an additional circumstance, available for the US and Italy, shows that inheritances remain the main explanatory factor.

According to the Economy and Development Report of the Development Bank of Latin America (Berniell and De La Mata, 2022), similar connections between inheritances and wealth distribution are observed in Latin America, and the empirical evidence shows a strong positive association between inequality and intergenerational persistence of income.

Korzeniewicz and Moran (2009) present a new comprehensive framework that goes beyond national borders to analyze economic inequality and social mobility on a global scale in over ninety-six countries. Inequality is best understood as a complex set of interactions that unfold globally over time. Thus, the same institutional mechanisms that have historically reduced inequality within some nations have also often accentuated the selective exclusion of populations in poorer countries and enhanced the balance of gross inequality between nations. National identity and citizenship are the fundamental contemporary bases of stratification and inequality in the world, the authors conclude. According to Alfani and Carballo (2023), Latin American countries are today characterized by relatively high levels of economic inequality. This circumstance has often been considered a long-term consequence of the Spanish conquest and the highly extractive institutions imposed by the colonizers.

Although it is difficult to determine the causes of external interference and establish limits within globalization, the development of a country itself should make it possible to control the possibility of greater internal growth, which in turn would contribute to global growth. However, the disconnection between economic and financial growth leads to the blurring of national borders, making it possible to move financial assets between different locations.

Ioannou and Wójcik (2023) examined the determinants of income inequality in 131 developed and developing economies in the period 1991-2017. They considered a wide range of variables associated with domestic financial development, banking crises, and financial globalization, including financial secrecy and offshore wealth. The results showed that the larger the size of a country's financial sector, the higher the level of inequality. Financial globalization, in all its facets, also appears to contribute to inequality. These findings are particularly strong for developed economies. Their analysis also shows that the financial aspects that aggravate inequality are positively associated with the degree of geographic centralization of the financial sector.

Beckert (2022) foregrounds the institutions, mechanisms and practices through which the families at the top of the wealth distribution protect and expand their wealth. Opportunity hoarding is based on legal institutions, especially inheritance law, trust law, advantageous financial regulations, and wealth tax policies. Wealthy owners also pay for a growing number of legal and financial experts to protect their fortunes. The stipulations of legal institutions are shaped through lobbying, campaign donations, and influence on public opinion, facilitating the intergenerational preservation of great fortunes. Philanthropy does not appear to be primarily a means to support general well-being, but rather an additional instrument to protect the wealth of the super-rich through its role in legitimizing large fortunes and obtaining tax benefits. The deeply-embedded nature of great fortunes raises questions about the normative identity of contemporary societies.

This state of affairs had already been described in the 1970s, pointing to the system itself as responsible for maintaining the *statu quo* (Arrow, 1971). Bowles and Carlin (2020) and Aghion *et al*. (2020) also mentioned individual behaviors as well as possible failures in institutions.

On the one hand, the decline in State revenues and, on the other hand, the lack of political responses to the various current social problems, coupled with the exacerbation of problems due to extreme weather events, could lead to a total lack of confidence in the global system, which might lead populations to call for a global shift in development, with States displaced by large monopolies.

Topic co-occurrence network

Four networks of co-occurrence of topics are observed in the references to Malthus (figure 4 left). The first network shows co-occurrence of human issues, models, animals, and population density. The second is linked to the dynamics of human reproduction, expressed by the terms "population", "demography", and "fecundity". Therefore, both networks could be considered to have an underlying humanistic point of view.

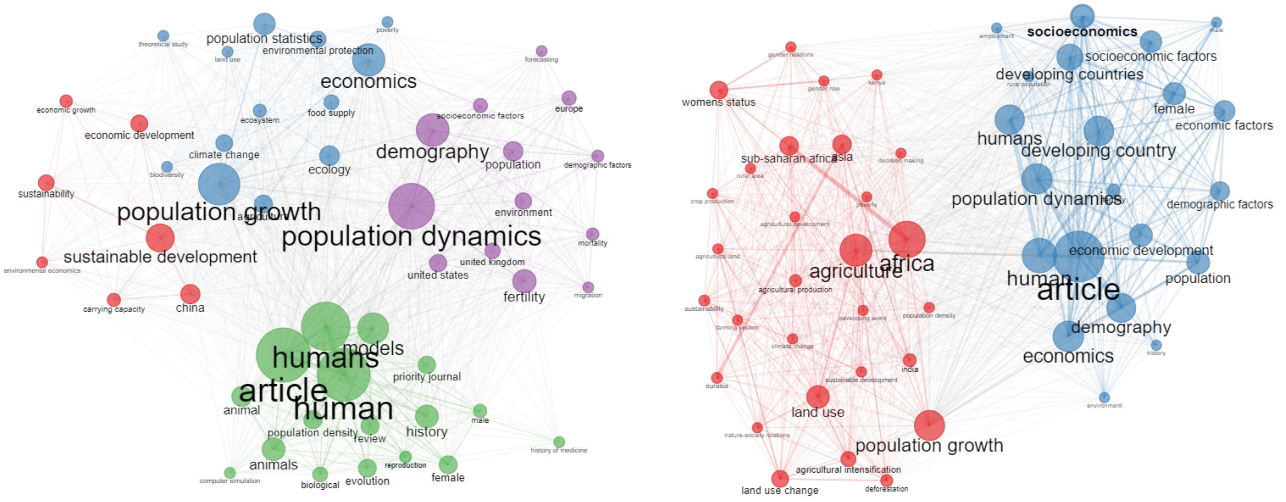

Figure 4. Co-occurrence network for Malthus (left) and Boserup (right). Source: prepared by the author.

The third network, on population growth, economics, ecology, and climate change, discusses population in the context of economic implications and could be considered under the neoclassical economics paradigm. The fourth network, on sustainable development, China, and economic development, can be associated to international sustainable development.

Two topic co-occurrence networks are identified for Boserup (figure 4 right): one on agriculture, Africa, population growth, and land use in connection with specific aspects of agricultural production, *i.e.,* the central theme of Boserup's work focused on food supply; while the second network comprises economics, demography, and economic growth of countries, linked to aspects of food demand and to socioeconomic factors of neoclassical economics.

When comparing the networks of Malthus and Boserup, the most diverse networks with the deepest content are observed in Malthus, although the largest number of documents are found for Boserup. Malthus' green network is associated with human aspects that are not linked to a specific economic paradigm, possibly indicating the emergence of a new scientific research area.

Thematic evolution

In the Biblioshiny interface for references to Malthus (figure 5 left) and Boserup (figure 5 right), the thematic evolution corresponds at the same time to 2 and to cut 1. The niche themes quadrant is empty for Malthus, while in Boserup it contains the human aspect. The human aspect appears in Malthus in the quadrant of driving themes, followed by population growth, sustainable development, China, and economy.

From the analysis of figure 5, one can see a substantial difference in the contemporary contributions that have been made since Malthus to the development of various stochastic simulation models and prey-predator models until arriving at the models of non-linear dynamical systems and bifurcations.

Malthus is cited in connection with human topics in seven papers published in 2023: Manninen *et al.* (2023) on false logistic growth; Zhao *et al*. (2023) on logistic growth of mutations in population-scale epidemics; Tomé and Oliveira (2023) on a stochastic approach to population dynamics; Gong *et al*. (2023) on how the continuous time scenario challenges computational explanations of active causal learning; Ashby (2023) on sustainable development; and Chu *et al*. (2023) on the evolution of the spatial distribution pattern of population and economy in Russia since the 21st century.

In the Boserup database for the year 2023, the topic of humans appears in three papers: Damann *et al*. (2023) on the resilience of gender norms and the importance of cultural legacies in maintaining and perpetuating gender (in)equality today; Aguirre Merino *et al*., (2023) which reports on a set of agroecological practices incorporated into the archaeological landscape used by pre-Hispanic Kañaris societies for 1,200 years (240-1438 AD). Finally, Boserup is cited in Manninen *et al*. (2023) as in Malthus.

In the basic themes quadrant, only Boserup is cited, in connection with status of women, India, and gender relations. However, substantial differences are observed in the quadrant of emerging or declining themes. In Malthus, it includes the prey-predator system, Hopf bifurcations, and cell proliferation, as well as population statistics, ecology, and stochastic systems. For Boserup, it includes agriculture, articles, and architecture.

When searching the Malthus database on population statistics, the most cited paper (382) is that by Stein Emil Vollset and Emily Goren (2020) on fertility, mortality, migration and population scenarios for 195 countries and territories from 2017 to 2100.

In relation to predator-prey systems, there are 34 articles on the following topics: ecoepidemiology (Sarwardi *et al*., 2011); mathematics (Elettreby, 2009; Santra and Mahapatra, 2020); war model (Samoilenko *et al*., 2019); ecology and evolutionary dynamics (Neverova *et al*., 2022; Lopes and Fontanari, 2019); on ecosystem sustainability and technological progress in adaptive gradient dynamics describing innovation and resilience at the societal scale (Lemmen, 2015). A search for Malthus in the Hopf's bifurcation database retrieves 55 articles.

Drawing on the Malthusian and Boserupian models, Freeman *et al*. (2023b) ask a basic question: What processes control the long-term carrying capacity of human societies? The results support the idea that both the Malthusian concept of limited resources and the Boserupian thesis of pressure to reorganize economic systems operate in hunter-gatherer populations over the long term. Their data and analyses contribute to assessing complex patterns of population growth and change in subsistence conditions in archaeological cases. Freeman *et al*. (2023) propose a model to explain episodes of demographic growth and the decline of human populations over the long term: intensification of production generates a trade-off between the adaptive capacity of individuals to generate surplus energy to maximize their short-term fitness and the long-term capacity

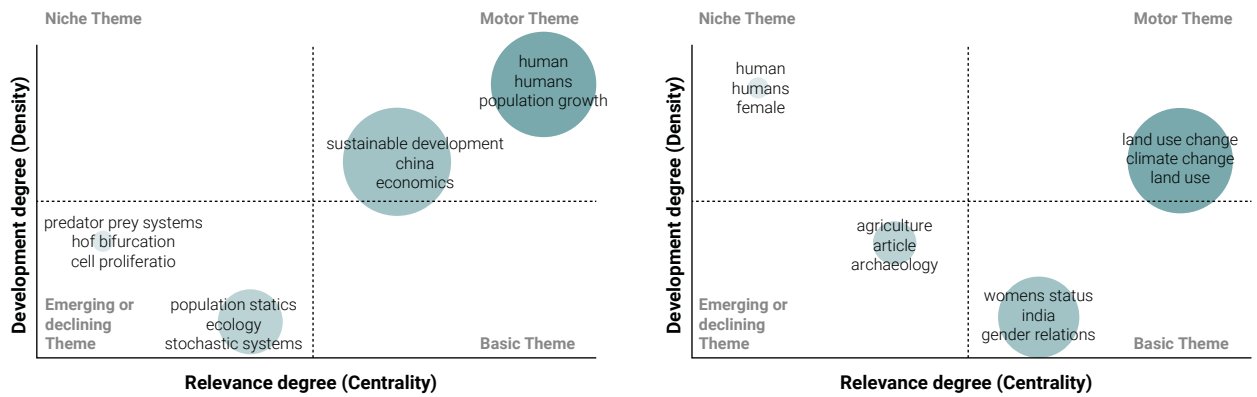

Figure 5. Thematic evolution in Malthus (left) and in Boserup (right) Source: prepared by the authors.

of a population as a whole to undergo a smooth transition to demographic equilibrium. The model reconciles the conflicting views on dynamic system models of human population change, and they conduct a preliminary test on the implications of the model in Central Texas, by developing time series that estimate changes in human population density, modeled ecosystem productivity, human diet, and labor force over the past 12,500 years. Evidence indicates that each of these increases, and reductions in resource extraction is associated with changes in the diet and labor devoted to processing high-density, low-quality resources to release calories and nutrients. In the long term, demographic recessions may be necessary for populations to experience changes in social and physical infrastructures that increase the carrying capacity of their environment.

In Boserup's database of references linked to agriculture in recent years, one of the most cited (204) is the work of Koch *et al*. (2019) on the impacts of the arrival of Europeans and of the massive mortality of indigenous people in the Americas after 1492 on the Earth system. Another work is that by Acemoglu *et al*. (2002), who argue that the current impoverishment of American countries, which were relatively rich before the European colonization, reflects changes in institutions resulting from European colonialism. European intervention seems to have created an "institutional reversal" among these societies, meaning that Europeans were more likely to introduce institutions that encouraged investment in the colonized regions. This institutional reversal explains the reversal in relative income.

One aspect added to the contributions of both authors is the work by Wilson *et al*. (2022), who highlights (with contributions, bifurcations, and points of degradation) that over the past 7,000 years, dietary changes have been influenced more by climatic than by sociodemographic processes. This raises the possibility that socio-political factors might not have been enough to overrule the influence of local climatic conditions on diet during this period.

Finally, an analysis of one of the emerging elements of the CAS, fairness (Valentine *et al*., 2022), shows that in Malthus database it appears in 1.17% of the documents analyzed, compared to Boserup in 0.56% of the documents analyzed.

Among the diverse works on fairness in the Malthus database, it is Chen et *al*. (2023) work, who showed that early exposure to hunger during childhood and adolescence significantly attenuated individuals' risk preferences in adulthood. Henrich *et al*. (2010), cited in Chen *et al*. (2023), conducted behavioral experiments among 15 diverse populations, and their results suggest that modern prosociality cannot be explained by innate psychology alone; rather, it seems to be sustained by norms and institutions that have emerged throughout human history.

The incidence of environmental factors affected by socioeconomic conditions leads to behaving in a certain way in the future, as in the case of risk preferences in adulthood. This raises the question of whether social conditions could be stimulating the development of certain genes in humans, a question linked to Malthus' contributions to co-evolution, specifically to evolutionary biology.

Lundberg (2023) also appears in the Boserup database on fairness. The author argues that despite the expansion of the economics literature on gender in recent years, gender gaps in economic outcomes are still largely explained in terms of "choice" due to the persistence of strong priors, like considering the default economic agent to be a man, and sticking to the tendency to avoid complex problems. In the references of this paper on fairness, we find a paper by Andre (2021) on meritocracy. In this work, Andre carried out behavioral experiments to investigate whether people's judgements of merit are sensitive to this endogeneity of choice. The results of this study suggest that, in practice, meritocratic judgements are likely to be "superficial".

The analysis of an emerging element of CAS such as fairness, which is observed in the behavior of agents, points to the need to leave traditional models and embrace complexity. Schill *et al*. (2019) maintains that human behavior is of great importance in the pathway to sustainability, which involves moving from simplistic to complex models. Understanding complex behavior requires different disciplines, including behavioral sciences, and complex adaptive systems. The complex adaptive systems approach allows capturing behavior as "enculturated" and "buried", co-evolving with socio-cultural and biophysical contexts.

CONCLUSION

The evolution of the human-environment relationship can be seen as the result of the combination of several variables, inter- and transdisciplinary scientific advances, and the contributions of complexity frameworks and of the behavioral sciences. In the same sense, in trying to understand the complexity of social systems, they must be modeled and framed in the biosphere under the different possible scenarios of the IPCC on Climate Change.

The seminal works of Malthus and Boserup contributed to several contemporary scientific developments and advances in the human-environment relationship involved in sustainability. The seeds of Malthus and Boserup in contemporary academic studies can be seen in the trends of topics as well as in current reports on current and future issues published by the IPCC and the World Economic Forum, among others.

When considering the human-environment relationship, *i.e*., aspects of sustainability, it is easy to appreciate the greater connection between Malthus and strong sustainability, as opposed to Boserup, who has a stronger connection with weak sustainability as her contributions were linked to the development of international economic policies.

Of the 29 works in which both authors are mentioned, ten are closer to Boserup, seven to Malthus, and three of the documents discuss the contributions of both authors evenly. Among Boserup's contributions, those on agricultural land use and international policies (creation of institutions) after World War II stand out. In Malthus, broader aspects linked to human development are glimpsed, considering aspects such as wealth and poverty, human nature and happiness.

The contributions of both authors have been applied to various countries, cities, time periods from the Neolithic to recent decades, present and future projections, and at the theoretical level for developing mathematical models and non-linear adaptive dynamical systems. Their legacy underpins contemporary theories and models developed to address a wide array of present issues like climate change, food security, waste management, carbon dioxide emissions, and social stratification, among others.

Economic growth would be closer to Boserup, to neoclassical economic theory. Economic growth is associated with economic progress. In considering economic progress, Boserup looked at the increase in the amount of crops harvested per

year, i.e., the increase in productivity over time. In the present, economic progress could be linked to a shift from economics to finance. In other words, given the relevance of financial markets, maximizing financial profitability will partly determine global land use. On the other hand, economic growth in documents citing Malthus is more associated to human factors, such as science, society, and decisions.

Both perspectives (Malthusian and Boserupian) offer unique and valuable contributions to the study of the relationship between humanity and the environment. The Malthusian perspective shows greater thematic diversity and depth. In part, it is linked to human aspects that are not tied to a specific economic paradigm, which could be shaping an area of scientific emergence. On the other hand, the Boserupian perspective stands out for its specific focus on agricultural and economic issues, especially in terms of food supply and demand.

Considering climate change, extreme weather events are among the first risks, along with failures in mitigation and adaptation to it, and the increase in inequalities it drives. Rapid progress is needed in the development of new production technologies (nanotechnology, synthetic proteins, cellular agriculture, gene-editing technology, artificial intelligence) to adjust supply to demand, considering that climatic-socio-environmental conditions should favor the adoption of such technologies.

ACKNOWLEDGMENTS

We sincerely thank Prof. Homero Dewes for his invaluable guidance and support. His expertise and inspiration were fundamental in carrying out this research. We acknowledge his significant contribution to our academic and professional development, and we are deeply grateful for his commitment and mentorship.

We would like to thank translator Gabriela Venturi for revising the English manuscript for grammar and syntax.

REFERENCES

ACEMOGLU, D.; JOHNSON, S.;ROBINSON, J. A. (2002). Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution. The Quarterly Journal of Economics, 117(4), 1231-1294. https://doi.org/10.1162/003355302320935025.

ADAMS, Z. (2019). "Wage", "salary" and "remuneration": A genealogical exploration of juridical terms and their significance for the employer's power to make deductions from wages. Industrial Law Journal, 48(1), 34-65. https://doi.org/10.1093/indlaw/dwy003

ADANU, K. (2023). Population, Institutions, and Violent Conflicts - How Important is Population Pressure in Violent Resource-Based Conflicts? Peace Economics, Peace Science and Public Policy, 29(3), 249-277. https://doi.org/10.1515/PEPS-2023-0004/MACHINEREADABLECITATION/RIS

AGHION, P.; BOWLES, S.; CARLIN, W.; SOSKICE, D. (2020). Shrinking Capitalism - YouTube. https://www.youtube.com/watch?v=4f5O54rbBdw.

AGUIRRE MERINO, C. P.; PIQUÉ HUERTA, R.; PARRA ORDOÑEZ, L. N.; GUAMÁN CAZHO, V.A.; VALDEZ BUSTAMANTE, W. O. (2023). The Archeological Landscape of the Chanchán Basin and Its Agroecological Legacies for the Conservation of Montane Forests in the Western Foothills of the Ecuadorian Andes. Land, 12(1), 192.https://doi.org/10.3390/LAND12010192/S1.

LEBRAHEEM, J. (2023). Predator Interference in a Predator-Prey Model with Mixed Functional and Numerical Responses. https://doi.org/10.1155/2023/4349573.

ALFANI, G.; CARBALLO, A. (2023). Income and inequality in the Aztec Empire on the eve of the Spanish conquest. Nature Human Behaviour 2023 7:8, 7(8), 1265-1274. https://doi.org/10.1038/s41562-023-01636-3

ALTIERI, M. (2001). Agroecología: Principios y Estrategias para Diseñar Sistemas Agrarios Sustentables. IN: SARANDÓN, S. (ed). Agroecología: El Camino hacia una Agricultura Sustentable. Ediciones Científicas Americanas. E.C.A.

ANDRE, P. (2021). Standard-Nutzungsbedingungen. www.econtribute.de

ARIA, M.; CUCCURULLO, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

ARROW, KENNETH J. 1971. "Political and Economic Evaluation of Social Effects and Externalities." In: Frontiers of Quantitative Economics, edited by Intrili- gator, 3-23. Amsterdam: North Holland.

ARTZROUNI, M.; KOMLOS, J. (1985). Population Growth through History and the Escape from the Malthusian Trap: A Homeostatic Simulation Model. Genus, 41, 21-39.

ASHBY, M. F. (2023). Materials and Sustainable Development, Second Edition. Materials and Sustainable Development, Second Edition. Elsevier. https://doi.org/10.1016/C2021-0-00557-5

ASHMORE, W. (2018). 10 Why the Archaeology of Political Ecology Matters. Archeological Papers of the American Anthropological Association, 29(1), 175-184. https://doi.org/10.1111/apaa.12105

BANERJEE, A.; SAILWAL, M.; HAFEEZ, M.; JANA, A.; PORWAL, J.; BHASKAR, T., & GHOSH, D. (2023). Dilute Acid Hydrolysis and Bioconversion of Waste Potato to Ethanol and Yeast Lipid for Evaluating Carbon Flow in Waste Biorefinery. Bioenergy Research, 16(1), 203–212. https://doi.org/10.1007/s12155-022-10433-1.

BARRERA, J. B. Y. (2012). Colombia entre dos mundos: un acercamiento a la relación entre investigadores de la biodiversidad y las comunidades.

BERNIELL, L.; DE LA MATA, D. (Eds.). (2022). Desigualdades heredadas. El rol de las habilidades, el empleo y la riqueza en las oportunidades de las nuevas generaciones. Caracas. Retrieved from https://scioteca.caf.com/handle/123456789/1981

BIRCHENALL, J. A. (2016). Population and development redux. Journal of Population Economics, 29(2), 627-656. https://doi.org/10.1007/s00148-015-0572-x

BLANCHET, D. (1989). Population growth and increase in per capita product during the demographic transition: their interaction viewed in the light of a Malthusian model [Croissance de la population et du produit par tete au cours de la transition demographique: un modele malthusien peut-il rendre compte de leurs relations?]. Population (Paris), 44(3), 613-629. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0024823197&partnerID=40&md5=43b82e6fc8c2e9ad9bfa379bf90881b6

BOISOT, M.; MCKELVEY, B. (2011). Integrating modernist and postmodernist perspectives on organizations: a complexity science bridge. Academy of Management Review, 35(3), 415-433. https://doi.org/10.5465/AMR.2010.51142028

BONNEUIL, N. (1994). Malthus, Boserup and population viability. Mathematical Population Studies, 5(1), 107-119. https://doi.org/10.1080/08898489409525390

BONNEUIL, N. (1997). Games, equilibria and population regulation under viability constraints. An interpretation of the work of the anthropologist Fredrik Barth [Jeux, équilibres, et régulation des populations sous contraintes de viabilité : Une lecture de l'œuvre de l'anthropologue Fredrik Barth]. Population, 52(4), 947-975. https://doi.org/10.2307/1534620

BOSERUP, E. (1965). The conditions of agricultural growth. The Economics of Agrarian Change under Population Pressure by Ester Boserup with a Foreword by Nicholas Kaldor. London. George Allen & Unwin LTD Ruskin House Museum Street.

BOWLES, S.; CARLIN, W. (2020). Shrinking Capitalism. AEA Papers and Proceedings, 110, 372-377. https://doi.org/10.1257/pandp.20201001

BOWLES, S.; GINTIS, H. (2002). The Inheritance of Inequality. http://www.santafe.edu/sfi/publications/working-papers.html.

BU, Y.; WANG, E.; MÖST, D.; LIEBERWIRTH, M. (2022). How population migration affects carbon emissions in China: Factual and counterfactual scenario analysis. Technological Forecasting and Social Change, 184. https://doi.org/10.1016/j.techfore.2022.122023.

ÇELIK, O.; ÇETINER, S.; ABDALLAH, I; UDEMBA, E. N. (2023). Environmental implication of international migration on high- and middle-income countries: A comparative analysis. Energy and Environment. https://doi.org/10.1177/0958305X231167464.

CHEN, X.; HU, X.; XU, J. (2023). When winter is over, its cold remains: Early-life famine experience breeds risk aversion. Economic Modelling, 123, 106289. https://doi.org/10.1016/j.econmod.2023.106289

CHU, N.; WU, X.; ZHANG, P.; XU, S.; SHI, X.; JIANG, B. (2023). Spatial Distri-

bution Pattern Evolution of the Population and Economy in Russia since the 21st Century. International Journal of Environmental Research and Public Health, 20(1). https://doi.org/10.3390/IJERPH20010684

COBO, M. J.; MARTÍNEZ, M. A.; GUTIÉRREZ-SALCEDO, M.; FUJITA, H.; HERRERA-VIEDMA, E. (2015). 25 years at Knowledge-Based Systems: A bibliometric analysis. Knowledge-Based Systems, 80, 3-13. https://doi.org/10.1016/j.knosys.2014.12.035

COCHET, H. (2004). Agrarian dynamics, population growth and resource management: The case of Burundi. GeoJournal, 60(2), 111-122. https://doi.org/10.1023/B:GEJO.0000033593.29549.3b

CODJOE, S. N. A.; BILSBORROW, R. E. (2011). Population and agriculture in the dry and derived savannah zones of Ghana. Population and Environment, 33(1), 80-107. https://doi.org/10.1007/s11111-011-0139-z.

DAMANN, T. J.; SIOW, J.; TAVITS, M. (2023). Persistence of gender biases in Europe. Proceedings of the National Academy of Sciences, 120(12), e2213266120. https://doi.org/10.1073/PNAS.2213266120/SUPPL_FILE/PNAS.2213266120.SAPP.PDF.

DAS, S.; GUPTA, P. K. (2011). A mathematical model on fractional Lotka–Volterra equations. Journal of Theoretical Biology, 277(1), 1-6. https://doi.org/10.1016/J.JTBI.2011.01.034.

DECKER, C. S.; REUVENY, R. (2005). Endogenous technological progress and the Malthusian Trap: Could Simon and Boserup have saved Easter Island? Human Ecology, 33(1), 119-140. https://doi.org/10.1007/s10745-005-1657-z.

DEMONT, M.; JOUVE, P.; STESSENS, J.; TOLLENS, E. (2007). Boserup versus Malthus revisited: Evolution of farming systems in northern Côte d'Ivoire. Agricultural Systems, 93(1-3), 215-228. https://doi.org/10.1016/j.agsy.2006.05.006.

EGGER, C.; HABERL, H.; ERB, K. H.; GAUBE, V. (2020). Socio-ecological trajectories in a rural Austrian region from 1961 to 2011: comparing the theories of Malthus and Boserup via systemic-dynamic modelling. Journal of Land Use Science, 15(5), 652-672. https://doi.org/10.1080/1747423X.2020.1820593

ELETTREBY, M. F. (2009). Two-prey one-predator model. Chaos, Solitons and Fractals, 39(5), 2018-2027. https://doi.org/10.1016/j.chaos.2007.06.058

EPPINGA, M. B.; DE BOER, H. J.; READER, M. O.; ANDERIES, J. M.; SANTOS, M. J. (2023). Environmental change and ecosystem functioning drive transitions in social-ecological systems: A stylized modelling approach. Ecological Economics, 211, 107861. https://doi.org/10.1016/J.ECOLECON.2023.107861

ERVIN, D.; LÓPEZ-CARR, D. (2017). Linkages among population, food production, and the environment at multiple scales. Journal of International and Global Studies, 9(1), 1-17. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85045335380&partnerID=40&md5=d051d6e72facc8cb2d6c8bb3680e81a9

EUROPEAN COMMISSION. (2012). Innovating for Sustainable Growth: A Bioeconomy for Europe. (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions No. SWD (2012) 11 final).

FOLCH, R. (1998). Ambiente, Emoción y Ética: Actitudes ante la cultura de la sostenibilidad. Editorial Ariel, S.A., Barcelona.

FOLKE, C.; POLASKY, S.; ROCKSTRÖM, J.; GALAZ, V.; WESTLEY, F.; LAMONT, M.; SCHEFFER, M.; ÖSTERBLOM, H.; CARPENTER, S. R.; CHAPIN, F. S.; SETO, K. C.; WEBER, E. U.; CRONA, B. I.; DAILY, G. C.; DASGUPTA, P.; GAFFNEY, O.; GORDON, L. J.; HOFF, H.; LEVIN, S. A.; LUBCHENCO, J.; STEFFEN, W.; WALKER, B. H. (2021). Our future in the Anthropocene biosphere. In Ambio (Vol. 50, Issue 4, pp. 834–869). Springer Science and Business Media B.V. https://doi.org/10.1007/s13280-021-01544-8

FRASER, S. W.; GREENHALGH, T. (2001) . Coping with complexity: educating for capability. BMJ (Clinical Research Ed.), 323(7316), 799-803. https://doi.org/10.1136/BMJ.323.7316.799

FREEMAN, J.; MAULDIN, R. P.; HARD, R. J.; SOLIS, K.; WHISENHUNT, M.; ANDERIES, J. M. (2023a). Hunter-Gatherer Population Expansion and Intensification: Malthusian and Boserupian Dynamics. Journal of Archaeological Method and Theory, 1-21. https://doi.org/10.1007/S10816-023-09617-6/TABLES/1

FÜRNKRANZ-PRSKAWETZ, A. (2015). Population Dynamics: Mathematic Models of Population, Development, and Natural Resources. International Encyclopedia of the Social & Behavioral Sciences: Second Edition. Elsevier Inc. https://doi.org/10.1016/B978-0-08-097086-8.31005-4

GALLOWAY, P. R. (1988). Basic patterns in annual variations in fertility, nuptiality, mortality, and prices in pre-industrial Europe. Population Studies, 42(2), 275-303. https://doi.org/10.1080/0032472031000143366

GEELS, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions, v. 1, n. 1, 24-40 pp.

GEELS, F. W. (2019) Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. Current Opinion in Environmental Sustainability Elsevier B.V.

GEORGESCU-ROEGEN, N. (1975). Bio-economics aspects of entropy. In: KUBAT, L.; ZEMAN, J. (Eds.). Entropy and Information in Science and Philosophy. Elsevier, Amsterdam.

GEORGESCU-ROEGEN, N. (1978). De la science économique à la bioéconomie. Rev. Econ. Polit. 88, 337-382.

GHOSH, R.; DAS, N.; MONDAL, P. (2022). Explanation of major determinants of poverty using multivariate statistical approach and spatial technology: a case study on Birbhum district, West Bengal, India. GeoJournal, 88(1), 293-319. https://doi.org/10.1007/S10708-022-10774-6/METRICS

GLICK, M.; LOZADA, G. A. (2021). The Erroneous Foundations of Law and Economics. Institute for New Economic Thinking Working Paper Series, 1-114. https://doi.org/10.36687/inetwp149

GONG, T.; GERSTENBERG, T.; MAYRHOFER, R.; BRAMLEY, N. R. (2023). Active causal structure learning in continuous time. Cognitive Psychology, 140, 101542. https://doi.org/10.1016/j.cogpsych.2022.101542

GROSSMAN, G. M.; HELPMAN, E. (1989). Product Development and International Trade. 97(6), 1261–1283. https://doi.org/10.1086/261653

HADUSH, M.; HOLDEN, S. T.; TILAHUN, M. (2019). Does population pressure induce farm intensification? Empirical evidence from Tigrai Region, Ethiopia. Agricultural Economics (United Kingdom), 50(3), 259-277. https://doi.org/10.1111/agec.12482

HEADEY, D. D.; JAYNE, T. S. (2014). Adaptation to land constraints: Is Africa different? Food Policy, 48, 18-33. https://doi.org/10.1016/j.foodpol.2014.05.005

HENLEY, D. (2005). Agrarian change and diversity in the light of Brookfield, Boserup and Malthus: Historical illustrations from Sulawesi, Indonesia. Asia Pacific Viewpoint, 46(2), 153-172. https://doi.org/10.1111/j.1467-8373.2005.00269.x

HENRICH, J.; ENSMINGER, J.; MCELREATH, R.; BARR, A.; BARRETT, C.; BOLYANATZ, A.; CARDENAS, J. C.; GURVEN, M.; GWAKO, E.; HENRICH, N.; LESOROGOL, C.; MARLOWE, F.; TRACER, D.; ZIKER, J. (2010). Markets, religion, community size, and the evolution of fairness and punishment. Science, 327(5972), 1480-1484. https://doi.org/10.1126/science.1182238.

HOLLAND, J. H. (1995). Hidden Order: How Adaptation Builds Complexity. (Available at: https://philpapers.org/rec/HOLHOH) [accessed 15.07.23].

HORNE, J. (2023). What Is Promoting Human Extinction? Contributions to Political Science, 13-64. https://doi.org/10.1007/978-3-031-25444-4_2.

HORNE, J. (2023). Managing Complexity Through Social Intelligence. Foundations of the Modern Organic Corporatist State. Contributios to Political Science. ISSN 2198-7297 (electronic). https;//doi.org/10.1007/978-3-031-25444-4.

IOANNOU, S.; WÓJCIK, D. (2023). Income Inequality, Finance, and Space: A Cross-Country Analysis. Global Perspectives, 4(1). https://doi.org/10.1525/GP.2023.89327/197671.

IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001.

JAHEL, C.; VALL, E.; RODRIGUEZ, Z.; BÉGUÉ, A.; BARON, C.; AUGUSSEAU, X.; LO SEEN, D. (2018) . Analysing plausible futures from past patterns of land change in West Burkina Faso. Land Use Policy, 71, 60-74. https://doi.org/10.1016/j.landusepol.2017.11.025

JENKINS, K.; SOVACOOL, B. K.; MCCAULEY, D. (2018). Humanizing sociotechnical transitions through energy justice: An ethical framework for global transformative change. Energy Policy, v. 117, 66-74.

JØRGENSEN, P. S.; WEINBERGER, V. P.; WARING, T. M. (2023). Evolution and sustainability: gathering the strands for an Anthropocene synthesis. https://doi.org/10.1098/rstb.2022.0251.

KORZENIEWICZ, R. P.; MORAN, T. P. (2009). Unveiling inequality: A world-historical perspective. Unveiling Inequality: A World-Historical Perspective. Russell Sage Foundation. https://doi.org/10.1177/0094306110380384y

KOCH, A.; BRIERLEY, C.; MASLIN, M. M.; LEWIS, S. L. (2019). Earth system

impacts of the European arrival and Great Dying in the Americas after 1492. Quaternary Science Reviews, 207, 13-36. https://doi.org/10.1016/J.QUASCIREV.2018.12.004

KREMER, M. (1993). Population Growth and Technological Change: One Million B.C. to 1990. The Quarterly Journal of Economics, 108(3), 681-716. https://doi.org/10.2307/2118405

LAMBIN, E. F.; TURNER, B. L.; GEIST, H. J.; AGBOLA, S. B.; ANGELSEN, A.; BRUCE, J. W.; COOMES, O. T.; DIRZO, R.; FISCHER, G.; FOLKE, C.; GEORGE, P. S.; HOMEWOOD, K.; IMBERNON, J.; LEEMANS, R.; LI, X.; MORAN, E. F.; MORTIMORE, M.; RAMAKRISHNAN, P. S.; RICHARDS, J. F.; SKANES, H.; STEFFEN, W.; STONE, G.D.; SVEDIN, U.; VELDKAMP, T.A.; VOGEL, C.; XU, J. (2001). The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change, 11(4), 261-269. https://doi.org/10.1016/S0959-3780(01)00007-3

LANGEVELD, H.; MEEUSEN, M.; SANDERS, J. (2010). The Biobased Economy: Biofuels, Materials and Chemicals in the Post-oil Era. Earthscan, London; Washington, D.C.

LEMMEN, C. (2015) Gradient adaptive dynamics describes innovation and resilience at the society scale. In: Barceló JA, Bogdanovic I (eds) Mathematics and archaeology. CRC Press, Boca Raton (FL), pp 405–415

LEVI, J. F. S. (1985). Why poor people really stay poor: a synoptic view with reference to food production. Occasional Paper - Queen's University of Belfast, Working Papers in Economics, 22. (Available at:https://www.scopus.com/inward/record.uri?eid=2-s2.0-0022179589&partnerID=40&md5=6801ae8836e89ba46ff0736477a83e82).

LOM, A. D. (1999). Demography and development. And if Malthus was right [Demographie et developpement. Et si Malthus avait raison.]. Pop Sahel : bulletin d'information sur la population et le développement, 28, 35-37. (Available at https://www.scopus.com/inward/record.uri?eid=2-s2.0-0033286179&partnerID=40&md5=95f4feedb3616877b2591dc711afebd7).

LOPES, G. M.; FONTANARI, J. F. (2019). Influence of technological progress and renewability on the sustainability of ecosystem engineers populations. Mathematical Biosciences and Engineering : MBE, 16(5), 3450-3464. https://doi.org/10.3934/MBE.2019173

LOTKA, A. J. (1925). Elements of Physical Biology. Williams and Wilkins.

LUNDBERG, S. (2023). GENDER ECONOMICS: DEAD-ENDS AND NEW OPPORTUNITIES. Research in Labor Economics, 50, 151-189. https://doi.org/10.1108/S0147-912120230000050006

MALTHUS, T. R. (1798). An Essay on the Principle of Population. (Available at: http://www.esp.org). [accessed 13.07.23].

MANNINEN, M. A.; FOSSUM, G.; EKHOLM, T.; PERSSON, P. (2023). Early postglacial hunter-gatherers show environmentally driven "false logistic" growth in a low productivity environment. Journal of Anthropological Archaeology, 70, 101497. https://doi.org/10.1016/J.JAA.2023.101497

MARQUETTE, C. (1997). Turning but not toppling Malthus: Boserupian theory on population and the environment relationships. Working Paper - Chr. Michelsen Institute, WP16. (Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-0031396884&partnerID=40&md5=00928b8aacd421f29320f81ceea5ae9a). [accessed 20.08.22].

MAYUMI, K.; GIAMPIETRO, M. (2019). Reconsidering "circular economy" in terms of irreversible evolution of economic activity and interplay between technosphere and biosphere. Romanian Journal of Economic Forecasting-XXII (Issue 2).

MEADOWS, D. H.; MEADOWS, D. L.; RGEN, J.; WILLIAM, R.; BEHRENS ILL, W. (1972). mJ A Potomac associates book.

MOHANKUMAR, L.; THIYAHARAJAN, M.; VENKIDUSAMY, K. S. (2023). The sustainability of fertilizer usage in the rice production system and its influencers; evidence from Erode district of Tamil Nadu, India. International Journal of Sustainable Development and World Ecology. https://doi.org/10.1080/13504509.2023.2190178

MOTESHARREI, S.; RIVAS, J.; KALNAY, E. (2014). Human and nature dynamics (HANDY): Modeling inequality and use of resources in the collapse or sustainability of societies. Ecological Economics, 101, 90-102. https://doi.org/10.1016/j.ecolecon.2014.02.014.

BORGERHOFF MULDER, M.; BOWLES, S.; HERTZ, T.; BELL, A.; BEISE, J.; CLARK, G.; FAZZIO, I.; GURVEN, M.; HILL, K.; HOOPER, P.L.; IRONS, W.; KAPLAN, H.; LEONETTI, D.; LOW, B.; MARLOWE, F.; MCELREATH, R.; NAIDU, S.; NOLIN, D.; PIRAINO, P.; QUINLAN, R.; SCHNITER, E.; SEAR, R.; SHENK, M.; SMITH, E.A.; VON RUEDEN, C.; WIESSNER, P. (2009). Intergenerational wealth transmission and the dynamics of inequality in small-scale societies. Science, 326(5953), 682-688. https://doi.org/10.1126/science.1178336.

NEVEROVA, G. P.; ZHDANOVA, O. L.; FRISMAN, E. Y. (2022). Evolutionary dynamics of predator in a community of interacting species. Nonlinear Dynamics, 108(4), 4557-4579. https://doi.org/10.1007/s11071-022-07372-z

NOGUEIRA, J. M. M.; COELHO, C.; AGUIAR, A. C. (2021). Enlightenment, critical theory, and the role of business schools in the anthropocene. Revista de Gestão Social e Ambiental, 15. https://doi.org/10.24857/RGSA.V15.2816

NYBORG, K.; ANDERIES, J. M.; DANNENBERG, A.; LINDAHL, T.; SCHILL, C.; SCHLÜTER, M.; ADGER, W. N.; ARROW, K. J.; BARRETT, S.; CARPENTER, S.; CHAPIN, F. S.; CRÉPIN, A. S.; DAILY, G.; EHRLICH, P.; FOLKE, C.; JAGER, W.; KAUTSKY, N.; LEVIN, S. A.; MADSEN, O. J.; POLASKY, S.; SCHEFFER, M.; WALKER, B.; WEBER, E.U.; WILEN, J.; XEPAPADEAS, A.; DE ZEEUW, A. (2016). Social norms as solutions. American Association for the Advancement of Science. Science Vol. 354, Issue 6308. 42-43pp. https://doi.org/10.1126/science.aaf8317.

OECD. (2009). The Bioeconomy to 2030: Designing a policy agenda. The Bioeconomy to 2030: Designing a Policy Agenda, v. 9789264056886. 1-322pp.

PALLIERE, A. (2018). Beyond Malthus and Boserup: A socially-embedded approach of land use dynamics at a local scale. A case study in Sierra Leone [Au-delà de Malthus et Boserup: Une approche intégrée des transformations des rapports sociaux et des modes d'exploitation du milieu à l'échelle territoriale. Un cas d'étude en Sierra Leone]. Espace-Populations-Societes, 2018(3), 1-18. (Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85066734628&partnerID=40&md5=d07f83c95c8417fdbf263e8fc3c28e87).

PANG, J.; JIAO, F.; ZHANG, Y. (2022). An Analysis of the Impact of the Digital Economy on High-Quality Economic Development in China—A Study Based on the Effects of Supply and Demand. Sustainability, 14(24). Switzerland. https://doi.org/10.3390/su142416991

PEURA, P. (2013). From Malthus to sustainable energy - Theoretical orientations to reforming the energy sector. Renewable and Sustainable Energy Reviews, 19, 309-327. https://doi.org/10.1016/j.rser.2012.11.025.

PIKETTY. T. (2014). Capital in the twenty-first century. Editorial: Fondo de Cultura Económica. ISBN: 9789877190625.

PIKETTY, T.; GOLDHAMMER, A. (2020). Capital and ideology. The Belknap Press of Harvard University Press. Harvard University.

PIKETTY, T.; RENDALL, S. (2022). A brief history of equality. The Belknap Press of Harvard University Press. https://doi.org/10.4159/9780674275898

PRICE, C. E.; FELDMEYER, B. (2012). The Environmental Impact of Immigration: An Analysis of the Effects of Immigrant Concentration on Air Pollution Levels on JSTOR. (Available at: https://www.jstor.org/stable/41409609.

PRYOR, F. L.; MAURER, S. B. (1982). On induced economic change in precapitalist societies. Journal of Development Economics, 10(3), 325-353. https://doi.org/10.1016/0304-3878(82)90034-7.

RASMUSSEN, L. V.; COOLSAET, B.; MARTIN, A.; MERTZ, O.; PASCUAL, U.; CORBERA, E.; DAWSON, N.; FISHER, J. A.; FRANKS, P.; RYAN, C. M. (2018). Social-ecological outcomes of agricultural intensification. Nature Sustainability 2018 1:6, 1(6), 275-282. https://doi.org/10.1038/s41893-018-0070-8

REES, B. M.; RICHARDS, C.; ROJAS, C. R. (2023). The Era of Global Risk. In The Era of Global Risk. Open Book Publishers. https://doi.org/10.11647/obp.0336

RÊGO, A. B.; DE GODOI, E. L. (2022). The behavior of the price of brazilian rural land under the light of land rental theories. Revista de Gestão Social e Ambiental, 16(3). https://doi.org/10.24857/rgsa.v16n3-002

ROSEGRANT, M. W.; CLINE, S. A. (2003). Global Food Security: Challenges and Policies. Science (Vol. 302, Issue 5652, 1917-1919 pp) https://doi.org/10.1126/science.1092958.

SALAS-ROJO, P.; RODRÍGUEZ, J. G. (2022). Inheritances and wealth inequality: a machine learning approach. Journal of Economic Inequality, 20(1), 27-51. https://doi.org/10.1007/S10888-022-09528-8/METRICS.

SAMOILENKO, I.; DONG, C.; DOVGAY, B. (2019). Information warfare model with migration. In LV HKLVSASNAPZESSTGPAIIWHDPALD. Bodyanskiy Y. Wolff C. (Ed.), CEUR Workshop Proceedings (Vol. 2353, 428-439 pp). (Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85065484560&partnerID=40&md5=45b656a2a60807fad020af4d62f8efc0.

SAMPAIO, R.; MANCINI, M. C. (2007). Systematic review studies: A guide for careful synthesis of the scientific evidence Article in Revista Brasileira de Fisioterapia Effects of the use of baby walker in the acquisition of independente gait in toddlers with normal development View project Task-oriented training program associated with functional electrical stimulation on the mobility of children with unilateral cerebral palsy. View project. Available at: https://www.researchgate.net/publication/262736363).

SANTRA, P.; MAHAPATRA, G. S. (2020). Discrete prey–predator model with square root functional response under imprecise biological parameters. In:

BHATTACHARYYA, G.K.; KUMAR, J. (Ed.). Springer Proceedings in Mathematics and Statistics (Vol. 320. 211-225). https://doi.org/10.1007/978-981-15-3615-1_14.

SAREEN, S.; HAARSTAD, H. (2018). Bridging socio-technical and justice aspects of sustainable energy transitions. Applied Energy, v. 228. 624-632 pp.

SARWARDI, S.; HAQUE, M.; VENTURINO, E. (2011). A Leslie-Gower Holling-type II ecoepidemic model. Journal of Applied Mathematics and Computing, 35(1-2), 263-280. https://doi.org/10.1007/s12190-009-0355-1

SCHILL, C.; ANDERIES, J. M.; LINDAHL, T.; FOLKE, C.; POLASKY, S.; CÁRDENAS, J. C. ; CRÉPIN, A. S.; JANSSEN, M. A.; NORBERG, J. ; SCHLÜTER, M. (2019). A more dynamic understanding of human behaviour for the Anthropocene. Nature Sustainability (Vol. 2, Issue 12. 1075-1082 pp). https://doi.org/10.1038/s41893-019-0419-7

SCHRÖDER, C.; BURKHARDT, C.; ANTRANIKIAN, G. (2020). What we learn from extremophiles. ChemTexts, 6(1), 8. https://doi.org/10.1007/s40828-020-0103-6

SCHUMPETER, J. A. (1911) 1934. The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Busi-ness Cycle. Cambridge: Harvard University Press.

SEN, A. (1981). Ingredients of famine analysis: Availability and entitlements. Quarterly Journal of Economics, 96(3), 433-464. https://doi.org/10.2307/1882681

SOBY, S. (2017). Thomas Malthus, Ester Boserup, and Agricultural Development Models in the Age of Limits. Journal of Agricultural and Environmental Ethics, 30(1), 87-98. https://doi.org/10.1007/s10806-017-9655-x

SØGAARD JØRGENSEN, P. FOLKE, C.; HENRIKSSON, P. J. G. ;MALMROS, K.;TROELL, M.; ZORZET, A. (2020). Coevolutionary Governance of Antibiotic and Pesticide Resistance. Trends in Ecology & Evolution, 35(6), 484-494. https://doi.org/10.1016/J.TREE.2020.01.011.

SOLOW, R. M. (1956). A Contribution to the Theory of Economic Growth. The Quarterly Journal of Economics, 70(1), 65-94. https://doi.org/10.2307/1884513

SPANGENBERG, J. H.; OMANN, I.; HINTERBERGER, F. (2002). Sustainable growth criteria minimum benchmarks and scenarios for employment and the environment. Ecological Economics, 42(3), 429-443. https://doi.org/10.1016/S0921-8009(02)00125-8.

SULLIVAN, D.; HICKEL, J. (2023). Capitalism and extreme poverty: A global analysis of real wages, human height, and mortality since the long 16th century. World Development, 161, 106026. https://doi.org/10.1016/J.WORLDDEV.2022.106026

TOMÉ T.; DE OLIVEIRA, M.J. (2023). Stochastic Dynamics and Irreversibility | SpringerLink. (Available at: https://link.springer.com/book/10.1007/978-3-319-11770-6) [accessed 30.]

TOMIYAMA, J. M.;TAKAGI, D.; KANTAR, M. B. (2020). The effect of acute and chronic food shortage on human population equilibrium in a subsistence setting. Agriculture and Food Security, 9(1). https://doi.org/10.1186/s40066-020-00261-x

TURCHIN, P.; WHITEHOUSE, H.; GAVRILETS, S.; HOYER, D.; FRANÇOIS, P.; BENNETT, J. S.; FEENEY, K. C.;PEREGRINE, P.; FEINMAN, G.; KOROTAYEV, A.; KRADIN, N.; LEVINE, J.; REDDISH, J.; CIONI, E.; WACZIARG, R.; MENDEL-GLEASON, G.; BENAM, M. (2022). Disentangling the evolutionary drivers of social complexity: A comprehensive test of hypotheses. Science Advances, 8(25). https://doi.org/10.1126/sciadv.abn3517

TURNER, B. L.; FISCHER-KOWALSKI, M. (2010). Ester Boserup: An interdisciplinary visionary relevant for sustainability. Proceedings of the National Academy of Sciences of the United States of America, 107(51), 21963-21965. https://doi.org/10.1073/pnas.1013972108.

TURNER II, B. L.; SHAJAAT ALI, A. M. (1996). Induced intensification: Agricultural change in Bangladesh with implications for Malthus and Boserup. Proceedings of the National Academy of Sciences of the United States of America, 93(25), 14984-14991. https://doi.org/10.1073/pnas.93.25.14984.

UMAN, L. S. (2011). Information management for the busy practitioner Systematic Reviews and Meta-Analyses Information Management for the Busy Practitioner. J Can Acad Child Adolesc Psychiatry (Vol. 20, Issue 1). (Available at: www.cochrane.org) [accessed 10.10.23].

EC. European Commission, (2012). Innovating for Sustainable Growth: A Bioeconomy for Europe. (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

VIVIEN, F. D. (2003). Landmarks for an history of the idea of sustainable development [Jalons pour une histoire de la notion de développement durable]. Mondes en Developpement, 31(1), 1-22. https://doi.org/10.3917/med.121.0001.

VIVIEN, F. D.; NIEDDU, M.; BEFORT, N.; DEFREB, M.; GIAMPIETRO, M. (2019). The Hijacking of the Bioeconomy. Ecological Economics, v. 159 189-197 pp.

VOLLSET, S.E.; GOREN, E.; YUAN C.W.; CAO, J; SMITH, A.E; HSIAO, T.; BISIGNANO, C; AZHAR, G.S.; CASTRO, E.; CHALEK, J.; DOLGERT, A.J.; FRANK, T.; FUKUTAKI, K.; HAY, S.I.; LOZANO, R.; MOKDAD, A.; NANDAJUMAR, V.; PIERCE, M.; PLETCHER, M.; ROBALIK, T.; STEUBEN, K.M.; WUNROW, H.Y.; ZLAVOG, B.S.; MURRAY, C.J.L.; (2020). Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100 a forecasting análisis for the Global Burden of Disease Study. The Lancet, 396, 10258.

VOLTERRA, V. (1926). Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. Mem. Accad. Lincei Roma 2:0, 31-113.

WALSHE, N. (2010). "Enough for everyone forever?": Considering sustainability of resource consumption with year 10 students. Teaching Geography, 35(2), 58-61. https://www.scopus.com/inward/record.uri?eid=2-s2.0-77952702013&partnerID=40&md5=abeaf65733587d7df274fdaa06934e25

WEYLAND, J. (2006). On encouragements to population increase. Population and Development Review, 32(1), 163-168. https://doi.org/10.1111/j.1728-4457.2006.00110.x

WIJERATHNA-YAPA, A.; PATHIRANA, R. (2022). Sustainable Agro-Food Systems for Addressing Climate Change and Food Security. In Agriculture (Switzerland) (Vol. 12, Issue 10). MDPI. https://doi.org/10.3390/agriculture12101554

WILSON, K. M.; MCCOOL, W. C.; BREWER, S. C.; ZAMORA-WILSON, N.; SCHRYVER, P. J.; LAMSON, R. L. F.; HUGGARD, A. M.; BRENNER COLTRAIN, J.; CONTRERAS, D. A.; CODDING, B. F. (2022). Climate and demography drive 7000 years of dietary change in the Central Andes. Scientific Reports 2022 12:1, 12(1), 1–16. https://doi.org/10.1038/s41598-022-05774-y

WOOD, J. W. (1998). A theory of preindustrial population dynamics: Demography, economy, and well-being in Malthusian systems. Current Anthropology, 39(1), 99-135. https://doi.org/10.1086/204700.

WORLD ECONOMIC FORUM. (2023). Marsh & McLennan., & Zurich Insurance Group. (2023). The global risks report 2023.

ZHANG, D. D.; LEE, H. F.; WANG, C.; LI, B.; PEI, Q.; ZHANG, J.; AN, Y. (2011). The causality analysis of climate change and large-scale human crisis. Proceedings of the National Academy of Sciences of the United States of America, 108(42), 17296-17301. https://doi.org/10.1073/pnas.1104268108.

ZHAO, S.; HU, I.; LOU, J.; CHONG, M. K. C.; CAO, L.; HE, D.; ZEE, B. C. Y.; WANG, M. H. (2023). The mechanism shaping the logistic growth of mutation proportion in epidemics at population scale. Infectious Disease Modelling, 8(1), 107–121. https://doi.org/10.1016/J.IDM.2022.12.006.