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Industry 4.0: a critical reflection on its impacts on family farming

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This paper identifies groups of disruptive technologies within the framework of Industry 4.0 that can advance and integrate sustainable rural development processes. Technological advances are described and an analysis is made of the possible positive and negative effects of their implementation in family and sustainable agriculture in Brazil. To support family farming's innovative potential here, the restructuring of existing power relations and higher levels of participation, training, and education are required.

KEYWORDS

Industry 4.0, sustainable rural development, family farming, innovation strategies, disruptive technologies

1 Introduction

In contemporary society, technology has become an indispensable component of daily life, seamlessly integrated into a wide range of activities. From ordering food and watching movies to communicating with friends and navigating transportation, technological devices have become ubiquitous. This pervasive presence of technology underscores its profound influence on modern lifestyles and interactions.

Technological advancements have significantly impacted the means of production, revolutionizing both industrial and agricultural sectors. Consequently, these developments have fundamentally altered the nature of work itself. Schwab (2016, p. 18) highlights pivotal moments of "revolution" in our social and economic structures, often driven by technological innovations and shifts in societal perspectives.

The author posits that one of the earliest major transformations in human lifestyles occurred with the transition from hunter-gatherer societies to agricultural ones. This shift necessitated new approaches to work, combining human and animal labor to optimize food production.

Following the shifts in food production, the world experienced a series of profound transformations. Urban centers began to emerge, and mechanical power gradually supplanted muscle power, a defining characteristic of the industrial revolutions (Schwab, 2016, p. 18).

The first industrial revolution (1784) was primarily characterized by the mechanization of various activities, with steam engines and railroads playing pivotal roles. The second industrial revolution (1870) was marked by the adoption of electricity and the implementation of mass production techniques in industries. The third industrial revolution (1969) witnessed significant advancements in science, digital technologies, computers, telecommunications, and many of the technologies that continue to shape our lives today (Kagermann et al., 2013, p. 13).

The ongoing fourth industrial revolution is characterized by a wide range of technological possibilities across the industrial, service, and agricultural sectors. Unlike its predecessor, which primarily focused on industrial applications, the fourth industrial revolution offers a broader spectrum of technological advancements.

While some countries have already begun to integrate fourth industrial revolution technologies into their agricultural sectors, the adoption of these technologies is uneven, often limited to well-resourced farmers. Given this disparity, it is crucial to consider how these technologies can be effectively integrated into agricultural practices that may not have a high level of capitalization.

In pursuit of its "17 Sustainable Development Goals" outlined in the 2030 Agenda[1], the United Nations has established Goal 2 with the aim of eradicating all forms of hunger and malnutrition by 2030. To achieve this ambitious target, the agenda prioritizes several key objectives.

Among these objectives, Goal 2.a emphasizes the importance of increasing investments in rural infrastructure development. By enhancing infrastructure, the agenda seeks to support sustainable agricultural practices and improve access to markets for rural communities. Additionally, Goal 2.4 focuses on promoting technological advancements through research and extension services. The goal is to foster the development of sustainable food production systems and implement robust agricultural practices that can contribute to global food security.

The confluence of the fourth industrial revolution's technological advancements and the imperative to strengthen sustainable family farming in developing countries presents a promising avenue for innovation. By integrating technological solutions into family farming practices, it is possible to positively impact various segments of the agricultural value chain.

A Critical question that arises in this context is: What specific technological and disruptive innovations can contribute to sustainable development in family farming? This exploration aims to identify potential solutions that can enhance the productivity, resilience, and sustainability of small-scale agricultural enterprises.

To address the question of how disruptive technologies of Industry 4.0 can be adapted by family farming, this research aims to critically analyze these technologies and their potential applications in the context of small-scale agriculture.

The research will involve a comprehensive review of existing literature on Industry 4.0 and family farming. This review will encompass global and Brazilian perspectives on Industry 4.0, as well as an examination of specific disruptive technologies identified by Schwab (2016). The analysis will consider both the potential benefits and challenges that these technologies may pose for family farming.

Furthermore, the research will delve into the current capabilities and limitations of family farming in generating innovative and sustainable rural development processes. By exploring these factors, the study will contribute to a deeper understanding of the potential synergies and challenges associated with integrating Industry 4.0 technologies into family farming practices.

1 Agenda 2030: The 17 Sustainable Development Goals. Available at: http://www.agenda2030.org.br/ods/17/ (accessed March 12, 2021).

2 Transition to big industry and the formation of the Modern Industrial Corporation

The transition from manufacturing to big industry was characterized by a significant disruption in the traditional work processes. This disruption was primarily driven by the escalating productivity of labor, which accelerated production speed and fostered automation. Underlying this transformation was a shift in the composition of capital, a process that Marx (1867) described as a gradual evolution from a statist society to the Industrial Revolution. This evolution coincided with a relative decline in variable capital and a corresponding increase in constant capital, reflecting the progressive accumulation and concentration of wealth (Hobsbawm, 1962; Harvey, 2001, 1982).

The pivotal factor in the rupture caused by rising labor productivity during the transition to big industry lies in the relationship between the technical and organic components of capital. The technical component, responsible for augmenting the mass of the means of production, operates in contrast to the organic component, which represents the mass of labor power that sets these means in motion (Marx, 1867; Foster, 2014; Mokyr, 2002).

As the means of production expanded exponentially, the demand for labor experienced a disproportionate shift. The organic component, reflecting the value composition of capital, demonstrated a growth in constant capital relative to variable capital (Marx, 1867). This divergence meant that the demand for labor could increase or decrease independently of the proportional growth in the mass of the means of production.

Marx's law of the falling rate of profit, as articulated in his analysis of capital accumulation (2013), posits that constant capital tends to increase relative to variable capital over time. This trend, driven by the transformation of the composition of capital, significantly influenced the dynamics of big industry compared to its manufacturing predecessor.

The increasing dominance of constant capital in the production process facilitated the progressive displacement of the workforce through technological advancements and the reorganization of work. This shift toward technification and mass production was a key strategy for accumulating capital. As the organic composition of capital grew with accumulation, there was a concomitant tendency toward the concentration and centralization of capital. This concentration was fueled by competition and credit, which enabled businesses to invest frequently in technological progress and the development of new technical compositions.

In the context of expanded reproduction, where a portion of newly created value is allocated to increasing the scale of accumulation, the goal is to reduce costs through mass production and lower commodity prices. This strategy aligns with the trend toward a higher organic composition of capital, as it necessitates greater investment in machinery and technology while potentially reducing the demand for labor.

The consequences of these transformations, stemming from the expansion of production scales, the accelerated generation of surplus value, and the cyclical reinvestment of surplus value into capital, had profound implications for the dynamics of the capitalist system, as well as for the nature and application of productive labor. The result was the relentless growth of constant capital at the expense of variable capital, coupled with a regulated control over wages. This structural shift entailed a more rapid expansion of the sector producing means of production compared to the sector dedicated to consumer goods. This disproportionate growth forms a central aspect of the cyclical behavior inherent to the capitalist mode of production, as it both arises from and further propels the accumulation of capital. The system's logic is not primarily oriented toward the production of consumer goods, but rather toward the continual production of means of production. Consequently, this sector's development is notably accelerated due to the concurrent expansion and centralization of total capital, alongside the modernization of existing capital through technological advancements. These processes underscore the system's inherent drive toward capital accumulation rather than the direct satisfaction of consumer needs, thus reinforcing its cyclical and self-sustaining nature (Marx, 1867; Hobsbawm, 1999; Foster, 2014; Harvey, 1982).

The transformations in the productive forces of labor, driven by technological advancements and the accumulation of capital, have inadvertently eroded the foundation upon which the capitalist system rests. By reducing the number of workers engaged in value-creating activities, these changes diminish the pool of labor from which surplus value can be extracted.

This inherent contradiction within the capitalist system has significantly modified the organic composition of capital, leading to repercussions for wage regulation. One such consequence is the generation of an "industrial reserve army," a concept introduced by Marx. This surplus labor pool exerts downward pressure on wages, as workers compete for limited employment opportunities. Additionally, increased productivity can lead to a reduction in the value of labor power, as the time required to produce a unit of value decreases.

The displacement of workers due to technological advancements, a hallmark of the transition to big industry, created a pool of unemployed individuals at the disposal of capital during periods of expansion. This phenomenon served as a mechanism for maintaining wages at subsistence levels within the capitalist system.

Moreover, the growth in productivity itself tended to exert downward pressure on wages. The logic of accumulation, coupled with the creation of an industrial reserve army, disciplined the workforce. This reserve not only enabled capitalists to extract a greater amount of labor from a smaller number of workers but also facilitated the replacement of skilled workers with less skilled ones. The resulting overwork of these less skilled workers became a source of wealth for individual capitalists (Marx, 1867; Harvey, 2001, 1982).

In summary, the transition to big industry fundamentally altered the relationship between productive labor, constant capital, and wages. Productive work became increasingly conditioned by the dynamics of constant capital accumulation, while wages were subject to fluctuations influenced by the industrial cycle and the availability of labor.

Classical administration and scientific management as new ways of organizing companies and work provided planning and management of individualized positions to try to solve problems of coordinating complex functions and subordination of work. Both became, based on the structural changes that oligopolistic capitalism was developing in the context of the Second Industrial Revolution, two critical challenges that needed to be overcome in order to guarantee the acceleration of productivity growth and the potentialization of capital accumulation in accordance with an increasingly mechanized, bureaucratized and routine way of life.

The first significant transformation stemmed from the emergence of a new competitive paradigm centered on innovation, aimed at differentiating and diversifying both production processes and industries. This shift was driven by the improvement or creation of new products, the establishment of higher barriers to market entry through substantial investments in research and development (R&D), and the implementation of strategic market planning. The second transformation arose from the increasing integration of science into the innovation process. This development facilitated the rise of new industrial sectors and marked a substantial transition from labor-intensive production to mechanization. Moreover, the innovation process—whether inventive or incremental—became internalized within firms, evolving from an external phenomenon into an institutionalized function through the creation of dedicated R&D departments. Lastly, the third transformation was characterized by an unprecedented concentration of capital, which promoted the formation of corporations. This shift gradually led to the decline of individual capitalists, as shareholders emerged as collective actors, consolidating and centralizing capital through the development of competitive markets and the incorporation of technology into the production process (Quadros Carvalho, 2021).

The Modern Industrial Corporation (MIC) emerged as both a coordination and subordination mechanism, designed to address the two key challenges mentioned previously: first, the need for speed, safety, and efficiency in production processes, and second, the necessity of controlling both the timing and content of workers' labor. Classical management theory, whose foundational ideas can be traced back to Charles Babbage, developed a coordination and macro-organizational framework that combined military and engineering principles. The primary objective of this framework was to establish a systematic process of "planning, organizing, directing, coordinating, and controlling." This approach was operationalized through methodologies such as "management by objectives (MBO)," the systems of budget planning and programming, and other techniques that emphasized comprehensive national planning and control (Morgan, 2006).

The organic growth of the Modern Industrial Corporation (MIC) also shaped the organizational culture of companies from a more rational managerial perspective. The most successful firms were those that effectively rationalized their production units, as their organizational structures adapted to market dominance achieved through acquisition and merger processes, resulting in increased centralization. As noted by Quadros Carvalho (2021), during this organizational phase, centralization primarily targeted decision-making processes, while integration encompassed the incorporation of new activities such as marketing, which played a key role in the development of new products driven by both R&D outcomes and market demand. Furthermore, segmentation involved the creation of new business areas with incremental costs managed in line with the economic cycle, and departmentalization fostered the specialization of functions within the firm, promoting efficiency and further enhancing organizational control.

In the macro-organization phase, as emphasized by Quadros Carvalho (2021), a pivotal idea emerged: the company must exercise complete control over its processes, allowing it to plan meticulously, regulate all variables, and anticipate potential problems. This approach underscored the importance of comprehensive oversight in modern industrial management. Engineers, in this context, became the driving force behind the social relations of modern capitalism, taking on both technical and managerial roles. Their influence extended to the creation of an intelligence center within the corporation, comprising key departments such as marketing, R&D, engineering, and finance.

Departmentalization during this phase advanced toward an increasingly rigorous specialization, dividing work technically according to the specific nature of tasks and strategic organizational functions. Furthermore, a strategic monitoring structure was established to oversee the creation of semi-independent business units, enhancing flexibility within the organization while maintaining centralized oversight. This entire system was built upon a vertical organizational structure, where communication flowed hierarchically, and the chain of command took precedence over technical authority, reinforcing the centralized control of decision-making and operations within the corporation.

> "The changes in organizational structure thus produced were aimed at operating as precisely as possible within frameworks of authority, for example, in terms of job responsibilities and the right to give orders and demand obedience. Patterns of authority serve as points of resistance and coordinate activities, restricting them in certain directions and encouraging them in others" (Morgan, 2006).

Technical management, as pioneered by Frederick Taylor, introduced a systematic mechanism for subordinating labor with the explicit objective of controlling both the time and content of workers' tasks. This approach, as described by Morgan (2006), "called for detailed observation and measurement of even the most routine work to discover the best way of doing things." To achieve this, the strategic planning of technical personnel required a comprehensive consideration of the entire production process, aimed at identifying the most efficient methods. Workers were then assigned specialized tasks, for which they were trained to execute with precision.

This process fostered a work environment heavily oriented toward productivity, where machines, technology, and the pace of work took precedence over the workers themselves. Under this model, laborers became subordinated to the technological systems in place, with their roles reduced to serving the demands of the production process. As Morgan (2006) notes, workers were ultimately transformed into "servants or accessories," subordinated to the technical and mechanical imperatives of the industrial system, highlighting the dehumanizing aspects of Taylorism within the capitalist production model.

The basic principles of scientific management can be summarized as follows: the control and discipline of workers' knowledge under management authority, the selection and training of workers, and the detailed planning and control of work processes. The first principle involves a systematic study of workers' elementary movements, with the goal of distinguishing between useful and inefficient actions. This analysis aims to increase the intensity of labor by optimizing the time required to complete specific tasks, using the ideal pace of work as a benchmark for evaluation. Through this process, management gains greater control over the labor process, ensuring that workers' knowledge and actions align with the company's efficiency objectives, ultimately subordinating worker autonomy to the imperatives of productivity.

The second principle of scientific management is closely linked to the first, as the detailed analysis of tasks enables management to more effectively select the right worker for each specific role, irrespective of the individual's prior skills or knowledge related to the task. This principle emphasizes the alignment of specific worker abilities with particular job demands, where the criteria for fulfilling these demands are determined by the company's operational needs or market forces. By doing so, management exercises control over the workforce, tailoring individual contributions to maximize productivity in accordance with business priorities.

The third and final principle involves the assignment of specialists from various professional backgrounds to oversee distinct productive functions. This practice laid the groundwork for the development of departments such as production planning and control, quality control, and the establishment of industrial regulations, among others, which are integral to industrial activity. These specialized departments further consolidated management's control over the production process, ensuring that every aspect of industrial operations was systematically regulated and optimized (Fleury and Vargas, 1983; Shou et al., 2022).

The limitations of Taylorist principles stem from their mechanistic conception of organizational structure and the work process. These principles assume that, regardless of contextual or environmental variations, standardized responses are both possible and desirable. This rigid framework diminishes the potential for innovative contributions from individuals outside of privileged corporate positions, who may otherwise enhance the efficiency of production or drive significant sectoral changes. By reducing workers' roles to narrowly defined tasks, Taylorism constrains the company's ability to adapt and respond to rapid political or economic transformations, resulting in diminished flexibility.

The rigidity of the organizational structure inherent to Taylorist management exacerbates these issues, as it limits improvisation, maneuverability, and responsiveness to unpredictable daily challenges. The excessive reliance on machines and pre-defined processes within this framework further reduces the capacity for creative problem-solving and adaptive responses. As a result, the system becomes vulnerable to disruptions and struggles to meet the demands of dynamic environments, where flexibility and innovation are crucial for sustained competitiveness and growth.

2.1 The role of industrial transformation in the modern world

The First Industrial Revolution, as interpreted by Hobsbawm (1999), must be understood as a period of accelerated growth driven by profound economic and social transformations. These transformations were rooted in the capitalist relationship between the owners of capital (money and means of production) and the owners of labor power—free workers—whose interactions were aimed at the valorization and accumulation of capital, as analyzed by Marx (1867). The revolution was the outcome of several key factors: changes in agricultural production designed to meet the needs of a rapidly growing population, the mass migration of rural peasants to urban centers where they became industrial workers, competition for control over colonial markets, and the rise of new production methods, most notably in the textile industry (Hobsbawm, 1999). These developments laid the groundwork for the capitalist system and fundamentally altered the socio-economic landscape, marking a critical juncture in the history of industrialization.

According to Ewen (1976), the second industrial revolution was marked by the establishment of the labor market and extended beyond the mere introduction of new methods for mass production. A pivotal development during this era was the emergence of the consumerist doctrine, which successfully manipulated individual desires and needs to align with the profit interests of industries. This process of conditioning individuals to prioritize the acquisition of goods and services as the fundamental purpose of existence permeated various aspects of society, including factories, politics, families, and everyday life.

Industrial revolutions represent pivotal moments in human history, radically altering our relationship with the world. These transformative periods are characterized by a confluence of innovations that revolutionize production processes, often leading to profound societal disruptions.

The effects of industrial revolutions extend beyond the realm of production, encompassing political, economic, social, cultural, and cognitive dimensions. These transformations have the power to reshape societies irrevocably. While capable of generating significant advancements and wealth, industrial revolutions can also exacerbate inequalities and social conflicts.

While the term "industrial revolution" is often used generically, it is possible to differentiate these transformative periods based on specific technological, economic, social, and political changes. By examining these underlying factors, we can gain a deeper understanding of the unique characteristics of each industrial revolution.

The Industrial Revolution, a period of transformative economic and social change, originated in Western Europe, with France, England, and Germany serving as pioneering nations. Beginning around 1780, these countries witnessed a remarkable acceleration in the productive capacity of their societies, fueled by the increasing production of goods and services. This era marked the consolidation of the capitalist accumulation process.

As noted by Hobsbawm (1999), the initial phase of the Industrial Revolution centered on the production of goods, particularly textiles and metal-mechanics. These industries employed relatively low-intensity technologies and primarily responded to existing demand for their products and services. To catalyze a more profound industrial revolution, however, a global expansion of trade and the establishment of mechanized workshops capable of producing large quantities of goods at reduced costs were essential. This combination of factors created a self-sustaining market for these goods, driving further industrial development.

At this juncture, England emerged as the first nation to initiate a process of industrialization, characterized by a confluence of technological and organizational innovations that represented a significant paradigm shift for the era. This transformation involved the establishment of various incentives and opportunities that facilitated the growth of manufacturing industries, particularly through the procurement of low-cost inputs from colonial territories.

Additionally, the availability of labor was bolstered by the migration of individuals from rural areas to urban centers, coupled with ongoing modifications to production methods that enhanced efficiency. The expansion of markets, particularly through the growth of extra-European frontiers, played a crucial role in this process. Colonies not only supplied raw materials but also served as markets for the finished goods produced in England. This intricate interplay of factors contributed to the emergence of a robust industrial economy, fundamentally altering the social and economic landscape of the time.

The First Industrial Revolution marked a significant transition characterized by the introduction of mechanical production systems powered by hydraulic and steam traction, primarily within the textile industry. This shift necessitated changes in the organization of work, as production became concentrated at specific physical locations. The demand for labor created a migration from rural areas to urban centers, fundamentally transforming England's economic structure from an agrarian and artisanal economy to an industrial one, driven by the manufacture of machinery utilizing steam power. This transformative process commenced in the mid-18th century and continued until the end of the 19th century.

In the early 20th century, a Second Industrial Revolution emerged, distinguished by a further evolution in production systems, notably through the implementation of Fordism. This phase introduced mass production techniques and a heightened division of labor. It was characterized by the widespread adoption of fossil fuels and electricity, which became integral to industrial operations. The Second Industrial Revolution was predominantly propelled by advancements in the chemical, electrical, and automobile industries, marking a new era of technological and organizational sophistication in manufacturing.

In the 1970s, a Third Industrial Revolution commenced, characterized by the integration of microelectronics and information technologies aimed at automating production and industrial processes. This revolution was marked by significant advancements in work organization, notably through the principles of scientific management articulated by Taylor et al. (1961). The incorporation of Taylorism into the framework of continuous improvement in production, as emphasized by Ohno (2018), played a pivotal role in shaping this era.

These developments naturally led to a gradual replacement of human labor on the factory floor, driven by the increasing reliance on scientific methodologies. The growing incorporation of a scientific component into industrial processes was underpinned by the extensive use of data and automation technologies. As a result, the Third Industrial Revolution not only transformed production capabilities but also fundamentally altered the dynamics of labor relations within the industrial sector, emphasizing efficiency and precision through technological innovation.

2.2 The fourth industrial revolution and Industry 4.0

The term "Industry 4.0" was first introduced at the Hannover Fair in Germany in 2011, representing an initiative by developed nations to reclaim their competitive share in the global industrial landscape, particularly in response to the rising influence of Asian countries in value-added manufacturing (FIRJAN, 2016). Schwab (2016) articulates that Industry 4.0, often referred to as "smart factories," facilitates the interaction between physical and virtual production systems on a global and flexible scale, potentially leading to innovative work practices.

Chancellor Angela Merkel emphasized the transformative nature of Industry 4.0, stating, "Industry 4.0 is the complete transformation of the entire sphere of industrial production through the fusion of technology and the internet with conventional industry" (European Parliament, 2015).

In a more detailed exploration of this concept, Hermann, Pentek, and Otto conducted a bibliometric study that cataloged various materials across five different databases in both German and English. Their research culminated in the following definition of Industry 4.0:

> Based on the results of the literature review, we define Industry 4.0 as follows: Industry 4.0 is a collective term for technologies and concepts for organizing the value chain. Within the modular structured smart factories of Industry 4.0, the SCP monitors physical processes, creates a virtual copy of the physical world and makes decentralized decisions. Through the IoT, the SCP communicates and cooperates with each other and with humans in real time. Through the IoS, both internal and inter-organizational services are offered and used by participants in the value chain (Hermann et al., 2015).

The authors also state that Industry 4.0 has four key elements in its composition. Table 1 provides a brief definition of these elements.

Table 1 shows that in Industry 4.0 there is a complete interaction between physical and virtual elements, with the aim of increasing production efficiency in the new industries. In addition, the elements also show us that there has been a major change in ways of working, with the integration of physical machines and the virtual world, in which people are increasingly being left out of production processes. On the other hand, according to the World Economic Forum (2020), the demand for Information Technology (IT) professionals, who are professionals with the requirements to work with the new technologies of industry 4.0, is increasing.

In Brazil, the advancement of Industry 4.0 has not yet reached the levels observed in other countries, as the nation remains primarily in the transition phase from Industry 3.0. FIRJAN (2016) indicates that a significant portion of the national industry is still moving from Industry 2.0 to Industry 3.0. This transition involves a shift away from traditional production systems reliant on assembly lines and electrical power toward more automated, robotics, and programming-based production systems.

According to the National Confederation of Industry (CNI, 2016), further development of Industry 4.0 in Brazil necessitates that companies begin integrating digitalization into their production and service delivery processes. A study conducted by CNI revealed that 42% of surveyed companies were unaware of the critical role that digital technologies play in enhancing industrial competitiveness. Furthermore, more than half of the respondents indicated that they do not employ any form of digital technology in their operations.

This context presents a considerable challenge for the implementation of Industry 4.0 in Brazil. While some companies are beginning to adopt technologies associated with Industry 4.0, a substantial number still need to embrace this paradigm shift. In light of these challenges, it is essential to engage in critical reflection and propose solutions that facilitate the integration of these technologies. FIRJAN (2016) identifies several key factors for discussion, including:

> (...) to obtain intelligent strategic policies, incentives and incentives from the government; to bring together entrepreneurs and industry managers with vision, boldness and a proactive attitude; to have technological development and the training of highly qualified professionals by academic and research institutions, preferably in close proximity to industry.

Incentive policies for Industry 4.0 represent a viable solution for the implementation of advanced technologies across various sectors. However, such initiatives must be executed thoughtfully and strategically, with a strong emphasis on investment in research and the integration of research institutions with the industrial, agricultural, and service sectors. Additionally, these policies should be designed to accommodate businesses of all sizes, ensuring that small and medium enterprises (SMEs) are not excluded in favor of large corporations that already possess the economic capacity to adopt digital technologies.

The Brazilian agricultural sector has begun to incorporate certain technologies associated with Industry 4.0, particularly within large farms and startups that offer services in this domain. In recognition of this potential, the Ministry of Agriculture, Livestock and Supply (MAPA), the Ministry of Economy (ME), the Ministry of Science, Technology and Information (MCTI), and the Brazilian Industrial Development Agency (ABDI) jointly launched a call for proposals for the Agro 4.0 Program in 2020[2].

The primary objective of the Agro 4.0 Program is to promote the adoption of Industry 4.0 technologies within agribusiness,

2 Brazilian Industrial Development Agency. Call for tenders No. 003/2020 agro 4.0: selection of projects to adopt and disseminate 4.0 technologies in agribusiness. Available at: https://agro40.abdi.com.br/SitePages/Layout/edital.aspx.

TABLE 1 Key elements of industry 4.0.

Cyber physical Systems—CpS	Internet of Things (IoT)	Internet of Services (ioS)	Smart factories
These are systems that allow real operations to be connected to automated computing and communication infrastructures.	It is the network of physical objects, systems, platforms and applications with embedded technology to communicate, sense or interact with internal and external environments.	When the IoT network works perfectly, the data processed and analyzed together will provide with a new level of added value.	In smart factories, CpS will be used in production systems, generating significant gains in efficiency, time, resources and costs compared to traditional factories.

Source: Own elaboration based on Hermann et al. (2015). Translation by FIRJAN (2016).

thereby enhancing efficiency, productivity, and cost-effectiveness in Brazilian agricultural practices. To achieve this goal, the program is designed to support companies or farms utilizing 4.0 technologies, which are categorized into four distinct groups.

Winners of the program will be awarded in each category, with a total of up to 14 projects eligible for recognition, as detailed in Table 2. To qualify, companies must actively implement 4.0 technologies and align themselves with the National Classification of Economic Activities. This initiative represents a crucial step toward fostering innovation and competitiveness within Brazil's agribusiness sector while addressing the need for equitable access to advanced technological resources.

One notable criticism of the Agro 4.0 Program pertains to the size and capacity of the companies eligible to participate. The program appears to favor firms that already possess substantial economic resources, thereby inadvertently excluding smaller enterprises that could also benefit from integrating Industry 4.0 technology concepts into their operations. A pertinent example is sustainable family farming, which plays a crucial role in feeding Brazilian society, contributing to ∼70% of the food consumed in the country. Despite its significance, this sector has yet to fully embrace digital technologies within its production processes and operational methodologies (Zoby et al., 2003).

Although the program faces these criticisms, it provides a valuable framework for reflecting on the application of disruptive technologies in sustainable family farming. The categorization of technologies by sector offers a constructive perspective for examining how these innovations can be leveraged effectively. In the subsequent section, we will explore various disruptive technological innovations, assessing their advantages and disadvantages within the context of sustainable family farming. This analysis will help illuminate the potential pathways for integrating advanced technologies into this vital sector, ultimately contributing to enhanced productivity and sustainability.

2.3 Disruptive technological innovations

With the advent of the Fourth Industrial Revolution, technological innovations have become increasingly integrated into our daily lives. For instance, the use of smartphones equipped with applications facilitates informed decisions regarding the application of organic products in agricultural production. Such technologies exemplify the new digital technologies associated with Industry 4.0, which are fundamentally reshaping the way we conduct activities—both professionally and recreationally. These innovations are often categorized as disruptive innovations due to their transformative potential.

TABLE 2 Distribution by category of awarded projects.

Category	Value	Number of winners
Category 1	R$ 300.000,00	Four projects
Category 2	R$ 300.000,00	Four projects
Category 3	R$ 300.000,00	Four projects
Category 4	R$ 600.000,00	Two projects

Source: Own elaboration based on Agro 4.0: Adoption and Diffusion of Technologies in Agribusiness (2020).

The concept of disruptive innovation was pioneered by Clayton Christensen in his seminal works *The Innovator's Solution* and *The Innovator's Dilemma*. Christensen builds upon Joseph Schumpeter's notion of creative destruction, which describes the continuous process of dismantling old structures while simultaneously fostering the emergence of new ones, akin to an industrial mutation (Schumpeter, 1961). In the context of disruptive innovations, while the applications may be simpler in nature, the effects on market structures can be comparably profound, mirroring the consequences of creative destruction.

Disruptive innovations introduce novel solutions to various market challenges, particularly addressing the needs of non-traditional consumers who may have been overlooked by existing products or services (Christensen et al., 2006). This dual capacity for simplicity in application and significant market impact underscores the pivotal role that disruptive technologies play in shaping contemporary economic landscapes and consumer behaviors.

According to Nogami (2018), "creative destruction involves disrupting the market through innovative products and processes, while disruptive innovation focuses on variations in demand requirements." This distinction is further elucidated by the author's examination of the characteristics inherent to both perspectives: innovations associated with creative destruction tend to be radical, whereas disruptive innovations are typically incremental. Nogami also notes the similarities between the two concepts, particularly their shared capacity to "destabilize dominant systems such as monopolies, oligopolies, and large, established companies."

Table 3 presents various disruptive technologies that could be leveraged in sustainable family farming, thereby enhancing its resilience and viability. However, it is crucial to approach the integration of these technologies with caution, ensuring that their implementation does not inadvertently subject family farms to the dominance of monopolies, oligopolies, and large corporations. Instead, the focus should also encompass strategies that empower families, fostering their independence and autonomy.

TABLE 3 Disruptive technologies in agriculture by segment.

Technology	Positive	Negative
Input segment		
3D printing	Accelerated product development; reduction of the design-manufacturing cycle; easy production of parts and tools	Increase in waste for disposal; production of anisotropic parts; piracy; brand and quality changed
Bioinsumos	Control of unwanted organisms in production; reduce environmental impact; increase the performance of seeds, soil and plants; biofertilizers	New environmental problems; registration and patenting; access and cost; production and knowledge
Seeds	Increased seed resistance to viruses and climatic variations; greater production efficiency; collaborative seed production; open patenting of genetic resources	Loss of seed varieties; dependence on the use of modified seeds; they can absorb herbicides or pesticides, causing possible damage to health and the environment
Primary segment		
Internet of things and for things	Increased efficiency in the use of resources; increased productivity; logistical efficiency; the equipment will be able to use its environment comprehensively and act autonomously	Breach of privacy; threat to people's safety in the virtual world; consequences of a possible "*Pearl Harbol* Digital"; loss of jobs in the countryside;
Exoskeleton	Contributing to weight and strength reduction for rural workers; increased productivity in jobs that require strength; avoid diseases caused by excess weight	Muscular atrophy; posture problems over time; increased cardiac and energetic effort
Secondary segment		
Food production	Reducing waste and increasing profitability; automation and dynamic information exchange; digitalization of production chains and demand	Technological dependence
Drones	Application of natural herbicides; application of biological agents; production mapping	High prices for small producers; dependence on companies that apply this type of technology; unemployment for professionals who don't master digital skills
Sensors	Monitor the weather; cost reduction; monitoring unwanted organisms	Technological dependence
Tertiary segment		
Big data	Faster and better decisions; open data for innovation; reducing costs	Loss of work; privacy concerns; confidence in the data
Ubiquitous computing	Greater economic presence of disadvantaged populations, located in remote or underdeveloped regions; access to knowledge, greater employment and changes in the way people work; expanding the size of the market.	Walled gardens (limited environments for authenticated users only) do not allow full access to some countries.
A supercomputer in your pocket	Greater economic presence of disadvantaged populations, located in remote or underdeveloped regions; access to knowledge, greater employment and changes in the way people work; expanding the size of the market.	Environmental impact of production and disposal

Source: Elaboration based on Schwab (2016) and Agro 4.0: Adoption and Diffusion of Technologies in Agribusiness (2020).

In this context, government organizations play a pivotal role in the development and dissemination of disruptive innovations. Their involvement is essential not only for facilitating access to these technologies but also for implementing supportive policies and programs that prioritize the needs and sustainability of family farms. By doing so, they can help create an environment conducive to innovation while safeguarding against the potential monopolistic tendencies that often accompany technological advancements.

The integration of disruptive technologies in agriculture offers numerous advantages across the four segments outlined in this paper. These benefits range from alleviating physical labor—an essential aspect of technological revolutions—to facilitating entry into the virtual marketplace. The adoption of disruptive innovations within family farming enables enhanced efficiency in production processes, risk monitoring, and the implementation of environmentally sustainable solutions.

Moreover, family farmers can gain access to both national and international markets through digital platforms, utilizing computers, tablets, or smartphones with internet connectivity. This connectivity not only enhances their operational capabilities but also brings them closer to consumer groups actively seeking specific products.

However, despite the myriad positive aspects associated with disruptive innovations, a strategic plan is imperative for their effective application in family farming. This plan should emphasize collaboration among farmers, society, government, and research institutions. The objective is to co-develop these technologies in a manner that empowers family farmers, ensuring they do not become overly dependent on the technology itself or on its suppliers. By fostering a collaborative approach, the agricultural community can harness the full potential of disruptive innovations while maintaining independence and resilience in the face of market fluctuations and technological changes.

2.4 Sustainable rural development and family farming

Reflecting on the impacts of Industry 4.0 on sustainable rural development, particularly concerning family farming, is crucial in understanding the evolving dynamics of agricultural practices. Family farming, characterized by its historical reliance on low technology and intensive labor, is at a crossroads where the integration of advanced technological solutions could redefine its future (Buainain, 2007).

Sustainable rural development encompasses a complex array of interrelated factors. According to Schneider (2007), studying development involves a thorough examination of the social processes enacted by diverse human groups, which result in significant transformations in nature, physical and social spaces, and territorial configurations. This multidimensional process encompasses the adaptation and adjustment of production methods while simultaneously transforming societal norms and values.

The configurations inherent in these processes possess the capacity to generate surpluses and catalyze broader development pathways. Since the 1990s, the state's role has been pivotal in shaping public policies that are intricately linked to rural areas, particularly with regard to family farming (Schneider, 2007, p. 12). Such policies aim to foster environments where family farmers can enhance their productivity and sustainability, creating a balanced framework that supports economic viability alongside ecological integrity.

As we consider the integration of Industry 4.0 technologies—such as data analytics, automation, and the Internet of Things (IoT)—into family farming, it is essential to acknowledge both the opportunities and challenges that arise. On one hand, these technologies can empower family farmers to optimize their production processes, improve resource efficiency, and make informed decisions that contribute to sustainability. On the other hand, there is a risk that such integration may lead to dependency on external technological solutions, potentially undermining the autonomy and traditional knowledge of family farmers.

In this context, the influence of state policies becomes increasingly important. Effective public policies must promote not only the adoption of innovative technologies but also the empowerment of family farmers. This involves ensuring access to training, resources, and support systems that facilitate the integration of technology without compromising the foundational principles of sustainable agriculture. By fostering collaboration among government entities, research institutions, and farming communities, we can create a holistic approach that leverages Industry 4.0 advancements while promoting resilience and sustainability in family farming practices. Ultimately, reflecting on these dynamics is essential to shaping a future where family farming can thrive in harmony with sustainable rural development goals.

The discussion on rural development is sustained as an alternative and opposition to agribusiness practices. From an environmental point of view and with criticism of the effects brought about by the green revolution, its technological packages and their environmental effects, other productive alternatives are being consolidated, linked to technical-productive models called alternative, ecological, organic, regenerative, agroecological and other nomenclatures (Almeida, 1999; Ehlers, 1996).

At this point, the ability of these types of models to propose new socio-technical configurations is fundamental, bringing new formats and production models that have become a possible horizon for sustainable rural development.

Given this scenario, it is possible to imagine that the future of rural development will be strongly linked to modernization and technology, especially when we talk about contexts such as family farming, where the basis of profitability is directly linked to agricultural production. In this sense, when we start a debate on technological innovation and agriculture 4.0 (in the context of industry 4.0), we first need to overcome the stereotypical conception of family farming that we still see today.

Although it is highly diverse (Schneider, 2009), we can understand Family Farming, henceforth referred to as FA, as the integration of family, production and work (Wanderley, 1996), as a counterpoint to the industrial logic of so-called Modern Agriculture—AM, or capital-intensive agriculture. CA is based on smallholdings with a wide variety of crops, managed by local owners and staffed essentially by family members (Lamarche, 1993). It is the family's main financial source, retaining the population in rural areas and therefore being one of the main factors responsible for maintaining the local culture and market. While AM is based on medium and large properties, essentially based on monoculture, managed by owners or business groups from outside the region, with employees and professionals generally hired from elsewhere, focused on trading their products in large markets (e.g., exports) and with intensive use of capital and technology.

This format of family-based sustainable rural development can be found in various countries, with different forms of support and local importance, especially in Asian countries such as China and India, African countries such as Ethiopia, and even developed countries such as the United States, Canada, France and Japan. According to the Food and Agriculture Organization of the United Nations (FAO), FA is responsible for a third of the food produced in the world and it is estimated that around 500 million families are in this economic regime. This system cannot be understood generically as a backward sector (mainly technologically and economically), since it is responsible for the production of basic products in the production chain (mostly food) and under an almost subsistence logic. Such an understanding ignores the real role of family farming in the world and in Brazil.

Family farming plays a major role in Brazil, representing around 10 million families and, according to data from the National Confederation of Workers in Family Farming in Brazil (2021), is responsible for 70% of the food that reaches the Brazilian population. The term is defined by law 11.326 of 2004 and states that a family farmer must meet four criteria in order to be legally recognized:

> I. does not own, in any capacity, an area larger than four fiscal modules; II. uses predominantly their own family's labor in the economic activities of their establishment or enterprise; III. has a minimum percentage of their family income originating from the economic activities of their establishment or enterprise, as defined by the Executive Branch; IV. runs their establishment or enterprise with their family (Brazil, 2006). *NOTE: A fiscal module is between 5 and 110 hectares.*

Therefore, a family farmer includes all farmers who carry out rural practices in compliance with the four legal criteria, as well as people from various sectors, such as: agrarian reform settlers (belonging to the Landless Movement—MST), quilombolas, indigenous people, foresters, fishermen and aquaculture producers.

Contrary to the importance of family farming, there is a continuous distancing from the process of modernization and technology, due to the very low level of schooling in the countryside, the lack of connectivity and limited access to credit. Also according to research by the National Confederation of Workers in Family Farming in Brazil (2021), if the country invested in expanding connectivity in the countryside (digital inclusion), the gross value of agricultural production in the country could increase by up to R$78 billion. However, the figures published by the Brazilian Institute of Geography and Statistics (2017) show that only 14% of family farms have access to agricultural mechanization.

Despite this national reality, AF is responsible for an annual turnover of 52.2 billion (2018), well-above AM's 30 billion in the same year. It would therefore be natural to infer that ML has less planted land and that its efficiency of use was or still is higher in ML than in FA. However, despite being present in 77% of all rural establishments, FA occupies only 23% of the country's cultivated areas. Its turnover in relation to the area occupied demonstrates its strength and importance for national and world food, even with the current poor technologies applied (Reichert et al., 2015).

The importance and diversity of family farming in Brazil requires the adoption of differentiated policies adapted to the different configurations. Even taking into account the risks of unemployment and other impacts on the social structure. This opens up a discussion about the innovative technologies that can and should be applied to family farming (Valdiero et al., 2015), the so-called appropriate technologies. As well as evaluating trends in the implementation of precision farming techniques, commonly used in PA, adapted to sustainable agriculture schemes (Hassall, 2010).

A foundational step in this discourse is to comprehend the extent to which technology serves as a cornerstone for decision-making, planning, and the implementation of optimal production techniques and processes within family farming. While technological advancements are undeniably crucial, it is imperative to recognize that rural development is not exclusively determined by these factors.

Contemporary rural development is significantly influenced by external factors, with national infrastructure playing a particularly pivotal role. The integration of technology into rural areas faces two primary infrastructure challenges: universal access to electricity and connectivity. As highlighted by Souza Filho et al. (2004), the average availability of electricity in Brazilian family farming establishments is a mere 38%. Moreover, the quality of this electricity, often supplied through single-phase networks prone to frequent interruptions, is insufficient for many production and technological applications.

According to the 2017 Agricultural Census, released in 2019 by the Brazilian Institute of Geography and Statistics (IBGE), of the 5.07 million rural establishments in Brazil, 3.64 million do not have internet access, or 71.8% of properties. Of the 5 million rural establishments, <28% have an internet connection and, of these, only 46% have broadband. Brazil's strategic growth, with no direct impact on nature, depends directly on bringing the internet to rural areas. In this scenario, a positive trend can be considered. According to data from Embrapa (2020), between 2006 and 2017 there was a 1,900% increase in access to the internet by rural producers, mainly due to smartphones.

In addition to infrastructure barriers, we can highlight some other important points when we think about the difficulties in implementing technology in family farming. These are

- Lack of economic protection mechanisms to cushion the impact of negative production results, leading to resistance to technological innovations on the part of producers. Rural credit in Brazil has always been channeled mainly toward medium and large farmers and has ended up excluding family farmers from technological insertion;
- Lack of interest from technology manufacturers and suppliers: family farming is not considered a relevant audience for agricultural technology manufacturers and suppliers. The innovations and technological tools that promise to make agricultural systems more efficient, sustainable and economically more profitable are not even designed for small producers to access. The very logic behind the development of these technologies is that the larger the farm and the scale of production, the greater the volume of data that can be collected and used in technological development;
- The need for a large investment: in order to meet the different needs of the field, a broad integration of different technologies and processes is necessary for the results to be effective. In other words, the investment in acquiring and implementing digital technologies in production tends to be extremely high and unfeasible for small producers;
- Low instruction level of rural producers: In many countries, information on agricultural innovations is provided by government extension agencies. In Brazil, given the social profile of many family farmers, in particular their low level of education, the use of conventional technical material is not very effective. As the traditionally important official extension services have been dismantled in recent decades, the issue of disseminating information and training to use it is a bottleneck for the development of family farming in the context of Agriculture 4.0.

To reverse the current scenario of limited technology adoption in rural areas, the federal government must prioritize a comprehensive plan for democratizing these technologies. The challenge lies not only in the availability of suitable technology but also in the lack of adequate financing and dissemination mechanisms to make family farming a sufficiently attractive market segment for technology and service providers.

Strengthening relationships and commitments between family farmers (end-users) and researchers and their institutions is crucial. This collaboration can foster the development and adaptation of technologies that address the specific needs of small-scale agriculture.

The current reality underscores the importance of government support and research institution involvement in facilitating the inclusion of family farming in the technology landscape. By providing the necessary resources and expertise, these entities can play a pivotal role in bridging the digital divide and empowering family farmers to leverage technological advancements for sustainable and profitable agricultural practices.

2.4.1 Institutions, innovation, and sustainability

As emphasized by Veiga (2002) and Abramovay (2004), family farming plays a vital role in bolstering local economies at various levels. This capacity stems from the innovative nature of family farmers and their ability to effectively interact with existing institutional networks. Such interactions facilitate the creation of value-added products, reduce logistical costs, and stimulate multi-level economic dynamics.

These authors highlight the inherent capacity of family farmers to generate innovative processes. The constant need to adapt and survive in often challenging environments has fostered a culture of innovation within this sector. Consequently, the social and productive diversification of territories can be attributed, in part, to the innovative and productive capabilities of family farmers (Schneider, 2007, p. 19).

Schneider (2007) analysis of Veiga's work underscores the critical role of rural entrepreneurship in driving local economic development. The demand for products and services generated by family farmers within a specific territory, considering their average scale, can create systemic dynamics that stimulate the circulation of wealth and foster development.

Abramovay (2004) further emphasizes the importance of factors such as collaboration, cooperation, reciprocity, and solidarity within proximity economies. These factors facilitate innovation processes by fostering collaborative dynamics and encouraging joint projects.

2.4.2 *On the limits of incorporating* innovation

Analyzing development processes requires a comprehensive understanding of both their potential and limitations. In rural areas, existing power relations and traditional modes of domination can hinder progress by perpetuating the status quo. To counter these obstacles, it is imperative to expand democratization processes and increase direct participation in decision-making, thereby limiting the influence of mediating groups and elites (Souza, 2021).

Navarro (2001) highlights the presence of conservatism among social actors in rural areas, coupled with a lack of technical capacity and human resources capable of generating innovative proposals for profound change. The author attributes part of this conservatism to the inherent instability of the organizational base within these communities.

Wilkinson (2006) points to a series of characteristics of family farmers and their organizations as limits to the development of innovative processes in rural development, among which the following stand out: the low level of instruction of farmers and their organizations' teams; the limited capacity of local markets to absorb surpluses; the scale required by traditional marketing networks; the issue of intellectual property rights and the danger of private appropriation of the results of innovations; the continuity of compensatory public policies; and the incorporation of the new rurality into public policies.

The integration of family farmers into agri-food or agri-industrial marketing chains, or even the creation of new ones, necessitates careful consideration of its potential social implications. Given the inherent inequalities in market entry conditions, it is crucial to examine these factors alongside the role of technological innovations and food chains in rural development processes.

In the current context, family farming faces increasing demands related to food security, environmental sustainability, and fair production methods. Wilkinson (2006) emphasizes the need for family farmers to develop skills that enable them to consolidate new markets through consumer interaction, the organization of socio-technical networks, and the establishment of short production and consumption chains aligned with consumer demands.

Schneider (2007, p. 29) highlights the remarkable capacity of family farming to successfully respond to the flexible demands of modern markets. This adaptability is rooted in their ability to innovate through experimentation (learning-by-doing) and collective learning facilitated by tacit knowledge.

3 Discussion

This paper explores the profound transformations brought about by the industrial revolutions across societies, economies, production systems, cultures, and the rural world. By examining the key disruptive innovations emerging in rural areas, the analysis aims to position these advancements within the context of sustainable rural development, where family farming plays a pivotal role. Industry 4.0, characterized by the convergence of physical and virtual systems, offers greater flexibility in production within a globalized environment. This paradigm shift introduces new forms of production that can generate novel work opportunities while also presenting unique challenges.

To illustrate the potential impact of disruptive technologies, this paper examines relevant examples across various sectors. By considering both the positive and negative aspects of these innovations, the analysis provides a comprehensive understanding of their implications for rural development. Given the current configuration of Brazilian agriculture, agribusiness stands out as the most dynamic sector for incorporating Industry 4.0 technologies. This is evident in the various programs, such as the Agro 4.0 Program, that actively promote the adoption of these innovations.

The Brazilian Agricultural Research Corporation (EMBRAPA) has undertaken commendable initiatives to facilitate the integration of technology into family farming. Through its research and development efforts, EMBRAPA has developed innovative technological tools aimed at boosting agricultural production among small-scale farmers. These tools encompass a wide range of technologies, including artificial intelligence, machine learning, automation and robotics, blockchain and cryptography for traceability, and the Internet of Things (IoT). The adoption of these technologies, such as sensors, drones, applications, software, management systems, satellite images, tractors, sprayers, and automatic harvesters, has the potential to transform traditional rural areas. By harnessing the power of these tools, family farmers can enhance their productivity, efficiency, and sustainability.

In forest management, the adoption of digital technologies has changed the reality of the activity, making it easier to carry out stages, reducing effort and speeding up and improving the accuracy of area mapping processes. Drones, for example, provide detailed knowledge of the forest from an aerial perspective, making it possible to carry out semi-autonomous inventories using high-precision tools and algorithms for automatic segmentation and geolocation of trees. Together with other automated technologies, such as the Digital Forest Exploration Model (Modeflora) and Lidar (Light Detection and Ranging), this equipment is part of what is known as "forest management 4.0", a new concept in forestry production based on the automation, generation, transmission and processing of precise data in the activity.

Another innovative research project, funded by the São Paulo State Research Foundation (FAPESP), uses drones to count cattle; the methodology could contribute to monitoring animal weight and health. Swamp (Smart Water Management Platform) uses the Internet of Things (IoT) to create an intelligent water management platform for precision irrigation, in partnership with the European Union and coordinated by the Federal University of ABC (UFABC).

Beyond the ongoing research initiatives, several other projects, some nearing completion with successful proof of concept and prototype testing, are poised to have a significant impact on key production chains, including fruits and vegetables, soybeans, coffee, cotton, dairy farming, and viticulture. These innovations have the potential to benefit family farms, provided that the necessary infrastructure is in place. The success of these projects underscores the feasibility of digital inclusion in rural areas, demonstrating that with appropriate government and institutional support, family farmers can effectively adopt and leverage advanced technologies.

4 Conclusion

While the challenges facing family farming are multifaceted, the issue of technology adoption should not be overlooked. Given the paradigm-shifting moment in production systems, particularly agri-food systems, due to the convergence of disruptive technologies, technological innovation offers significant potential for family farmers.

Recognizing the inherently innovative nature of family farming, its capacity to incorporate various technologies and adapt its processes can contribute to more dynamic and sustainable rural development. This involves establishing multi-level networks that foster collaboration among various organizations.

To achieve this, it is imperative to dismantle existing power relations and modes of domination within Brazilian agriculture. Additionally, public policies must evolve beyond compensatory measures to actively support the development of family farming's innovative potential.

Promoting democratic processes that encourage the participation of family farmers, providing training and education for farm managers, and strengthening the role of support institutions are essential steps. Furthermore, given the current limitations of state-centric public policies, exploring alternative mechanisms to ensure autonomy and continuity in policy implementation is crucial.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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