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Agriculture 4.0 and climate change in Brazil

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Abstract: This article introduces the debate on low-carbon socio-technical transitions in Brazilian agribusiness, based on the premise that a growing portion of the industry adopts digital technologies in its business models, configuring a new productive paradigm: agriculture 4.0. We use the Sustainability Transitions theory to examine the relationship between agriculture 4.0 and climate change in Brazil, classifying Brazilian agribusiness into three subsectors: family farming, conservative agribusiness, and sustainable agribusiness. The article demonstrates technical, institutional, and political-economic challenges for each of these subsectors to support Brazil's journey towards a low-carbon economy, observing that sustainable agribusiness has performed the best so far.

Keywords: Agriculture 4.0; climate change; Brazil; sustainable agribusiness; sustainability transitions

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Introduction

Agriculture 4.0 has been arousing political, economic, and environmental interest. Techniques such as genome editing of crops, satellite monitoring of meteorological variables, software for agricultural management, pesticide and irrigation control sensors, digitalized mapping of fertility, humidity, temperature, and physical-chemical conditions of the soil are characteristic of agriculture 4.0 (CLAPP; RUDER, 2020; THIELE, 2020). Such practices have been diffused for some time now in the developed countries, especially in top agricultural producing countries like the United States, given the gains in productivity that they offer. There has also been a noticeable recent movement towards incorporating agriculture 4.0 technologies in middle-income countries like Brazil.

Recent studies have focused on the environmental aspects of agroindustry 4.0, especially as regards climate change, the use of agricultural chemicals, and a more efficient use of natural resources. Nicholson and Reynolds (2020) investigated how geoengineering could help revert anthropogenetic climate change if used in the production of low-cost, zero-carbon energy, electricity storage, and the removal of CO2e from the atmosphere. Others have been studying informal technology diffusion networks and how they affect the governance of sustainability (BERNARDS et al., 2020). Some studies have concentrated on the application of synthetic biology for assisted evolution, de-extinction, and the restoration of biological diversity (THIELE, 2020), gaining an understanding of the inter-relations between genetically modified organisms and gene-conductor organisms and how they could contribute to the conservation of nature (REYNOLDS, 2020).

Although some papers on agriculture 4.0 have already been published in the country (ALBIERO et al., 2020; MASSRUHÁ; LEITE, 2017), the subject is still far removed from Brazil's social science community. In particular, there has been no analysis of the possible relations between agriculture 4.0 and climate change in Brazil. This article seeks to fill this gap, based on the theoretical framework of Sustainability Transitions (GEELS, 2011). We examine how agriculture 4.0 has been advancing in Brazil and the relations between this new paradigm and climate change. There have been very few studies on sustainability transitions in agriculture compared to transition studies focusing on the energy and mobility industries. This article is, therefore, an original contribution insofar as it uses the Brazilian case to illustrate how sustainability transitions are achieving only partial progress with agriculture 4.0. since only a small part of the industry is applying such technologies, and how their impacts on climate change are largely unknown.

This research adopted the following methodology: a) analysis of national and international literature and secondary documents; and b) qualitative analysis of the bibliography and documents by reading and systematization without the use of any specific software. The article consists of this introduction and four other parts. The first one defines agriculture 4.0 in the context of the Anthropocene. The part that follows presents a theoretical-conceptual review of Sustainability Transitions. Then comes an analysis of the Brazilian case in three sections: family farming, conservative agribusiness, and sustainable agribusiness. The last section presents the article's conclusions.

Agriculture 4.0 in the Anthropocene

The term Anthropocene defines a period in which the Earth System is no longer in a stage of natural ecosystem transformations, as it was in the Holocene, but instead at a moment when human agency has intensely corroded the planet's natural resources. We are at a planetary crisis in which climate change is just one of the axes of tension, albeit an extremely serious one. At least two other limits, the level of biodiversity loss and the changes in the nitrogen cycle, can be added to climate change, constituting boundaries already transgressed that bring us ever closer to the limits of the Earth System (ROCKSTRÖM et al., 2009; BIERMANN et al., 2012; VIOLA et al., 2013; STEFFEN et al., 2015).

Thus, the Anthropocene is a geological epoch characterized by irreversible anthropogenic interference in the planet's dynamics. This new epoch has an ambivalent significance, however. On the one hand, the socioeconomic development model has dilapidated the planet's natural resources, a process accelerated in the post-war period. On the other, scientific and technological progress has been enormous, enabling a more accelerated evolution of humanity in the last two centuries than in the entire eleven thousand years of the Holocene. Three milestones have marked the inauguration of the Anthropocene: "the industrial revolution that happened from the end of the 18th century until the first half of the 19th century; the powerful acceleration of that process which began in 1945 (the atom bomb, population growth, progressive increase in the use of natural resources and energy, the erosion of biodiversity); and the beginning of the 21st century with the scientific consensus on the anthropogenic nature of global warming" (VIOLA; FRANCHINI; BARROS-PLATIAU, 2017, p.180).

In such a context, agriculture 4.0 has been defined on the basis of an earlier concept, Industry 4.0. At the dawn of the 21st century, the term Industry 4.0 emerged to designate the most recent technoscientific progress. In 2011 the United States government launched its program *Ensuring American Leadership in Advanced Manufacturing* in an effort to leverage the country's economy in the light of the slow industrial growth of the preceding decade. All around the world, governments have mimicked that strategy, among them Germany, which launched its *Industry 4.0* program in 2014. The term spread rapidly, appearing in speeches at the World Economic Forum, as well as in many programs in other parts of the world, such as *Made in China 2025*, *Make in India*, and the Japanese program *Society 5.0*.

With the advent of Industry 4.0, new technologies entered the market, such as artificial intelligence, blockchain, 5G networks, 3D Printing, augmented, virtual and mixed realities, big data and analytics, nanotechnology, and drones, just to mention a few. In this process of unprecedented technological progress, analytical tools (virtualization, computational vision, mixed realities, predictive algorithms, etc.) and physical techno-structures (robotics, drones, 3D manufacturing, autonomous vehicles, etc.) have restructured the technological capacities of productive systems (MENDES, 2020, 2021). Agriculture 4.0 is among those developments, as we explain below:

Definition of Agriculture 4.0

Over time, Agriculture has gone through at least four evolutive stages. Agriculture 1.0 was marked by rustic mechanization, high dependence on human labor and animal traction, and low technological intensity, and was predominant until the mid-twentieth century. Subsequently, Agriculture 2.0, or the Green Revolution, progressively incorporated technology in the form of inputs (fertilizers, pesticides, herbicides), adaptive biotechnology, and agronomic technology directed at large-scale commodity production, and characterized the period 1950-1990. It was only after 1990 that digital technologies, i.e., Information and Communication Technologies (ICTs), began to be used in Agriculture 3.0. This was marked by integrated systems for crop and livestock management and farm administration, remote crop monitoring, and precision agriculture. It also included considerable progress in biotechnology, incorporating the initial stages of bio and agro-informatics.

As regards the linearity of these developments, some agriculture systems have been through a disruptive inflection point since the second half of the 21st century. These transformations resulted from the incorporation of smart technology (artificial intelligence - AI, the Internet of Things – IoT, big data, etc.) into agriculture through autonomous precision agriculture, complex modeling of agricultural and agro-food systems, and omnipresent agricultural sensing, forming what has come to be known as Agriculture 4.0 (ALBIERO et al., 2020; EMBRAPA, 2019; MASSRUHÁ; LEITE, 2017).

It is important to underscore the differences between Agriculture 3.0 and 4.0 since both incorporate ICTs, but with different levels of complexity and sophistication. Agricultural research has been using digital technology ever since the 1990s and that includes Brazil. For example, since 1991, the Brazilian Agricultural Research Corporation (*Empresa Brasileira de Pesquisa Agropecuária* - Embrapa) has had an agency specifically dedicated to Information Technology (*Agência Embrapa de Informação Tecnológica* - Ageitec) that has been responsible for developing various computerized systems for use in basic research and for agro-industrial application. The Ageitec is, therefore, part of Agriculture 3.0 and has developed systems such as the Interactive System to Support Environmental Licensing (*Sistema Interativo de Suporte ao Licenciamento Ambiental* - SISLA), the Interactive System for Geospatial Analysis of the Legal Amazon (*Sistema Interativo de Análise Geoespacial da Amazônia Legal* - SiaGeo), and the Temporal Analysis of Vegetation System (*Sistema de Análise Temporal da Vegetação -SATVeg*) (MASSRUHÁ; LEITE, 2017, p.32).

Unlike these linear developments of Agriculture 3.0, developments in Agriculture 4.0 are on the newest technological frontier, in light of Industry 4.0. For example, Agriculture 4.0 incorporates technologies such as: a) IoT (physical-digital devices applied to precision agriculture, cattle monitoring, smart greenhouses, remote verification of climate conditions, etc.); b) robots and autonomous systems (biodiverse crops, 3D food printing, aerial fertilization via drones); and c) artificial intelligence (autonomous seed control, smart classification and harvesting systems, automated diagnosis of diseases, machine learning for predictive modeling of harvests, computerized recognition of species) among others (LIU et al., 2021).

With the advent of Agriculture 4.0, the intensity, robustness, and complexity of agro-industrial technological systems are advancing considerably. That leads to: unprecedented volumes of data on the national agriculture system that can serve as input for industry-oriented public policies; a progressive reduction of the workforce needed, with impacts on Brazil's agricultural labor market and the need for more specialized labor; the need for regulatory adaptation in terms of data privacy policies and the security of public and private computational systems that manage and store data on Brazilian agriculture. In this scenario, the potential of agriculture 4.0 for a low carbon transition has come up for discussion and can be analyzed through the theory of Sustainability Transitions

Sustainability Transitions

Sustainability Transitions (STs) models are based on the diagnosis that certain dynamics have profoundly affected the planet's support systems: increasing global population, technological development, and economic growth. Hence, there has been an urgent need to discuss objectives, indicators, and metrics to guide our journey toward sustainability. In the 1990s, two fields contributed to originating STs: science technology and innovation studies (ST&I), and research on the environment and sustainability. It was only in 2001, however, that the term Sustainability Transition was used for the first time, in the *Dutch National Environmental Policy Plan*. In that plan, the Dutch government presented four urgent transitions for a sustainable future, namely: i) energy; ii) natural resource and biodiversity use; iii) agriculture; and iv) mobility (LOORBACH et al. 2017). The plan defined STs as "fundamental, long-term multi-dimensional transformation processes by means of which extant socio-technical systems are gradually transformed into sustainable production and consumption models" (MARKARD; RAVEN; TRUFFER, 2012, p.1).

Geels (2011) developed a sophisticated and widely accepted approach to STs called the Multi-Level Perspective (MLP). Incorporating elements of the neo-institutional theory and the agency-structure debate, Geels' (2011) model is based on three components: 'regime', 'niche', and 'panorama'. I) sociotechnical regime: the 'deep structure' that explains the stability of an existing socio-technical system; it refers to the semi-cohesive set of rules that orientate and coordinate the activities of the social groups that reproduce the various elements of the extant technological system. II) niches: 'protected spaces' such as R&D laboratories, structured research projects, or market niches in which users have specific demands and are willing to support emerging innovations; niche actors (scientists, entrepreneurs, startups, etc.) work on innovations that diverge from the incumbent regime. III) panorama: the 'broad context' that influences niche and regime dynamics; importance is attributed not only to the technical and material scenarios but also to demographic trends, political ideologies, social values, culture and macro-economic patterns, that is, the external scenario which niche and regime actors cannot influence in the short term.

Despite its sophistication, Geels' (2011) model emphasizes the structures but does not explore the dimension of agency in depth. Therefore, new perspectives have been proposed to address that lack. Avelino and Wittmayer (2016, p.642), for example, developed a Multi-actor Perspective (MaP) in which they situate the State, the market, the Community, and the third sector in distinct levels of interaction along public-private, formal-informal, for-profit/non-profit axes. Such an agency-based approach makes it possible to reflect more profoundly on which actors exercise power in STs, how the mutations in power relations among them come about, and at whose cost.

Another widely recognized ST model was proposed by Kivimaa and Kern (2016), who, inspired by Schumpeter's notions of innovation drivers and creative destruction, emphasized 'policy mixes.' They state that "creative destruction has been conceptualized as a process, in which an innovative entrepreneur challenges incumbent firms and technologies in a way that makes the existing technologies obsolete, forcing incumbents to withdraw from the market" (KIVIMAA; KERN, 2016, p.207). Indicators have been developed in two dimensions. First, the creation of 'green' technology (ST&I policies, market niches, experimentation, cost/price alignment, resources to be mobilized, support of elites and power groups). Second, the 'phase-out' or discontinuation of carbon-intensive socio-technical regimes (transition and control policies, changes in laws and regulations, reduction of incentives for 'dirty' industries, replacement of key actors).

Those conceptual models are important insofar as they provide subsidies for investigating how STs have been taking place (or how they might occur) in various economic sectors such as agriculture. However, some authors have identified extant limitations in the STs models. Aykut, Morena, and Foyer (2020) criticize the 'technocratic-managerial culture' that exists in the low-carbon socio-technical transitions. Other limitations include: (i) STs are mainly concerned with energy transition and there are fewer studies in socio-technical domains like water, agriculture, mobility, etc.; (ii) the debate still focuses on developed countries, especially from Western Europe and Japan, being still a long way off from the epistemic communities in Africa, Asia and Latin America; (iii) the diffusion of low-carbon innovations is interrupted if they fail to align with broader changes in the socio-technical and cultural systems; (iv) STs in different environmental domains are interdependent but the goals of their associated actors, institutions and regulations are not necessarily convergent; (v) there is multiple resistance to the progressive elimination of unsustainable technologies, especially those from large corporations in incumbent sectors (oil and gas, automotive, chemical, electrical etc.); and (vi) STs are not associated exclusively with public policies that stimulate low-carbon innovation and the decline of unsustainable technology, but they also face a series of challenges in the governance of common-pool resources, thus there is the need for horizontal and vertical political coordination.

In the next section, we explain how these STs models can be handy in the analysis of low-carbon transitions in three segments of Brazilian agriculture: family farming, conservative agribusiness, and sustainable agribusiness.

Agriculture 4.0 and Low-Carbon Transitions in Brazil

Family Farming: low technological capacity and low climate commitment

In Brazil, there are so many types of rural smallholder properties that it is hard to characterize family farmers as a homogeneous group. However, Brazilian Federal Law 11.326, dated July 24, 2006, and its updates establish four criteria for considering a rural property to be family farming: the area must be less than four fiscal units (varying from 4 to 110 ha), the workforce must be predominantly members of the family itself, a certain minimum percentage of the family income must come from activities in the rural property, and the farm must be run and managed by the family itself.

Even so, it is nonetheless hard to measure the size of Brazil's family farming, making the task of analyzing its potential for low carbon transition a complex one. Based on the Agriculture and Livestock Census for 2017, carried out by the Brazilian Geography and Statistics Institute (*Instituto Brasileiro de Geografia e Estatística* -IBGE), Embrapa analysts have estimated that 76.8% of the 5.073 million rural establishments in Brazil fit into the family farming category. In 2017, family production generated revenue of R$ 106.5 billion (23% of the total for the industry) whereas non-family farming generated R$ 355.9 billion (77% of the total). There was a reduction of 10.2% in the value that family farming generated compared to the previous census in 2006 (NETO; SILVA; ARAÚJO, 2020, p.1). The sub-sector represents 24% of the agricultural area and 74% of the labor employed in rural areas in Brazil (12 million people) (MASSRUHÁ; LEITE, 2017, p.30).

A minor, although growing, segment of family farming has migrated from conventional agriculture to organic agriculture (in some cases following Agroecology or Permaculture principles), increasing its market share in various metropolitan regions of Brazil and even in foreign markets (particularly in Europe), in the case of more capitalized families.

Based on the above, two analytical axes are useful to scrutinize the climate impacts and the potential for a low-carbon transition in family farming in Brazil: first, it is necessary to identify whether it has been adopting sustainable practices and delineate the profile of the subsector's emissions; second, we need to examine the institutional framework that makes it possible (or hinders) for small-scale agricultural enterprises to adopt low-carbon technology 4.0.

The rising global demand for food and recent technological progress have led agriculture to use standardized crop varieties and monoculture. "With the expansion of the agricultural frontier, mechanized soil management and the use of agro-chemicals and irrigation, farming, livestock-raising, and forestry activities have come to be carried out in an intensified, independent, and disassociated manner" (BALBINO et al., 2011, p.1). Over time, that has led to increased soil and pasture degradation, low replacement of nutrients in the soil, and low investment in technology. With a traditional mindset, little knowledge of, or interest in, sustainability, lack of access to technology, and the preponderance of an economic subsistence mindset, part of Brazilian family farming maintains a business model based on deforestation and soil degradation.

To address that problem, some techniques are being tested and recommended, especially by Embrapa. Among them, no-till farming, agro-silvopastoral systems, and the integration of crop and livestock farming. However, such techniques are hard to incorporate into family farming, except in the more capitalized farms. These techniques are associated with considerable investments in terms of capital and technical knowledge that usually lie beyond the reach of small-scale agriculture.

While agriculture has an impact on climate change, at the same time climate change poses a risk to the sector. Agriculture's most threatened segment is the one least endowed with resources and technology: family farming. Brazil has systematically presented a considerable part of its GHG emissions as stemming from land use, land-use change and forestry (LULUCF), especially associated to deforestation in the Amazon. In 2015, LULUCF emissions represented almost 46% of total emissions from Brazil, the energy sector 24%, agriculture 22%, heavy industry 5%, and waste 3% of Brazil's total emissions (VIOLA; FRANCHINI, 2018). Furthermore, emissions from the agricultural industry had a 100% increase in the period from 1990 to 2019, going from 290 MtCO2e to 598 Mt CO2e (SEEG, 2019).

Although sustainable agribusiness (as defined later in this paper) has improved its energy efficiency, reducing the intensity of emissions associated with production, its expansion has been one of the main drivers of deforestation and forest conversion in the Amazon and the Cerrado biomes (PEREIRA; VIOLA 2021). There is little disaggregated data on family farming's participation in Brazil's emissions trajectory, but Rivero et al., (2009) estimated that in the period 2000-2006 Amazon deforestation was strongly correlated with cattle raising (causing approximately 54% of the deforestation in that period), or associated to logging in addition to extensive farming of crops like soy (ibid., p.42).

It is well known that climate change will reduce agricultural productivity, leading to a gradual loss of the capacity to plan production. Around 30% of food productivity can be explained by climate variations while the remaining 70% can be attributed to inputs, fertilizers, genetics, and agricultural practices. In other words, when the climate becomes unpredictable, productivity drops regardless of how much is invested in technology. Prolonged droughts in the Brazilian North and Northeast, regions where family farming concentrates, can also have drastic effects on the means of subsistence of small-scale farmers.

To address these challenges, Embrapa conducts R&D activities focusing on rural producers, family farmers, and other agricultural segments to enable them to adopt technologies designed to support sustainable agriculture (MASSRUHÁ; LEITE, 2017, p.30-1). Some of these technologies include agro-meteorological information systems that supply data for the Climate Risk Agricultural Zoning (*Zoneamento Agrícola de Risco Climático* -Zarc), an agricultural policy and risk management instrument. Some banks make this kind of zoning a condition for the concession of rural credit, and Embrapa works alongside other government sectors to increase agro-climate zoning.

On the other hand, recent studies have shown that public policies for family farming in Brazil, despite some important advancements, are problematic in certain aspects and have a negative impact on the subsector's potential for a low-carbon transition. Contracts of credit access and technical assistance programs such as the National Program for Strengthening Family Agriculture (*Programa Nacional de Fortalecimento da Agricultura Familiar* -PRONAF) have been largely concentrated in Brazil's Southern and Southeastern regions to the detriment of the North and Northeast. Even more recent programs such as the National Program for the Sustainable Development of Rural Lands (*Programa Nacional de Desenvolvimento Sustentável de Territórios Rurais* -PRONAT) and the Citizenship Land Program (*Programa Território da Cidadania* -PTC) have continued to concentrate the credit offer on farmers with greater capital and resources (SABOURIN, 2017; GRISA; SCHNEIDER, 2015).

Previous research has demonstrated that socioeconomic variables (land ownership, financing options, access to information and technical assistance, schooling level, percentage of income generated by managing the rural property, family size, age of the farmer) and agronomic variables (water availability, soil quality) influence Brazilian agriculture's adoption of agroforestry systems that would make it better adapted to climate change (CARLOS; CUNHA; PIRES, 2019; SCHEMBERGUE et al., 2017). However, given the inequality in access to those resources, the vast majority of family farmers have no incentive whatsoever to adopt sustainable, low-carbon business models. In other words, despite the subsector's sustainability potential (e.g., organic agriculture, potential flexibility for adopting no-till farming, and crop-livestock-forest integration (ILPF)) the institutional framework has not been propitious for that. It must be noticed, however, that even though the institutional environment is unfavorable, organic family farming has increased in the areas surrounding large and medium-sized Brazilian cities.

As identified in the conceptual framework of STs, governance challenges for a low-carbon transition in Brazilian family farming illustrate the need for greater inter-institutional coordination (e.g., among financial institutions, agricultural cooperatives, distribution and consumption value chains, and political institutions) and greater technical coordination (e.g. Embrapa, universities) in supporting such initiatives. Based on insights from the "policy mixes" framework (KIVIMAA; KERN, 2016), we observe that the phase-out of carbon-intensive practices in the Brazilian family farming sector lacks not only regulations and policies to guide those initiatives but also actions to foster the creation and diffusion of green technologies, specifically focusing on small-scale agriculture and involving ST&I policies, the construction of specific market niches, and sectorial rearrangements that take into account the scale, capacity and economic limitations of family farmers.

Conservative Agribusiness: technologically advanced, but low climate commitment

The Ruralist Front (*Bancada Ruralista*) in the Brazilian Congress mainly represents large-scale and high-tech portions of Brazil's agribusiness, whose practices are misaligned with sustainability and climate change mitigation. To understand the factors that explain why this portion of agroindustry maintains unsustainable production patterns, it is necessary to analyze the social constitution and interests of this 'agrarian bourgeoisie'

(BARROS, 2018), which has historically influenced Brazilian politics. What are the vectors of the environmental degradation brought about by agroindustry? It is worth mentioning the rising global demands for sustainability in the agro-industrial suppy chain in order to understand how this 'conservative agribusiness' model represents a risk to Brazilian international trade since the global agro-industrial and food chains are gradually distancing themselves from suppliers with harmful environmental practices. The Multi-level Perspective (MLP) model (GEELS, 2011), which emphasizes the role of the socio-institutional regime, priority market niches, and the political-economic panorama of the sector will guide our analysis.

In the course of the 19th and 20th centuries, the Brazilian agrarian bourgeoisie played a crucial role in national politics given that the country maintained (and still maintains) its role as an agro-exporting power. The agrarian bourgeoisie that composes the Ruralist Front represents such sectors as the large landowners who maintain vast areas of unproductive land, and parts of the agroindustry dedicated to foreign markets but adverse to sustainable practices.

In the period from 1990 to 2020, given the pressures of economic globalization and financialization, the agribusiness sector became strategic for Brazil's insertion into global value chains in a process of agro-industrialization characterized by ever closer relations between the State and the agribusiness elites (BARROS, 2018; SØNDERGAARD, 2020). Large agribusiness groups came to enjoy priority in agriculture public policies to the detriment of small farmers and sectors associated with agro-ecology. Additionally, there was strong financial capital support and ready access to credit for these large groups so that agricultural commodities have become important dynamos for Brazilian financial markets, including future markets for agricultural and livestock commodities, as well as for the country's international trade (GOLFARB, 2015).

In terms of market structure, there is a strong concentration in the Brazilian agroindustry whereby "10% of the firms control 80% of the production value" (BARROS, 2018, p.179). For conservative agribusiness groups, market and financial imperatives have always been preponderant to the detriment of environmental protection, despite the growing awareness of European Union and Japanese markets, and part of civil society, as regards the deleterious effects agribusiness can have on the environment and the climate. According to Geels' (2011) model, the socio-institutional regime and the deep forces that structure State-conservative agribusiness relations in Brazil explain why the subsector represents a hindrance to the country's low-carbon transition in the agriculture industry. We must notice that conservative agribusiness also makes use of agriculture 4.0 technologies, but exclusively in order to increase productivity, thus devoid of any interest in becoming sustainable or reducing the sector's emissions.

The environmental impacts of agribusiness are widely known. The advance of the Brazilian agricultural frontier began in the 1960s, first in Brazil's southern states, then into the Cerrado biome, and more recently heading at an accelerated pace towards the Amazon. This movement has caused, among other impacts: a) expropriation or acquisition of the land of small farmers formerly occupied by a diversity of crops; b) the compacting and impermeabilization of soils due to the extensive use of heavy agricultural machinery; c) erosion; d) contamination of water, food, and animals with pesticides; e) harmful impacts stemming from the removal of the native vegetation cover from extensive continuous areas; f) silting up of rivers and reservoirs; g) the appearance of new pests and increased presence of already existent ones; h) risks for the survival of animal and plant species through natural habitat loss caused by the expansion of the agriculture frontier; and i) alterations to the local climate (DOMINGUES; BERGMANN; MANFREDINI, 2014, p.37).

Sauer (2018) observed that conservative agribusiness, especially in its expansion into the Amazon, has caused new forms of land grabbing, new mechanisms for concentrating land, and has raised conflicts with indigenous communities, Quilombola communities, and small farmers. Although this article does not intend to statistically differentiate the extent to which those impacts derive from conservative agribusiness or from sustainable agribusiness, the main point is that while the latter group shows intentions of reducing those impacts, the former hardly assigns any importance to the problem.

In terms of impacts on emissions and energy consumption, with a focus on Brazil's leading agricultural commodity (soy) in the period 2000-2014, energy consumption rose at an average annual rate of 7.1%. Over the same period, total emissions increased by 90.75%, while for the soy production chain the increase was 155% (MONTOYA et al., 2019).

Conservative agribusiness uses Agriculture 4.0 technologies progressively in Brazil, but without any environmental commitment. These technologies have the potential to optimize productivity by increasing the performance of equipment, cutting down on time and resources, and improving harvest predictability. However, these technologies are only accessible to the most capitalized portion of the industry as investments are costly. Agriculture automation and digitalization also have to face the challenge of poor connectivity infrastructure in the rural zones, discouraging such investments. The National Social and Economic Development Bank (*Banco Nacional de Desenvolvimento Econômico e Social* -BNDES) has been providing resources and designing projects to address that problem (MILANEZ et al., 2020).

The Multi-actor Perspective (MaP) model developed by Avelino and Wittmayer (2016) emphasizes the importance of public-private arrangements and a diversity of actors in socio-technical low-carbon transitions. This is applicable to the case of conservative agribusiness because the model helps us depict the different political and economic movements towards Agriculture 4.0. In other words, despite the industry's environmental and climate impacts, conservative agribusiness exerts its influence on public institutions and the market, encouraging the adoption of agriculture 4.0 technologies to enhance productivity, but with no interest in sustainability or climate action. That is precisely the aspect that distinguishes it from "sustainable agribusiness," as we analyze below.

Sustainable Agribusiness: technologically advanced, and increasing climate commitment

In 2017, agribusiness represented 23% of the Brazilian GDP, 40% of exports, and around 20% of the employment positions. The country is the world's third-largest agricultural exporter and the leader in the export of beef, chicken, sugar, corn, orange juice, and coffee. In terms of market share, Brazil has 18% of the international beef market and 32% of the poultry market (VALE, 2018). In 2011, taxes generated by the agriculture and livestock industries (20.68%) were greater than the average value of all the other economic sectors (13.59%), in addition to being the main driver of the influx of foreign currency to Brazil (MOREIRA et al., 2016). Brazilian exports reached 180 countries in 2016 and included 350 products, with soy being the most outstanding, responding for 29.9% of the total revenues (81% grains, 16% food products, 3% oil) (ABRAHAM et al., 2020).

Being an important driver in the national economy, agribusiness is responsible for an expressive portion of Brazil's emissions. Since 2010, Brazilian emissions have been around 2 Gt CO2e a year. In 2019, the three main vectors of emissions were: land and forest use changes, i.e., deforestation (968 Mt CO2e), agriculture and livestock production (598 Mt CO2e), and energy (413 Mt CO2e) (SEEG, 2019). The Nationally Determined Contributions (NDCs) that Brazil proposed in the Paris Agreement aimed to reduce total emissions to 1.3 Gt CO2e by 2025, and to 1.2 Gt CO2e by 2030, which was considered to be a moderate ambition. In the composition of the NDCs, Agriculture, Forestry and Land Use (AFOLU) are at the core of Brazil's decarbonization strategy, whilst initiatives in other sectors are vague (KÖRBELE et al., 2020).

In regard to the NDCs, there is the National Plan on Low-Carbon Agriculture (*Plano Nacional para Agricultura de Baixo-Carbono* - Plano ABC) which foresees a reduction of between 133.9 and 162.1 Mt CO2e in the industry's emissions through an intensification of sustainable livestock raising and low-carbon productive systems. The plan prioritizes the recovery of degraded pastures, crop-livestock-forest integration, as well as agro-forest systems, no-till farming, biological nitrogen fixation, and enhanced agricultural efficiency. Brazilian NDCs also propose to put an end to illegal deforestation (BRASIL, 2018).

Such measures were designed to reduce the sector's emissions without jeopardizing productivity. Between 2009 and 2050, it has been estimated that global food consumption will increase by 70% thereby pressuring the agricultural industry to produce more and consequently increase its emissions (PIVOTO et al., 2018). That is why FAO (2019) has recommended the inclusion of climate change adaptation and mitigation plans in the NDCs related to agro-food systems. In this context, Agriculture 4.0 is being progressively applied globally and in Brazil.

Artificial neural networks are applied to calculate the optimum size of plantation areas and forecast Brazilian soy harvests (ABRAHAM et al., 2020). Applications such as *BovChain* manage socio-environmental parameters via big data and cloud computing. Smartphones connect farmers, slaughterhouses, buyers, and investors so that the herds and commercial transactions can be monitored in real-time, within a common digital market which, ideally, would facilitate accountability and environmental management of the agricultural and livestock production chains (BERGIER et al., 2020). In the case of precision agriculture, even though it is dominant in advanced economies such as the USA, it is also growing in emergent markets. In Brazil, it is applied in satellite monitoring and computational visualization of crops and herds, intelligent irrigation, and the optimization of agricultural chemicals use. For example, Agrosmart is a Brazilian digital agriculture platform that seeks to reduce environmental impacts and enhance crop performance (COOK; O'NEIL, 2020).

Other branches of the agroindustry have been adopting agriculture 4.0 technologies. Regarding Genetically Modified Organisms (GMOs), Brazil has far more restrictive legislation compared to countries like the USA and Japan. For example, Act Nº. 11105/2005 instituted the National Biosecurity Council (*Conselho Nacional de Biossegurança* -CNBS) and restored the National Biosecurity Technical Committee (*Comissão Técnica Nacional de Biossegurança* -CNTBio) imposing surveillance and protection measures and associating the commercial liberation of GMOs to national interests and socioeconomic convenience. Nevertheless, in 2013, Brazil was already second in the world in areas with GMO crops. While in 2007, Monsanto, Bayer, and Syngenta had approved the three initial transgenic strains of corn cultivated in Brazil, in 2016, the CTNBio had already approved 18 transgenic species. Currently, there are 66 transgenic crops in Brazil, the three main ones being of corn, cotton, and soy. On the other hand, in the period 2010-2016, there was only one Brazilian company (EMBRAPA) among the top 10 soliciting transgenic patents in Brazil (FIGUEIREDO et al., 2020). Furthermore, comparing crops of genetically modified soy and organic soy, the latter has a 77% probability of lesser climate impacts and a 60% chance of being more profitable for farmers (KAMALI et al., 2017). Thus, compared to organic products, the GMOs are not necessarily the most sustainable, in addition to the fact that GMOs involve the use of glyphosate, a molecule with deleterious impacts on human health insofar as it undermines the integrity of the intestinal biota, which is fundamental to the regulation of the immune system.

Biofuels are also decarbonization vectors and are directly related to Agriculture 4.0. The National Biofuels Policy (*Política Nacional de Biocombustíveis* -RenovaBio), instituted by Act 13.576/2017, seeks to address Brazil's Paris Agreement NDCs. It aims to expand the presence of biofuels in the country's energy matrix, reducing emissions in energy production, commercialization, and use. The Law does not stimulate any specific generation of biofuel but from the second generation onwards they are considered to be less environmentally aggressive and can be produced based on: GMOs; the transformation of biomass into biogas or biohydrogen; biomass using molecular procreation techniques; strengthening harvests even when produced on acid soils or low-fertility soils; modified trees that store significantly more carbon dioxide such as some Eucalyptus varieties currently being tested (SAHA et al., 2018). The more advanced generations of biofuels significantly reduce CO2e emissions and other pollutants (NOx, SOx), and are considered to be ultra-clean. In fourth-generation agro-biological systems, the synthetically produced biomasses are considered to be carbon-sequestering machines as they retain higher levels of CO2 than natural organisms. These carbon removal methods are considered to be low-risk, or carbon negative, geo-engineering. RenovaBio is an important instrument for encouraging such methods, thus contributing to a low-carbon economy in Brazil (KLEIN et al., 2019).

EMBRAPA (2018) recommends some additional techniques to increment agricultural sustainability. The no-till farming system for example is climate-positive insofar as it mitigates emissions of N2O, a gas with a greenhouse effect 340 times greater than CO2. However, it is harmful to human and animal health as it is associated with the use of glyphosate, a herbicide with carcinogenic potential and destructive to the intestinal microbiota. In that respect, it would be important to exercise rigorous control over the application of glyphosate and eventually banish it altogether, replacing it with healthy substances. Other techniques include agro-silvopastoral systems, the integrations of crop and livestock farming, methods for recovering degraded pastureland, and improving the soil's physical, biological and chemical properties thereby improving productivity.

In this context, there have been some promising experiences in the Brazilian Amazon under the aegis of the National Program for the Recuperation of Pastures (*Programa Nacional de Recuperação de Pastagens* - Propasto). It is important to underscore the sustainable potential of such techniques given that the introduction of no-till farming into crop-livestock integration increments the carbon sequestering capacity of the soil.

Land and forest use and vegetation cover, when associated with their potential as carbon sinkers, are of fundamental importance in tackling climate change. Among the recommended practices for the preservation of land and forest are a reduction in land use through the intensification of agricultural productivity and the use of agricultural techniques friendly to the carbon cycle (VIOLA, 2011). Controlling deforestation, replanting forests, recovering degraded pastureland, and the non-use of areas with poor agricultural productivity are some of the recommended policies (KÖRBELE et al., 2020). These measures have been recommended for the governance of the Amazon rainforest, for example.

The South American Amazon has two 'tipping points': temperature increase of 4ºC or more, and deforestation rates of over 30% of the original forest cover. If either of these tipping points is surpassed, then an irreversible process of *savannization* will begin. In the last 60 years, the temperature has risen by around 1.2ºC and 20% of the original forest cover has been deforested. In the period 2004-2012, the deforestation rate in the Brazilian Amazon basin dropped by 80%. However, from 2013 on there has been a gradual increase in deforestation, and it has accelerated since 2019. In addition to deforestation, in 2015 and 2019 there were immense forest fires (NASCIMENTO et al., 2019). In the Amazon year of 2020 (August 2019 to July 2020), 11,000 square kilometers were cleared, more than double the area of 2012. In the Amazon year of 2021, deforestation increased by 22% reaching a total of 13,200 square kilometers of forest loss.

Many strategies have been proposed to preserve the Amazon Forest, some including technologies 4.0. Some examples are: more frequent environmental inspections; forest administration methods that integrate public policies and private governance; intensification of agribusiness in smaller, more productive land areas as a way of controlling the expansion of the agricultural frontier. Other suggestions include an entirely new paradigm for the sustainable development of the Amazon that incorporates platforms and services following the guidelines of agriculture 4.0. That would include: biomimetic innovations emulating natural formations and Amazonian processes and ecosystems; biomaterials such as biomechanical sensors inserted into the forest functional processes through artificial intelligence and robotics. In such arrangements, the recommended governance models include public and private R&D laboratories, social entrepreneurialism, and investment in companies that create clean and climate-smart technologies. However, given that the region only produces 2% of the Ph.D. holders in Brazil (330 out of the 16,745 doctorates awarded in 2014), human resources qualified in digital technologies, biotechnology, and other advanced technologies are scarce (NOBRE et al., 2016), a problem that urgently needs to be addressed.

In 2017, Brazil had 132 smart farming start-up companies. Those companies are known as Agtechs (ABSTARTUPS, 2017), and they were located 31% in São Paulo, 16% in Minas Gerais, 10% in Paraná, and 10% in Santa Catarina. Thus only a minimal portion of these companies was located in other states or regions such as the North and Northeast. The solutions these firms offer involve: software, drones, and IoT sensors for farm management (44% of the companies); trading platforms (22%); agricultural data management and analytics (15%); food traceability and security platforms (9%); communication tools (7%); and biomaterials, bioenergy and biotechnology (3%). Most of the companies operate based on Software as a Service (SAAS) models by issuing licenses for a limited period of product use. The growth in the number of Agtechs has accompanied the recent emergence of the use of technologies 4.0 in Brazilian agribusiness (PIVOTO et al., 2018). However, only a few Agtechs have business models focusing on agricultural sustainability or environment/climate change-related services. Most of these start-ups basically seek to increment agro-industrial productivity.

Conclusion

Theoretical models of Sustainability Transitions are useful in the analysis of the trajectories of different sectors toward a low-carbon economy. However, the Brazilian socio-environmental sciences have largely neglected such models. This article proposes the use of this conceptual framework to deepen the debate on agriculture 4.0 by highlighting its potential and limitations toward the decarbonization of the agricultural industry. For analytical purposes, we segmented the Brazilian agroindustry into three subsectors: family farming, conservative agribusiness, and sustainable agribusiness, discussing different movements within these subsectors for the adoption of low-carbon 4.0 technologies. This paper aims to fill this gap, which is still little explored, although agribusiness is a major contributor to the Brazilian emissions and has enormous potential for advancing a low-carbon economy.

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AMBIENTE & SOCIEDADE
25 anos años years

Agricultura 4.0 e mudanças climáticas no Brasil

Eduardo Viola
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Resumo: Este artigo introduz o debate sobre transições sociotécnicas de baixo-carbono no agronegócio brasileiro, partindo da premissa de que parcela crescente do setor adota tecnologias digitais em seus modelos de negócios, configurando um novo paradigma produtivo, a agricultura 4.0. Utilizamos a teoria de Transições para a Sustentabilidade para examinar a relação entre agricultura 4.0 e mudanças climáticas no Brasil. Para tanto, classificamos o agronegócio em três subsetores: agricultura familiar, agronegócio conservador, e agronegócio sustentável. O artigo demonstra desafios de ordem técnica, institucional e político-econômica para cada um desses subsetores avançar em direção a uma economia de baixo carbono, sendo o agronegócio sustentável o que tem tido melhor desempenho até o momento.

***Palavras-chave*:** Agricultura 4.0; mudanças climáticas; Brasil; agronegócio sustentável; transições para a sustentabilidade

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Artigo Original

AMBIENTE & SOCIEDADE 25 anos años years

SciELO

Agricultura 4.0 y cambios climáticos en Brasil

Eduardo Viola
Vinícius Mendes

Resumen: Este artículo introduce el debate sobre las transiciones socio-técnicas de bajo carbono en la agroindustria brasileña, partiendo de la premisa de que una porción creciente del sector adopta tecnologías digitales en sus modelos de negocio, configurando un nuevo paradigma productivo, la agricultura 4.0. Usamos la teoría de Transiciones hacia la Sostenibilidad para examinar la relación entre la agricultura 4.0 y el cambio climático en Brasil. Clasificamos la agroindustria brasileña en tres subsectores: agricultura familiar tradicional, agroindustria conservadora y agroindustria sostenible. El artículo demuestra los desafíos técnicos, institucionales y político-económicos para cada uno de estos subsectores contribuir al avance hacia una economía de bajo carbono, y observamos que la agroindustria sostenible tiene el mejor desempeño hasta el momento.

Palabras-clave: Agricultura 4.0; cambios climáticos; Brasil; agroindustria sostenible; transiciones hacia la sostenibilidad

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