REVIEW

Agricultural frontiers and environment: a systematic literature review and research agenda for Emerging Countries

Arthur Pereira Sales[1]

Abstract

Despite having the largest land and water reserves for agriculture on the planet, intensive agricultural production in emerging countries has stimulated research around the world, especially due to the numerous environmental impacts caused by the expansion of agricultural frontiers. Motivated to analyze the literature on the transformations brought about by the development of intensive agriculture since the middle of the twentieth century, this study analyzes the main studies on the interference of agricultural frontiers on the environment in emerging countries over the last 30 years (1993–2022). To do so, the Systematic Literature Review methodology was used, with the CIMO planning approach and the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) reporting guideline. The analysis initially included 14,366 scientific articles from a wide range of subjects in the social and natural sciences, available on the Web of Science (Clarivate Analytics), ScienceDirect (Elsevier), and Google Scholar databases. One of the most significant findings of this study is that there is no specific framework to analyze the relationship between the agricultural frontier and the environment in developing countries; however, literature has mainly been concerned with measuring the impact of intensive agriculture on natural resources, as well as verifying how local socio-economic factors and/or public policies affect populations' behavior regarding this relationship between the environment and agricultural production. The data also revealed that Brazil is the "country of origin" of the literature on agricultural frontiers and the environment, especially due to studies on the Amazon rainforest, followed somewhat distantly by studies on South America in general and the island regions of Indonesia and Malaysia. There is also a lack of studies on European economies in transition, emerging African countries and Russia, or on the agri-environmental impact of the demand for food in populous countries such as India and China. Finally, in addition to country-specific suggestions, this systematic literature review suggests directions and implications for future research.

Keywords Emerging countries · Literature review · Agricultural frontiers · Environment

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1 Introduction

The total weight of grains produced in the world adds up to over 3 billion tons, but one of the characteristics of global agricultural production is the concentration of a few products and countries. The three main commodities (corn, rice, and soybeans, respectively) account for two-thirds of all grains produced in the world, especially in emerging countries, in which China, the United States, Brazil, and India, for example, accumulate 54% of all global grains. In addition, with the largest land area in the world, Russia is a leading producer of wheat, barley, and sunflower, with 124 million hectares of the country's area under cultivation. Indonesia and Malaysia together produce around 95% of the world's palm oil, while Argentina, Bolivia, and Paraguay, as well as excelling in soybean production, are Latin America's leading beef exporters, alongside Brazil (FAO, 2021).

The main drivers of the expansion of agricultural frontiers in emerging countries are the current global demand for agricultural products, the flexibility of environmental regulations, foreign investments, the reduction of production costs, as well as poverty, energy, and food dependency, which consequently aggravate environmental problems (Gibbs et al., 2010; Feintrenie, 2014; Villela et al., 2014; Avagyan, 2018; Ibrahim et al., 2022; Jahanger et al., 2022; Makhdum et al., 2022; Usman & Balsalobre-Lorente, 2022; Usman et al., 2023).

Increasing rates of deforestation, polluting gas emissions, food waste, loss of animal biodiversity, and water pollution, among others, are some of the problems arising from unsustainable agricultural production in emerging countries (Avagyan, 2010, 2017 and 2021; Adegbeye et al., 2020). Another problem to be mentioned is the increasing use of fertilizers and pesticides (Avagyan, 2018). According to Schreinemachers and Tipraqsa (2012), there has been an increase in production and consumption in countries such as Brazil, Mexico, Uruguay, Cameroon, and Malaysia, due to the visible changes in the soil, while there is no concern about environmental issues and population's food security.

Such environmental problems could be addressed by using wood waste and agricultural residues to produce board, binderless board, and paper, or else by converting these organic residues to clean fuels and/or petrochemical substitutes via pyrolysis. Organic waste may be also converted chemically—by hydrolysis—into different types of sugar, which may be fermented to generate bioethanol. Moreover, such residues may be used for composting (Fahmy, 1982; Fahmy et al., 1982; Mobarak et al., 1982; Mobarak, Fahmy, & Schweers, 1982a, 1982b; El-Shinnawy et al., 1983; Mobarak, 1983; Fahmy & Mobarak, 2013; Fahmy et al., 2017 and 2020). Another way to attempt to minimize environmental problems, as well as the storage and production of clean energy through simple and economically sustainable methods, is to adopt the use of new technologies, such as nanotechnology (Zinatloo-Ajabshir & Salavati-Niasari, 2019; Zinatloo-Ajabshir et al., 2019, 2020 and 2022; Etemadi et al., 2021; Tabatabaeinejad et al., 2021; Zinatloo-Ajabshir & Mousavi-Kamazani, 2021; Heidari-Asil et al., 2022; Zonarsaghar et al., 2022).

For this study, the agricultural frontier is defined as an expression indicating the advance of intensive agricultural production over the environment; however, as the term "environment" itself is subjective, analyzing and measuring the impact of intensive agricultural production in locations as diverse as emerging countries can have many aspects and connections. Thus, the following questions arise: how can we synthesize the studies that link agricultural frontiers and the environment in emerging countries? Do the studies show that there is an equal interest in this topic among emerging countries? What would be the main indications and suggestions for future work?

To answer these questions, this article aims to identify and analyze the main research on the interference of agricultural frontiers in the environment in emerging countries, through a critical discussion of the theories used to follow the transformations that have occurred in the last thirty years (1993–2022). The choice of the period of analysis, as well as the justification for this work, was due to the curiosity and importance of analyzing the literature that involves the environmental impacts promoted by the development of intensive agriculture in the mid-twentieth century while presenting a recent discussion on sustainable agriculture in emerging countries and serving as a basis for future work. Moreover, as the "Agricultural Frontier" is a theme that is intrinsic not only to environmental problems, but also to psychological, social, and cultural aspects, it lacks a better-qualified debate. Thus, the choice to use the Systematic Literature Review is because it is an adequate method to evaluate and synthesize the best evidence on a given subject, and, in this particular study, it will work as a gap to fill the lack of an in-depth discussion on studies dealing with the environmental impacts of agricultural frontiers in emerging countries, since, to date, there is no systematic literature review which addresses such discussion.

2 Methodology

2.1 Systematic literature review method

According to James et al. (2021), a systematic review does a thorough search of the literature, evaluates the data found, and synthesizes the best evidence on a specific research question, to provide accurate and evidence-based information from the study. Therefore, to analyze the studies that encompass the theme of agricultural frontiers and the environment in emerging countries, this study used the Systematic Literature Review (SLR) methodology.

Initially, to plan this SLR, the CIMO approach (Denyer & Tranfield, 2009) was used as a search for scope and understanding of context "C," intervention "I," mechanisms "M," and "O" outputs that surround the search, that is, this phase includes planning the research questions and defining the scope of the study. After understanding the planning process, it is necessary to adopt a protocol to be used in the selection of articles. This study adopted the Preferred Reporting Items for Systematic review and Meta-Analysis Protocols (PRISMA-P), which consists of organizing and analyzing the results of previous studies, and identifying the main questions and problems addressed in the research (Moher et al., 2015).

Thus, this SLR consists of 7 procedures[1]: 1: search for possible articles following selected search queries based on expert recommendations; 2: search for potential papers by other sources; 3: implementation of inclusion and exclusion criteria; 4: analysis of duplicate papers; 5: selection of papers for first reading (title, keywords, and abstract); 6: selection of papers for full reading; 7: analysis of the synthesis.

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[1] Procedures 1 to 3 are part of the planning stage and, from procedure 4 onwards, the procedures are part of the PRISMA protocol.

2.2 Source of analysis and data

The Systematic Literature Review was conducted from 01/August/2022 to 30/November/2022 with articles published in the last 30 years (1993–2022). Data analysis was carried out as follows: Initially, 14,366 scientific articles from the most diverse disciplines of the social and natural sciences were observed through search queries on the environment and agricultural frontiers made available in electronic databases of the Web of Science (Clarivate Analytics), ScienceDirect (Elsevier) and Google Scholar platforms. The key terms used in the database search were: "agriculture*[2] or livestock or farming and frontier AND environment*."

Then, articles that, even if not on the three main research platforms cited, are relevant to the subject, including articles of recommendations or already known, were verified. From there on, the inclusion and exclusion criteria were implemented, in which only scientific articles written in English, published between 1993 and 2022, with a citation number[3] of > 50 or with an average of 10 citations per year, and which had emerging countries as the area of study were analyzed. The key terms for the emergent countries analysis were more specific, namely: "Emerging countries OR Developing countries OR Latin America OR Transitional economies OR BRIC* OR Brazil OR China OR India OR Russia OR Malaysia OR Indonesia OR Argentina OR Mexico OR Turkey OR Poland OR Hungary OR Croatia OR South Africa OR Morocco OR Egypt."

Following the inclusion and exclusion criteria, as well as the search queries, 138 articles were analyzed for possible duplicates using a reference management software—EndNote. From then on, the analyses were more carefully refined, in which 108 articles were selected for an initial reading of the title, keywords, and abstract, and, after a cutout of 42 papers, 66 articles were fully read. Finally, after reading them entirely, only 6 articles were excluded and 60 were ready for the literature review. The entire process is illustrated in Fig. 1.

3 Geographical distribution and main topics

In total, 15 countries/regions are addressed in the selected articles about the relationship between the agricultural frontier and the environment, being Brazil is the most explored country, corresponding to more than 33% of the sample. In the second position are the articles whose area of study is South America in general (6 articles), followed closely by the island region of Indonesia/Malaysia with 5 articles, and Mexico, Indonesia (alone), and China with 4 articles each. Papers addressing Emerging Countries, in general, were only 2. The geographical distribution of the selected papers is illustrated in Table 1.

In line with the methodology adopted in the articles, it was observed that the influence of agricultural frontiers can address several factors and be assessed in different ways, therefore, regarding the characteristics of the methodological process, most of the studies were empirical (46), while only 14 had a theoretical approach. The empirical articles used different research models and methods, including satellite mapping analysis (15 articles), linear regression models (10 articles), simulation models (8 articles), logit models (6),

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[2] Asterisks next to keywords indicate that the exact spelling of the word was included in the search, e.g., agriculture, agricultural; environment, environmental; BRIC, BRICS.

[3] The citation number was not an exclusion criterion for inclusion when additional articles (other sources) were selected in Step 2.
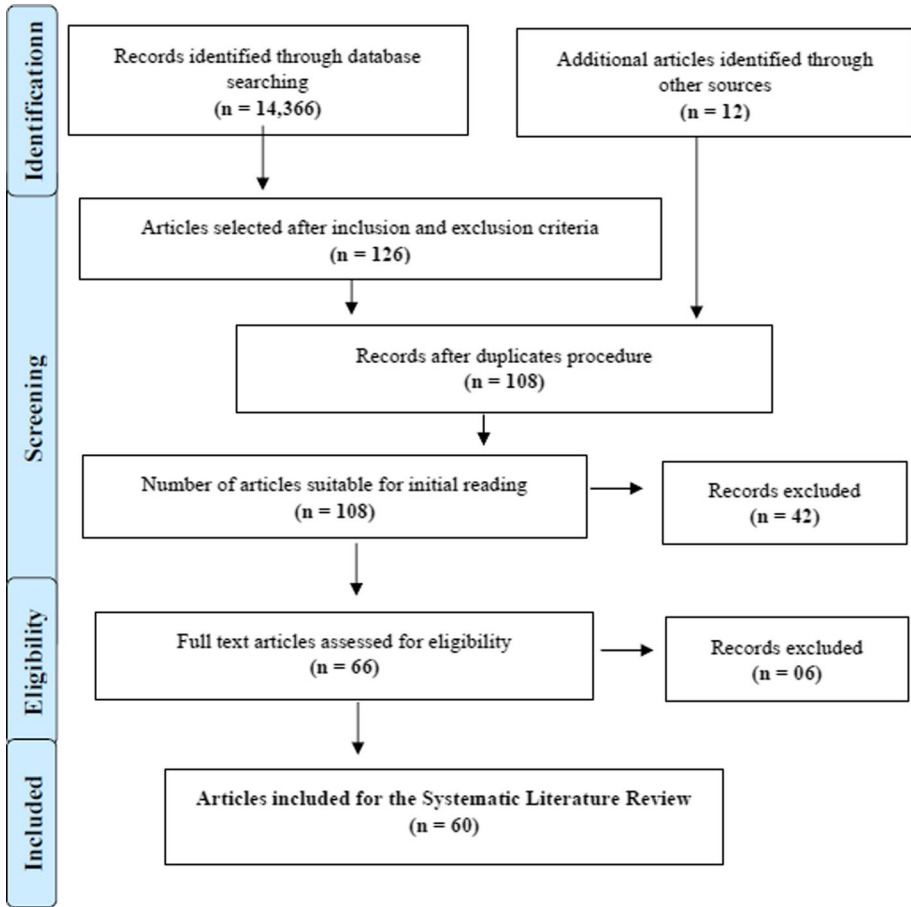
Fig. 1 Results of the scoping search—PRISMA flow diagram. *Source:* own elaboration

analysis of variance (3), probabilistic models (2 articles), case studies and mathematical model (with 1 article each). On the other hand, theoretical articles focused on discussing the topic at hand through the descriptive method (14 articles).
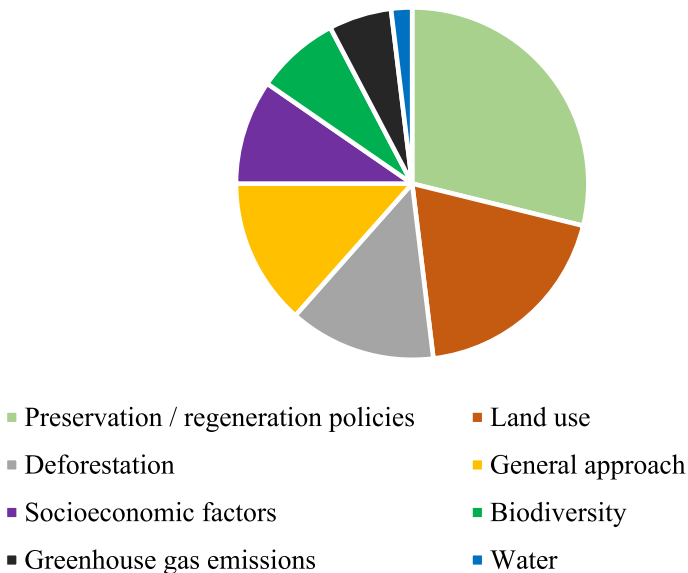
Although the articles had specific objectives, their main focus was to analyze the interference of agricultural production on nature, assessing this impact on the various environmental factors or analyzing the public policies and socio-economic aspects involved in the process. As illustrated in Fig. 2, most authors were concerned with studying public policies for preservation or regeneration in agricultural frontiers (15 articles). The environmental impact on land use was the second most studied topic (10), followed closely by articles that had deforestation as their focus (7 articles). The interference of socio-economic factors in the relationship between the environment and agricultural frontiers or vice versa was studied in 5 articles, followed by studies that addressed the environmental impact on animal biodiversity (4 articles), on the measurement of greenhouse gas emissions (3), while only 1 article analyzed this environmental impact on water.

In addition, as "environment" is a subjective and broad concept, some articles (15 in total) did not have only one specific point, i.e., they addressed two or more themes in the

Table 1 Distribution of articles studied by Country/Region

Country/Region	Number of papers	Percentage in total papers (%)
Brazil	20	33.34
South America	6	10
Indonesia/Malaysia	5	8.35
Indonesia	4	6.66
Mexico	4	6.66
China	4	6.66
Argentina	3	5
India	3	5
Bolivia	2	3.33
Emerging countries	2	3.33
Latin America	2	3.33
Russia/Ukraine	2	3.33
South Africa	1	1.67
Euro-Asia	1	1.67
India/China	1	1.67
Total	60	100

Source: own elaboration

- Preservation / regeneration policies
- Land use
- Deforestation
- General approach
- Socioeconomic factors
- Biodiversity
- Greenhouse gas emissions
- Water

Fig. 2 Key topics for environmental impacts on agricultural frontiers. *Source:* own elaboration

analysis. Some articles jointly analyzed the interference of agricultural frontiers on land and water use (1 article), greenhouse gas emissions and land use (1), interference of socio-economic factors and water use (1 article), deforestation and animal biodiversity (1), deforestation and socio-economic factors (1), as well as deforestation and preservation or

regeneration policies (3 articles). When the article had more than two themes as its main focus, it was defined as a general approach paper, and 7 papers as such were studied.

4 Results and discussion

The analysis of studies on agricultural frontiers in emerging countries brings a broad context, especially due to the distinct characteristics between these countries. Whether it is the number of inhabitants, the landform, the climate, or the politics, studying emerging countries means dealing with a diverse range of aspects and issues. Thus, Sect. 4.1 presents an overview of the main research conducted in emerging countries, emphasizing what the authors are concerned with studying in each country.

4.1 Key Studies in Emerging Countries

Considered the source of biodiversity in the world, the data reveal that Brazil is the home country of studies on the environmental impacts promoted by intensive production, especially because of the Amazon Rainforest (Nepstad et al., 2001, 2006 and 2008; Mertens et al., 2002; Soares-Filho et al., 2002 and 2004; Rodrigues et al., 2009; Pacheco, 2009; Macedo et al., 2012; Schiesari et al., 2013; Verburg et al., 2014; Ochoa-Quintero et al., 2015; Nobre et al., 2016). The paradigms addressed by studies on the Brazilian Amazon are vast and range from loss of animal biodiversity, measurement of deforestation, and land use to analysis of forest preservation policies.

Nepstad et al. (2001) and Soares-Filho et al. (2004) studied the impacts of road paving on deforestation. Rodrigues et al. (2009) analyzed how human development levels interfere with deforestation in the region. In turn, Mertens et al. (2002) measured the deforestation of the Amazon due to cattle ranching, and Ochoa-Quintero et al. (2015) the loss of native species caused by environmental degradation. Regarding the implementation or effectiveness of public policies, Nepstad et al. (2006), for example, compared inhabited and uninhabited reserves in the process of slowing the conversion of land to agriculture. Pacheco (2009) studied the impact of land reform and agrarian structures on deforestation in the region. Nepstad et al. (2008) analyzed synergistic trends in Amazonian economies, forests, and climate. Verburg et al. (2014), in turn, tried to reconcile conservation policies with commodity prices. Nobre et al. (2016) proposed a new sustainable development paradigm for land use and climate change.

In addition to the Amazon Rainforest, studies—fewer in number—have addressed other Brazilian biomes of global importance, such as the Cerrado and the Atlantic Forest, or else have studied the country in general. Studies on the Cerrado Biome have focused on land use and water reuse (Spera et al., 2016), the expansion of soybean production and its impacts (Rausch et al., 2019), as well as trying to optimize the agricultural profit with freshwater quality and biodiversity (Kennedy et al., 2016). In turn, Umetsu and Pardini (2007) studied changes in small mammal habitats due to human interference in the Atlantic Forest. Regarding studies with a more general focus, Barretto et al. (2013) analyzed agricultural intensification and land use patterns in Brazil. Picoli et al. (2018) mapped the expansion of crops and land changes due to pasture intensification in the country's agricultural frontiers, and Da Silva Junior et al. (2020) checked persistent fires in Brazilian biomes and to what extent this would or not follow the 2015 Paris Agreement.

However, the literature on agricultural frontiers and the environment does not only "live" in Brazil. The data revealed that Indonesia and Malaysia are also prominent in this topic, as they face major agricultural expansion due to palm oil production (Koh & Wilcove, 2008; McCarthy & Cramb, 2009; Koh et al., 2011; Wicke et al., 2011; Carlson et al., 2012, 2013 and 2018; Miettinen et al., 2012; Busch et al., 2015). In addition, articles that address Emerging Countries together feature discussions on the environmental impact of commodity production and exports (Henders et al., 2015) and smallholder farmers' decisions on deforestation in forest areas (Babigumira et al., 2014). In turn, studies that focus on the South American region address the intensification of agricultural products in the Chaco, formed by the territories of Paraguay, Bolivia, Argentina, and Brazil (Baumann et al., 2017; Fehlenberg et al., 2017; Le Polain de Waroux et al., 2018), and in research on the Río de la Plata, which covers an area that passes through Brazil, Argentina, Bolivia, Paraguay and Uruguay (Baeza & Paruelo, 2020).

With China as a study area, some authors have been concerned with analyzing land use variations in the country (Chen et al., 2014; Lin & Ho, 2003), as well as measuring the efficiency of agricultural production (Deng & Gibson, 2019) and water use (Wang et al., 2019). In turn, articles about Mexico were more "duelistic" and addressed trade-offs between ecological reserves versus archeological-ecotourist zones (Turner Ii et al., 2001), economic benefit for irrigation versus negative effects on groundwater (Raquel et al., 2007), and between community-based forest management versus protected areas (Ellis & Porter-Bolland, 2008).

Articles from Argentina have predominantly studied the Argentinean Chaco, focusing on the expansion of agriculture and its impacts on deforestation (Gasparri & Grau, 2009) and animal biodiversity (Mastrangelo & Gavin, 2012), as well as the controlling factors of this expansion (Volante et al., 2016). On the other hand, studies on India have addressed the environmental consequences of agriculture during the Green Revolution (Singh, 2000), the environmental impacts produced by human interference in watersheds (Rao & Pant, 2001), the presence of big cats in agricultural areas (Athreya et al., 2013).

To date, studies have shown that agricultural frontiers, through intensive production, impact the environment in emerging countries. However, the extent of these impacts may vary according to the natural resources affected, as well as country-specific factors, namely: public policies, regulations, and incentives, among others. To provide more recent results and serve as a basis for the discussion in the next section of this study, Table 2 presents the literature on agricultural frontier and environment in emerging countries published in the last ten years (2013 to 2022).

4.2 The connections between agricultural frontiers and the environment

The literature has focused on analyzing the impact of intensive agriculture on the still available natural resources, as well as the processes that can help preserve and regenerate the environment. Therefore, the interaction between agricultural frontiers and the environment in Emerging Countries will be analyzed from here on out in two ways: The Extended Industrial Agriculture Focus, in which the literature focuses on the measurement, analysis, and interpretation of the impacts that natural resources (water, soil, air, fauna, flora, etc.) suffer due to the advance of agricultural production; and the Socio-Economic-Ecological Focus, when the studies are concerned about verifying/measuring how local socio-economic factors and/or public policies affect the behavior of the population in this relationship between the environment and the agricultural frontiers.

Table 2 Reputable articles on agricultural frontiers and the environment from the last 10 years (2013–2022)

Reference	Study area	Approach/Issue	Contribution
Nobre et al. (2016)	Brazil	Preservation or regeneration policies	The Amazon Rainforest allows the production of high-value products, services, and platforms via digital, biological, and advanced materials technologies. For that reason, it is identified as a global audience of biological assets
Carlson et al. (2013)	Indonesia	Greenhouse gas emissions	Intensive palm oil production between 2000 and 2010 promoted the deforestation of 47% of intact forests in the country. Projections show that if this path was followed, the expansion of plantations in Kalimantan alone would contribute to about 20% of Indonesia's CO_2 emissions in 2020
Chen et al. (2014)	China	Land use	There are two "lessons" from China's rural development policies: land zoning and other ecological protection policies should restrict border deforestation, and non-migrants should be encouraged to adjust their farms during the emigration process in rural areas and have their interests also protected by the government
Spera et al. (2016)	Brazil	Land use/Water	The amount of water recycled into the atmosphere via evapotranspiration (ET) decreased each year from 2003 to 2013, due to the increase in the agricultural area from 1.2 to 2.5 million hectares, with 74% of this newly cultivated land coming from native Cerrado vegetation
Athreya et al. (2013)	India	Biodiversity	While a huge variety of wild carnivores inhabit agricultural land dominated by humans, other wild animals, and wild herbivore prey are lacking, which indicates human interference in native areas via agriculture
Henders et al. (2015)	Emerging countries	Greenhouse gas emissions/Land use	Soybean and beef exports from Latin America to China, Europe, North Africa, and the Middle East accounted for the main embodied flows of land use change in emerging countries between 2000 and 2011, while exports of palm oil and wood products from Indonesia and Thailand to Europe and Asia (mainly China and India) accounted for the main embodied flows of carbon emissions
Carlson et al. (2018)	Indonesia	Preservation or regeneration policies	Palm oil plantations certified by the Roundtable on Sustainable Palm Oil (RSPO) have reduced deforestation by 33% in the country. However, most plantations contained little residual forest when certified, which does not demonstrate the effectiveness of certification
Graesser et al. (2015)	Latin America	Land use	Between 2001 and 2013, across Latin America, forests were replaced by 17% of new farmland and 57% of new grassland

Table 2 (continued)

Reference	Study area	Approach/Issue	Contribution
Barretto et al. (2013)	Brazil	Land use	Unlike agricultural frontier areas, where the intensification of land use coincided with the expansion of agricultural land, agriculturally consolidated areas' intensification of land use coincided with the contraction of cultivated and pasture areas
Baumann et al. (2017)	South America	Greenhouse gas emissions	Crops or pasture replaced 20% of all Chaco Forest between 1985 and 2013, resulting in significant carbon emissions, totaling 824 Tg C between 1985 and 2013 and 46.2 Tg C in 2013 alone
Busch et al. (2015)	Indonesia	Preservation or regeneration policies	Concessions for oil palm plantations and logging activities in newly licensed areas have increased deforestation rates in the country. This could have been avoided with the carbon pricing policy or by expanding the moratorium beyond new concessions, i.e., also covering existing concessions and areas outside concessions and protected areas
Fehlenberg et al. (2017)	South America	Deforestation	Livestock was highly associated with deforestation in Argentina, Bolivia, and Paraguay. Nevertheless, soy cultivation in Argentina—which was a direct driver of deforestation only in the Argentine Chaco—may be indirectly linked to deforestation in the Bolivian and Paraguayan Chaco
Meyfroidt et al. (2016)	Russia and Ukraine	Preservation or regeneration policies	After 2000, Less cropland abandonment and more re-cultivation happened in areas with a growing rural population and a younger workforce. From the 47.3 million hectares (Mha) of cultivated land abandoned in 2009, just 8.5 Mha are potentially available agricultural land with low environmental cost and socio-economic constraints
Gasparri and De Waroux (2015)	South America	Preservation or regeneration policies	The existence of coupled agricultural frontiers creates the need for more actor-centered approaches to conservation policy and research, which need to be based on realistic models that consider the increasing coupling between productive sectors and geographic locations
Deng and Gibson (2019)	China	Socio-economic factors	Land productivity is concentrated in cities far from the economic or provincial center, but eco-efficiency is higher in areas of developed cities. Therefore, punctual management of trade-offs between agricultural production and urbanization must bring about sustainable agricultural production

Table 2 (continued)

Reference	Study area	Approach/Issue	Contribution
Ochoa-Quintero et al. (2015)	Brazil	Deforestation/Biodiversity	Fewer species of mammals and birds are found in landscapes with less than 30 to 40% of forest cover. Predictions for 2030 indicated that because of deforestation, only 22% of landscapes would likely be able to support at least 75% of these species
Kennedy et al. (2016)	Brazil	Land use	When biodiversity and ecosystem services are the focus of land use, better results occur. The Cerrado can also generate greater agricultural income, as well as offer considerable improvements in biodiversity and water quality compared to current land use
Le Polain de Waroux et al. (2018)	South America	Socio-economic factors	Revenue created by new agricultural technologies, infrastructure, and rising producer prices caused frontier expansion in the Chaco. However, the dynamics of these frontiers are shaped by the existence of abnormal economic rents and the presence of a limited number of actors able to influence the whole process
Jewitt et al. (2015)	South Africa	General approach	Agriculture, timber plantations, the built environment, dams, and mines were the main causes for the loss of 7.6% of KwaZulu-Natal's natural habitat from 2005 to 2011. The anthropogenically transformed land covers (including secondary vegetation) also bring negative impacts on the remaining biodiversity in these areas or nearby
Volante et al. (2016)	Argentina	Preservation or regeneration policies	The "Native Forest Law" was created to control the deforestation process; however, it was not enough to restrict deforestation, and the area transformed in the region
Wang et al. (2019)	China	Socio-economic factors / Water	The per capita income of rural households and the higher proportion of secondary or higher education resulted in the efficient use of water in agriculture in China between 2000 and 2017
Baeza and Paruelo (2020)	South America	Land use	There is a strong process of land use change in the Campos do Rio da Prata, mainly due to the advance of the agricultural frontier (an increase of 23% between 2000 and 2014) and the loss of field areas, on both sides of Uruguay River and the western portion of the Pampa Interior

Table 2 (continued)

Reference	Study area	Approach/Issue	Contribution
Babigumira et al. (2014)	Emerging countries	Socio-economic factors/Deforestation	When compared with households with medium to high assets and greater market orientation, poorer and isolated families were less likely to clear forests in Emerging Countries
Picoli et al. (2018)	Brazil	Land use	The dual production system can be an alternative to save land use for agriculture
Schiesari et al. (2013)	Brazil	Preservation or regeneration policies	There has been an increase in the use of pesticides by small farmers with little education and no technical support. On the other hand, large producers, who have greater levels of technical knowledge and resources, follow technical recommendations more and even voluntarily replace the most dangerous compounds
Nolte et al. (2017)	South America	Preservation or regeneration policies	Encouraging public and private actors to adopt effective policies to combat deforestation in The Cerrado, Chaco, and Chiquitano is probably more challenging than it has been in the Brazilian Amazon
Verburg et al. (2014)	Brazil	Preservation or regeneration policies	A reduction of the average policy target of the Forest Code (FC) from 80 to 60% leads to additional deforestation of 41 to 57%, depending on the commodity price scenario, which shows the importance of conservation policies
Horion et al. (2016)	Eurasia	General approach	Rainfall use efficiency has decreased due to the fall of the Soviet Union and the abandonment of agricultural land, as well as anthropogenic impacts (grazing intensity, increased salinization, and changes in irrigation practices)
Rausch et al. (2019)	Brazil	General approach	Soy expansion accounted for 22% of the conversion of the Cerrado biome between 2003 and 2014, even though this sector has incentives to shift production to already deforested land
Da Silva Junior et al. (2020)	Brazil	Preservation or regeneration policies	Brazil must control deforestation caused by the expansion of the agricultural frontier in the Amazon and Cerrado biomes through government policies, the private sector, and society in general. If not, the sum of emissions from fires in the six Brazilian biomes will exceed 5.7 Gt CO_2, compromising national GHG reduction targets

Source: own elaboration

4.2.1 Extended industrial agriculture focus

Many studies showed that there are strong environmental impacts due to the intensification of agricultural frontiers in Emerging Countries, in which the Extended Industrial Agriculture Focus was present in the most varied natural resources: land, fauna, flora, air, and water. To reach this conclusion, the authors used research methods such as Argumentative/Narrative text, Satellite-based maps, and Linear, Probabilistic, and Simulation Models.

The subjectivity and breadth of the term "environment," already discussed, causes some researchers to address more than one natural resource in the same study. In this context, the data revealed that the articles that analyze two natural resources mainly address the environmental impact promoted by agricultural production on land use or flora (deforestation) in addition to a second resource. Studying the impact of agricultural frontiers on Flora and Biodiversity in the Brazilian Amazon, for instance, Ochoa-Quintero et al. (2015) concluded that due to deforestation, environments with 30 to 40% forest cover harbored lower numbers of mammals and birds. Furthermore, predictions for 2030 indicated that under the same devastation scenario, only 22% of Amazonian landscapes would be able to harbor at least 75% of these species.

In a study of the impact of agricultural production on land use and greenhouse gas emissions in Emerging Countries, Henders et al. (2015) found that alterations in land use and carbon fluxes from 2000 to 2011 were mainly due to exports of beef, palm oil, and soybean. Furthermore, in an analysis of land and water use in agricultural production in the Brazilian Cerrado, Spera et al. (2016) found that the increase in the agricultural area from 2003 to 2013 caused a decrease in the amount of water recycled into the atmosphere.

In turn, articles that analyze two or more natural resources (defined here as the "general approach") provide a broader picture of the impacts caused in a given region. In a study on India, for example, Rao and Pant (2001) concluded that agricultural and extractive activities, together with population growth, caused the decline of vegetation cover in the central Himalayan region between 1963 and 1996, which subsequently stimulated soil and water loss in the Sadiyagad watershed region.

In a study involving Malaysia and Indonesia, Koh et al. (2011) state that 6% of all tropical peatlands in the region were used for palm oil production, which consequently caused the emission of over 4.5 million Mg of carbon per year, and the loss of 140 million g of biomass carbon, in addition to destroying the biodiversity of the region. In the same vein, Carlson et al. (2012) state that the impact of intensive palm oil production caused a 4% reduction in forest cover from 1989 to 2008 in Indonesia alone, due to the deforestation of 40% of peat lands in the country, in addition to possibly leveraging deforestation, according to projections, on regional lands and community lands.

Articles that point out the impacts of agricultural frontiers on a variety of natural resources have also been seen in studies for Eurasia, Africa, and Brazil. Researching the regions from Western Ukraine to Eastern China and from Southern Russia to Turkmenistan, Horion et al. (2016) found that rainfall use efficiency decreased due to the fall of the Soviet Union in 1991 and the abandonment of agricultural land thereafter, but natural resources in the region were also impacted by anthropogenic effects such as grazing intensity, increased salinization, and changes in irrigation practices.

In a study for South Africa, Jewitt et al. (2015) found that the coastal province of KwaZulu-Natal had over 7% of its natural habitat devastated between 2005 and 2011

due to the intensification of agricultural production and the construction of mines and dams, which resulted in land use transformation and generated losses of endemic biodiversity. For Brazil, analyzing the expansion of soybean production in the Cerrado Biome, Rausch et al. (2019) stated that this was responsible for converting 22% of the biome from 2003 to 2014, with most of the deforestation occurring within legal limits. For them, one way to try to decrease degradation would be to encourage policies coming from the private sector that restrict deforestation carried out by soybean producers.

After presenting the studies that analyze the impact of agricultural frontiers on more than one natural resource with an Extended Industrial Agricultural Focus, this Systematic Literature Review brings the articles that focus on only one of the resources.

4.2.1.1 Land use Land use was the most studied topic among those covering the Extended Industrial Agricultural Focus in Emerging Countries. To quantify the impact between the agricultural frontier and land use in Brazil, Barretto et al. (2013), for instance, used the OLS model and found that the intensification of land use promoted a decrease in pastures and crops in the consolidated regions of agriculture, but this same intensification caused an increase in agricultural land in the agricultural frontiers, i.e., in areas where land management practices differ from those already established. In addition, in an analysis of the Río de la Plata[4] region, Baeza and Paruelo (2020) found that the increase in the agricultural area, mainly on the banks of the Uruguay River and in the western part of the Pampa Interior, also caused a decrease in pastures in the region. Still in this context, Graesser et al. (2015) emphasize, in their study for Latin America, the importance of distinguishing between pastures and crops when analyzing land use efficiency in agricultural production, since they are two distinct agricultural systems and bring different consequences to the soil.

With a more theoretical bias, Wicke et al. (2011) used data from Indonesia and Thailand from 1975 to 2005 and concluded that, despite the precariousness of the data, the studies showed that the impact of palm oil production on land use change was intense, which generated the loss of forest cover of 40 million hectares (Mha) of land in Indonesia and almost 5 Mha in Malaysia. In turn, in studies on China, Lin and Ho (2003), through data from the 1996 land survey, stated that there was a large loss of agricultural land in the country mainly due to the rapid process of urbanization, rural industrialization, and restructuring of the agricultural process; furthermore, combining Zelinsky's hypothesis of the mobility transition model and the theory of land use transition, Chen et al. (2014) stated that it is necessary to consider the process of rural out-migration when studying land use change in China.

Some authors have pointed out ways to try to minimize the environmental impact of agricultural production on land use. Picoli et al. (2018) concluded, in an analysis of the state of Mato Grosso—Brazil, that the increase in double cropping systems saved the amount of land used for agricultural production. Still focusing on Brazil, Kennedy et al. (2016) stated, through a probabilistic model, that optimal outcomes between land use for agriculture and the environment occur when land use meets environmental preservation and biodiversity regulations. In the same line of reasoning, in a study on Russia and Ukraine, Smith et al. (2007) stated that soil organic carbon loss due to climate change in these two countries is imminent, but this loss will be lower when environmental considerations are met and outweigh the others.

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[4] The Rio de la Plata forms a natural border between the South American countries of Uruguay and Argentina.

4.2.1.2 Flora The data showed that the flora of emerging countries is currently being devastated due to agricultural production, in which a large part of this deforestation is attributed to soy and livestock production. Fehlenberg et al. (2017) concluded that deforestation was directly driven by soybean cultivation in the Argentine Chaco, while cattle ranching increased deforestation rates in Argentina, Bolivia, and Paraguay. In a study of the Brazilian Amazon, Mertens et al. (2002) saw that cattle production evolved and promoted greater trade flows, thus increasing deforestation and fire outbreaks in the region. Furthermore, Müller et al. (2012) stated that in Bolivia, deforestation is largely driven by intensive agriculture, followed by cattle ranching and smaller-scale agriculture, in which fertile soil, favorable climate, and local and export markets are factors stimulating these impacts.

In a study for the Argentinean Chaco, Gasparri et al. (2009) stated that 1.4 million hectares of dry forest were cleared between 1972 and 2007 due to the global demand for soy during the 1980s and 1990s. On the other hand, in a study of the Brazilian Amazon, Macedo et al. (2012) believed that the relationship between deforestation and soybean production could be inversely proportional in topic forests once land and efficient land use policies are in place.

In addition to the intensive production of soy and cattle ranching, other factors are driving deforestation on the agricultural frontiers of emerging countries. According to Nepstad et al. (2001), investment in paving and building roads tends to increase deforestation rates in the Amazon Rainforest. Moving to microeconomic analysis, Pacheco (2006) concluded that deforestation in Bolivia intensified when the economic model of import substitution industrialization was changed to a more liberal model.

4.2.1.3 Fauna The loss or extinction of animal biodiversity due to advancing agricultural frontiers in emerging countries has also been addressed in the literature. Koh and Wilcove (2008) noted, for example, that oil palm cultivation through the conversion of primary and secondary forests caused a decrease in the number of birds and butterflies in Malaysia and Indonesia. Accordingly, in a study on the Argentinian Chaco, Mastrangelo and Gavin (2012) stated that in areas of cattle production, there are far fewer bird species compared to areas of intact forest.

Some studies have concluded that there have also been migratory processes of animals due to the advance of intensive agricultural production in emerging countries. In a survey of the Atlantic Forest of Brazil, Umetsu and Pardini (2007) found that the destruction of native vegetation increased the number of invasive species in the Morro Grande Reserve. In a study conducted in India, Athreya et al. (2013) stated that intensive agriculture has led to large wild carnivores being seen in areas previously inhabited only by humans.

4.2.1.4 Air To verify the impacts that agricultural frontiers could cause in the atmosphere, the authors quantified the emissions of polluting gases arising from intensive production and simulated scenarios of the behavior of this pollution over time. In a study for the South American Chaco, Baumann et al. (2017) used satellite data and found that pasture and crop intensification was responsible for decimating 20% of the Chaco Forest between 1985 and 2013, which subsequently caused substantial emissions of 824 Tg of carbon.

Studying the region of Malaysia and Indonesia, Miettinen et al. (2012) found that the devastation of peatlands from oil palm cultivation emitted 230,310 Mt CO2e into the atmosphere. Furthermore, the authors projected that following these numbers, there would be a conversion of 69 Mha of peatlands by 2020, causing the annual carbon increase in the two countries to be between 380 and 920 Mt CO2e. Along the same lines, Carlson et al. (2013) stated that between 2000 and 2010 oil palm production grew more than 270% in the Kalimantan region of Indonesia, with projections for 2020 indicating that this region alone would contribute to about 20% of the CO2 emissions of the entire country.

4.2.1.5 Water The analysis showed that only one study discusses the environmental impact of agricultural frontiers on water. Raquel et al. (2007) used Game Theory to verify the optimal decision between increasing agricultural production using irrigation or decreasing environmental effects on groundwater in the Alto Rio Lerma Irrigation District—Mexico. The authors stated that irrigation used for agricultural production can considerably decrease groundwater in the region, in which the optimal consumption decision depends on the relative importance given to irrigation and overall water use. Considering only the environmental impacts, the Pareto optimum would be to extract about 370 million cubic meters of water per year.

4.2.2 Socio-economic-ecological focus

To analyze the articles with a Socio-Economic-Ecological Focus, the authors also presented data on the environmental impacts caused by agricultural frontiers. However, they essentially focused on listing possible solutions for preservation and/or regeneration, as well as analyzing how the socio-economic aspects of the population can stimulate or reduce environmental degradation. First, the literature on possible solutions to environmental problems is discussed and then the influence of socio-economic aspects is presented.

In a study on Mexico, Ellis and Porter-Bolland (2008) showed the importance of protection areas in the forest preservation process, since they visualized that deforestation was higher in regions with community-based forest management when compared to protected areas. In turn, taking the Argentine Chaco as a study area, Volante et al. (2016) showed that some forest laws, such as the "Native Forest Law," are still insufficient to restrict deforestation and transformation of the region, so they believe that changes in implementation and enforcement strategies in the law itself or the insertion of alternative incentives, such as the European Union's biofuel import standards, may be solutions to attempt to reverse this situation.

Some studies point to the understanding of heterogeneity between regions as a key factor for the adoption of environmental protection measures in emerging countries. In a study for Latin America, Pacheco et al. (2010) state that although Reducing Emissions from Deforestation and Forest Degradation (REDD) is an important mechanism to preserve and conserve tropical forests, the implementation of public policies is hampered by socio-economic and land use heterogeneity in the region. In a discussion on South American biomes, Nolte et al. (2017) state that the Cerrado, Chaco, and Chiquitano regions have lower carbon stocks and biodiversity, but have greater agricultural importance, a higher number of private properties and greater compliance with forestry regulations on private lands when compared to the Amazon; subsequently, policies aimed to combat deforestation

in South America must consider the specialties and subjectivities of each agricultural frontier. According to Gasparri and De Waroux (2015), despite the diversity among countries, there is a coupling of soybean and cattle production frontiers in South America, which are the main drivers of deforestation in the region, so it is necessary to adopt models that analyze the coupling between geographic locations and productive sectors.

The literature on Brazil, unsurprisingly, has focused on the Amazon Rainforest. Some of the solutions for forest preservation and/or regeneration analyzed and suggested by the authors were: The creation of ecological parks and preservation of indigenous reserves (Nepstad et al., 2006), and the continuation and enforcement of the Forest Code to stem deforestation (Verburg et al., 2014); regulated and controlled use of fire by landowners, increased environmental performance in commodity markets, and incentives in the carbon market (Nepstad et al., 2008); and the encouragement of biological, digital, and materials technologies to promote sustainable land use development and climate change (Nobre et al., 2016).

The studies for Southeast Asia (Indonesia and Malaysia) presented the main "drivers" for palm oil cultivation in the region and tried to find solutions to mitigate the environmental problems arising from this production. For McCarthy and Cramb (2009), the shift from social government to neoliberalism facilitated the devastation of forests by agricultural frontiers in Malaysia and Indonesia, in which subsistence farming by indigenous peoples and smallholders gave way to mechanized agriculture. According to Carlson et al. (2015), agricultural concessions are the main stimulus for deforestation in Indonesia, so reducing these licenses, as well as encouraging carbon emission reduction policies, are important steps to try to reverse the process of environmental degradation in the country. In addition, Carlson et al. (2018) state that, although it does not solve all environmental problems, RSPO certification is an important mechanism to aid conservation, as it significantly reduced deforestation in Indonesia from 2001 to 2015.

The discussion on palm oil has extended to Southeast Asia, where, in a study of India and China, Wilcove and Koh (2010) concluded that there are some ways to try to minimize the problems arising from palm oil production, but it should be noted that "boycott" policies will not work for this region, so promoting competitiveness through incentives for REDD, for example, will be more effective. However, the environmental impacts of agricultural frontiers in Asia have not been restricted to palm oil alone. In a study in India, Singh (2000) found that intensive agricultural production during the Green Revolution led to soil degradation and alteration, and water pollution, so to help restore degraded areas, it is necessary to increase and diversify biomass productivity, as well as focus on the effectiveness of moisture conservation and water harvesting policies, nutrient management and land use planning, and recharge of groundwater reservoirs.

Moving to the literature that discusses the influence of socio-economic factors, some articles have shown that environmental degradation rates in emerging countries are reduced when there are aspects of socio-economic development among the population, whether intellectual or financial. Studies for the Brazilian Amazon have exemplified this relationship very well. Rodrigues et al. (2009) concluded that literacy, expectation, and relative standards of living corroborate with the hypothesis of the Environmental Kuznets Curve, i.e., these aspects are inversely proportional to environmental degradation at higher stages of development. Also, Schiesari et al. (2013) asserted that small-scale farmers with higher levels of education and technical support tend to use fewer pesticides and/or resources that degrade the environment less.

Along these lines, in a study of the Shandong region in China, Deng et al. (2019) concluded that land productivity is concentrated in cities far from the economic or

provincial center, but eco-efficiency is higher in areas of developed cities, eco-tourism, or belonging to the coastal and mountainous economic zone. On the other hand, although fewer in number, the literature has shown that the environmental impacts of agricultural production are also caused by the "most developed part" of the population. An example of this was demonstrated in the study by Babigumira et al. (2014) who, using 24 emerging countries as a study area, concluded that farmers with high and middle incomes tend to deforest more than smallholder farmers who are considered poor and lack market knowledge.

Going beyond this direct discussion between environmental degradation and the economic and social levels of the population, some studies point to other ways in which socio-economic factors interfere with the relationship between agricultural frontiers and the environment. In a study on Russia and Ukraine, Meyfroidt et al. (2016) argue that one of the main problems Europe faces today is the abandonment of agricultural land so factors such as young labor and an increasing rural population become essential to leverage the re-cultivation of this land and consequently stimulate the creation of new agricultural frontiers in the region. In a study on the South American Chaco, Le Polain de Waroux et al. (2018) found that while the expansion of agricultural frontiers has responded well to the use of new technologies and infrastructure and rising prices, the dynamics of these frontiers are shaped by the existence of abnormal economic rents and the presence of a limited number of actors (commodity producers, speculators, rentiers, etc.) able to capture and influence this whole process.

5 Research agenda

Considered the "home country" of the discussion between intensive agricultural production and the environment, the literature on Brazil has mainly focused on studies of the Amazon rainforest. Regarding these studies, it was noted that some of the possible "solutions" to reverse the process of environmental degradation have been implemented in the region for some time, such as the expansion of protected areas, national and foreign financial incentives, national public policies, etc. However, the literature still lacks studies that seek to measure the effectiveness (joint or not) of such measures or even to see if these measures have the same effect within the limits of the Amazon Rainforest, since the region covers nine states in Brazil alone, besides belonging to six different countries. Furthermore, considering the research criteria, other Brazilian biomes of worldwide importance were almost "forgotten" among the authors, such as the Cerrado, Atlantic Forest, Caatinga, Pampas, and Pantanal. The Cerrado, for example, comprises the most recent agricultural frontier in Brazil (Matopiba) and I believe it deserves special attention, especially due to the current rates of deforestation in the region, as it contains unique biodiversity and large natural aquifers.

Research on Indonesia and Malaysia has shown that the intensive production of palm oil has brought countless environmental impacts to the region, and there are already studies in the literature that measure the effectiveness of some certificates that help preserve the environment, such as the RSPO. However, even with the destruction of tropical forests and

the adoption of programs and incentives with an environmental focus, the production of palm oil continues "full steam ahead," as well as the degradation rates. With this, what would the next steps be? According to Pirker et al. (2016), there are only 17% of the area in the world left suitable for the expansion of palm oil, which, besides being scarce, are areas with little accessibility. Thus, I suggest, in addition to research that seeks to verify spatially where these scarce areas are and if there is a change in the variability of this percentage, studies that analyze more concisely if the process of deforestation and changes in soil, for example, accompany the expansion of palm oil. Are there indications that the soil in Indonesia and Malaysia may be going through a process of desertification? If so, how can this process be reversed?

It was also seen that in populous countries like India and China, the form of analyzing the impacts of agricultural frontiers on the environment was more connected to a possible scarcity of land and food. While areas are needed for cultivation and food production, space is also needed to meet the growing population levels. Therefore, I suggest research to discuss how to meet the current demand for food with minimal impact on the environment. Are the management of soil and already degraded areas important in this process? Besides, because it covers large territories, the question remains: is there migration of people due to intensive production and/or degraded areas in these countries? Studies that visualize how soil changes and deforestation promoted by the expansion of agricultural frontiers stimulate migration in these countries will be highlighted.

Looking more generally, it was noted that emerging countries are heterogeneous, but they carry within themselves a strong political-structural dependence, that is, they are mostly guided by internal and external stimuli. When it comes to issues such as agricultural production and the environment, the scenario is no different, in which many measures for and against the devastation promoted by the agricultural frontiers are motivated by the markets and especially by the governments in force. One suggestion is to analyze how emerging countries deal with the relationship between agricultural frontiers and the environment considering the form of government of these countries. Is there a consensus among them? Are these measures spatially dependent or just tied to the local government? Furthermore, although there have been studies at the national level, the interference of foreign markets in the agricultural production and preservation policies of a group of emerging countries, for instance, has not yet been visualized. Is there a strong interference between the markets of the emerging countries themselves or is there a greater influence of external markets? Are these influences more toward an Extended Industrial Agriculture bias or a Socio-Economic-Ecological Focus?

In addition, while it is necessary to stimulate agricultural production in emerging countries to promote economic growth, it is also necessary to know, visualize, and measure how the expansion of agricultural frontiers affects the environment and try to minimize these impacts as much as possible. This raises the question: can there be sustainable development in countries that have agricultural production as the main means of economic growth, as is the case in most emerging countries? To what extent will the environment support the expansion of agricultural frontiers? These are dilemmas to solve, almost a virtuous cycle. It is already clear that natural resources are increasingly scarce, so I would put the adoption—increasingly—of multi-component forecast models, such as System Dynamics Modeling. And, from there on, to adopt the necessary measures to balance intensive agricultural production and environmental impacts in a more incisive way.

6 Conclusions

This study analyzed, through a Systematic Literature Review, the main research on the interference of agricultural frontiers on the environment in emerging countries, discussing the theories that have accompanied the environmental and agricultural transformations that have taken place in these countries over the last thirty years (1993–2022).

One of the most significant findings of this literature review is that there is no specific framework to synthesize studies on agricultural frontiers and the environment in developing countries, i.e., to study the environmental impacts arising from intensive agricultural production in regions as heterogeneous as emerging countries, authors have adopted different approaches, theories, and methodologies. However, it is noticeable that much of the literature has been mainly concerned with analyzing and measuring the impact of agriculture on natural resources, which I have called the Expanded Industrial Agriculture Approach, as well as verifying and measuring how local socio-economic factors and/ or public policies affect the behavior of the population in this relationship between the environment and agricultural frontiers, which I have defined as the Socio-economic-Ecological Approach. This is the most appropriate way (at the moment) to summarize how the literature on agricultural frontiers and the environment in emerging countries is being conducted.

In the analysis with the Expanded Industrial Agriculture Focus, it was found that intensive agriculture degrades the most varied natural resources, but the articles brought discussions essentially on the environmental impact on flora (through the analysis of deforestation rates), air (through the measurement of polluting gases) and changes in land use, thus generating the need for further research into the impacts of agricultural production on water, for example. In turn, the articles with a Socio-Economic-Ecological Focus brought possible solutions to environmental problems in emerging countries, such as the creation of ecological parks and increase in forest protection areas, public policies that take into account the specificity of each region, implementation and enforcement of stricter environmental laws, encouragement of biological, digital and material technologies, increase in environmental performance in commodity markets and incentives in the carbon market. In addition, research has shown that the existence of some socio-economic aspects among the population, such as literacy, expectation, and high standard of living, tends to decrease the rates of environmental degradation in these countries.

The data also revealed that there is no equal interest in research on agricultural frontiers and the environment among emerging countries, with most studies discussing the impacts of intensive agricultural production in Brazil, followed somewhat distantly by studies on South America in general and the island region of Indonesia and Malaysia. Unsurprisingly, research on Brazil has been almost entirely on the world's largest tropical rainforest, the Amazon Rainforest, thus leaving a large gap in the literature on other Brazilian biomes of global importance, such as the Cerrado, the Atlantic Forest, the Caatinga, the Pampas and the Pantanal. Moreover, the literature still lacks research on European economies in transition, emerging African countries, and Russia, or on the agricultural environmental impact of the huge demand for food in populous countries such as India and China.

Therefore, in addition to country-specific suggestions, future research on agricultural frontiers and the environment should not only propose solutions but also measure the effectiveness of proposals aimed at reducing/reversing the degradation process in emerging countries in general, considering the interference of markets, types of government and the high heterogeneity among them. Moreover, as this is a delicate debate with multiple

components involved, research should adopt more dynamic forecasting models to seek a balance between intensive agricultural production and environmental impacts. There is also a need for studies that bring more recent discussions, such as agricultural digitalization, migration of agro-industrial poles, nanotechnology, and circular economy, among others.

Data availability The final set of data supporting the conclusions of this study is available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The author states that there is no conflict of interest.

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