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EDITED BY
Vinod Kumar Singh,
Indian Council of Agricultural Research, India

REVIEWED BY
Rebecca McLaren,
Johns Hopkins University, United States
Amit Kumar,
The ICAR Research Complex for North Eastern Hill Region (ICAR RC NEH), India

*CORRESPONDENCE
Yuri Durán
✉ yuri.duran@intec.edu.do

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Socio-technical transitions and sustainable agriculture in Latin America and the Caribbean: a systematic review of the literature 2010–2021

Yuri Durán[1]*, Víctor Gómez-Valenzuela[2] and Katerin Ramírez[1]

[1]Instituto Tecnológico de Santo Domingo (INTEC), Santo Domingo, Dominican Republic, [2]Institute of Public Goods and Policies, Spanish National Research Council (CSIC), Madrid, Spain

The challenges and opportunities Latin American and Caribbean (LAC) countries face to meet sustainable development force nations to seek technological alternatives to ensure better policy design. It also includes technology transfer for the productive inclusion of the rural population in the region. This paper aims to characterize the conceptual frameworks applied to studying socio-technical transitions related to sustainable agriculture in the region. A systematic review literature (SRL) was conducted covering 2010–2021. The main findings suggest that the general ideas of socio-technical transition have been used to study sustainable agriculture in LAC. However, its use has been more implicit than explicit, with some predominance of the Strategic Niche Management (SNM) and the Transition Management Approach (TM) frameworks. In addition, the socio-technical transitions as a straightforward approach have started to be incorporated more clearly after 2020. Finally, the leading technologies to foster socio-technical transitions to sustainable agriculture in the region are related to pest control and soil conservation, so social practices such as certifications have had preponderance in this transition. This paper contributes to the existing literature, broadens the frontier of socio-technical analysis in the transition to sustainable agriculture, and expands our knowledge on applying socio-technical analysis in marginal contexts.

KEYWORDS

socio-technical transitions, sustainable agriculture, a systematic review of literature, Latin America and the Caribbean, agroecology

1. Introduction

This paper aims to characterize the conceptual frameworks applied to analyzing socio-technical transitions related to sustainable agriculture in LAC and identify the technologies supporting these processes. For this purpose, the paper conducts a systematic SRL based on a relevant post mapping approach. This SRL emulates the paper of El Bilali (2020), "Transition heuristic frameworks in research on agro-food sustainability transitions," which addressed the issue on a global scale. For this case it has been used four analytical frameworks most practiced in the analysis of socio-technical transitions (Markard et al., 2012): Multilevel Perspective (MLP), Technological Innovation Systems (TIS), SNM and Transition Management (TM) approach. The analysis in the LAC context has a special

significance due to the challenges that the transition towards sustainability in food production must face considering the limited availability of economic and technological resources in most of their countries, in contrast to European or North American countries. In the Latin American region itself, differences can be observed in the availability of options for the approach: in Brazil, the process goes in hand with financing and technology provided by the governments and corporations from the food sector, while in Cuba the transition is driven by shortages in both aspects. The results of the analysis suggest that these circumstances influence the selection of the analytical frameworks of the sociotechnical transitions towards sustainability.

The characterization conducted in this paper provides a better conceptual understanding to promote a more comprehensive policy-oriented research agenda. At the same time, it sheds some light on the technological alternatives that would ensure better policy design regarding technology transfer for the productive inclusion of the rural population in the region. Also, it can help formulate public policies appropriate to each country's environmental, social, and economic environment, contributing to the formulation of their plans in terms of food security, poverty reduction and responsible production. This paper is intended to answer two main research questions:

1. What the literature in LAC countries indicates about the dominant approaches of socio-technical transitions on sustainable agriculture?
2. What does regional literature tell us about the leading technologies supporting a technological transition in sustainable agriculture in Latin America and the Caribbean?

According to the United Nations Development Program (UNDP), the LAC region comprises 42 countries and territories, currently home to 600 million people (Fifka et al., 2016). It has a rural population of 123 million (one in five workers are in the rural sector). The poverty rate is 45.7% of the population, with levels two to three times higher in rural areas (Cepal, 2019). Agriculture and practices related to the value chain of food production constitute a vital component of the regional economy linked to other sectors and services of the economy, such as trade, agribusiness, or tourism as the transition of Brazilian agriculture from low productivity and backwardness to its status as a significant player in international markets (Mueller and Mueller, 2016). In the same way, agriculture is relevant as part of the subsistence practices of rural communities and traditional societies that still exist in LAC, as the traditional maize agroecosystem in Mexico (Dominguez-Hernandez et al., 2018).

Moreover, to the systemic problem of rural poverty in LAC, new environmental challenges related to climate change, biodiversity conservation and resource depletion are significant challenges that should be considered and addressed. The response to these environmental challenges could be tackled from the production systems' "technological transitions" perspective (Geels, 2010). These changes in the production systems are labeled as "socio-technical" because they involve changes in technologies, markets, user practices, and political and cultural meanings (Geels and Schot, 2007).

Geels (2010) states that a transition occurs when the regime is destabilized through pressure. It also may be influenced by the interactions among three levels (niche, panorama, and regime), which occur until a new system state is reached. It is not attributable to a single interaction or driving pressure but to processes on multiple levels (Papachristos and Adamides, 2016). Within the studies of socio-technical transitions, two broad approaches can be distinguished: (1) Historical studies of completed socio-technical transitions (such as the replacement of horses by automobiles) and; (2) Studies on current social changes (energy consumption from fossil fuel to renewables sources; Sutherland et al., 2015).

After the introduction with the conceptual framework, definitions and concepts of socio-technical analysis and sustainable agriculture made in section 1, the section 2 presents the materials and methods used for the research design, as well as the inclusion and exclusion criteria of the SRL. Section 3 shows the analysis results using a descriptive approach to the publications, and some of the limitations found. The discussion of the results is presented in section 4, with citations of the most relevant findings of the analysis and the section 5 it is dedicated to the conclusions, with the answers to the research questions and suggestions of new perspectives for the analysis.

2. Materials and methods

This SRL started from a research problem translated into operational terms in research questions. Then, the scope of the systematic literature review was defined. Afterward, the reference databases' inclusion criteria for the search were defined. The primary searches were generated, and a characterization scheme was defined to support the analysis of the results.

For this SRL reviews papers that address the transition towards sustainable agriculture in LAC published between 2010 and 2021. Table 1 shows the search as it was conducted in the Scopus database based on the defined criteria [TITLE-ABS-KEY (transition) AND TITLE-ABS-KEY (sustainable*) AND TITLE-ABS-KEY (Agri*) OR TITLE-ABS-KEY (agro*)]. It was held on October 26, 2021. In this first search, 2,868 papers emerged. In a second step, the search was restricted to papers published after 2010, based on LAC, published in Open Access databases, either in English, Spanish or Portuguese, reducing the list to 187 papers. Finally, only 61 papers addressed the transition to sustainable agriculture in LAC. The inclusion and exclusion criteria used were the country subject of the research (LAC or one of the LAC countries as the subject), type of document (scientific/academic papers), year of publication (from 2010 onwards), and language (English, Spanish or Portuguese). The transition analytical frameworks were used as a reference for classifying the papers.

The search exercise used titles and abstracts of the papers as the first filter for selection. Then, the complete papers were read in a second filter. This exercise resulted in the final selection of 63 records. Table 1 describes the paper selection process, while Table 2 classifies the selected papers by year of publication.

Based on the framework of transition analysis and in the methodology, the topic addressed, and the region covered corresponds to step 6 (definition of analysis criteria), the papers' characterization to step 7 and based on such steps follows step 8 about the analysis of results (step 8).

TABLE 1 Systematic review literature (SRL) in socio-technical transitions and sustainable agriculture in Latin America and the Caribbean (2021).

Systematic literature review (SRL) step	Number of records selected	Process description
TITLE-ABS-KEY (transition) AND TITLE-ABS-KEY (sustainab*) AND TITLE-ABS-KEY (agri*) OR TITLE-ABS-KEY (agro*)	2,868	Records identified according to search criteria in Scopus
Record identification in Scopus	187	Refinement of the search limited to Latin America and the Caribbean, papers in English, Spanish and Portuguese
Removal of duplicates	186	One duplicate record removed
Selection of papers based on titles	133	Fifty-three records removed133 records focused on the transition to sustainability in sustainable agriculture.
Summary-based scrutiny and full-text records to determine eligibility	73	Sixty records were excluded, and 73 selected records focused on the transition to sustainable agriculture.
Inclusion of papers for systematic review	63	Nine records were removed, and the remaining 63 selected records focused on the transition to sustainability in sustainable agriculture in Latin America and the Caribbean.

Adapted from El Bilali (2019).

TABLE 2 Number of records included in a systematic review on the transition to the sustainability of agriculture in Latin America and the Caribbean (2021).

Year	Number of records	Reference
2021	6	Cunha et al. (2021), Monjardino et al. (2021), Palestina-González et al. (2021), Perillo et al. (2021), Pompeia and Schneider (2021), Rossing et al. (2021)
2020	17	Benítez et al. (2020), Boza and Kanter (2020), Chaibub et al. (2020), de Souza Amaral et al. (2020), Edivaldo and Rosell (2020), Gaitán-Cremaschi et al. (2020), Garrett et al. (2020), Gassner et al. (2020), Heredia-R et al. (2020), Lucantoni (2020), Mottet et al. (2020), Passos Medaets et al. (2020), Schiller et al. (2020a), Schiller et al. (2020b), Scotton et al. (2020), Tittonell et al. (2020), Van Loon et al. (2020)
2019	5	Coquil et al. (2019), Delgado Berrocal (2019), Paiva et al. (2019), Silva et al. (2019), Yagi et al. (2019)
2018	8	Casimiro Rodríguez and Casimiro González (2018), Coser et al. (2018), Dominguez-Hernandez et al. (2018), Fernandez et al. (2018b), Fernandez et al. (2018a), Ianovali et al. (2018), Teixeira et al. (2018), Withers et al. (2018)
2017	7	Da Silva et al. (2017), Garrett et al. (2017a), Garrett et al. (2017b), Gazzano and Gómez Perazzoli (2017), Latawiec et al. (2017), Reis et al. (2017), Santamaria-Guerra and González (2017)
2016	6	Hammond Wagner et al. (2016), Mueller and Mueller (2016), Pérez Sánchez et al. (2016), Salvini et al. (2016), Tejada et al. (2016), Hammond Wagner et al. (2016)
2015	1	Lima and Vargas (2015)
2014	5	Bonaudo et al. (2014), Jacobi et al. (2014), Leitgeb et al. (2014), Ramirez-Guerrero and Meza-Figueroa (2014), Sherwood and Paredes (2014)
2013	2	Rosas-Baños and Lara-Rodríguez (2013), Rondon et al. (2013)
2012	3	Das Chagas Oliveira et al. (2012), de Souza et al. (2012), Lovatto et al. (2012)
2011	3	Astier et al. (2011), da Silva et al. (2011), Rosset et al. (2011)
2010	0	There was no

3. Conceptual basis

3.1. Socio-technical analysis

Research in socio-technical transitions and innovation systems aims to understand technological changes by analyzing the causes that allow or inhibit a particular level of the system in long-term processes (Papachristos and Adamides, 2016). Below is a summary of the four chosen analysis frameworks for socio-technical analysis in this SRL.

The MLP understands transitions in terms of the interactions between niche, landscape, and regime (Rosenbloom and Meadowcroft, 2014). The distinction between the three levels is analytical and not ontological, as the levels are helpful for better categorizing and understanding socio-technical change (Raven et al., 2010). The MLP was created to understand technological transition but was later developed and refined to serve as a heuristic device to study sustainability transitions (Svensson and Nikoleris, 2018). It has developed mainly based on history rather than contemporary cases (Smith and Stirling, 2010), so it should be applied critically to modern transition cases from the social and technological context (Papachristos, 2014).

The TIS approach, is a widely applied framework for analyzing technology development in the context of sustainability transitions (Markard, 2020).The focus on TIS is defined as a network of agents interacting in the economic/industrial area under a particular institutional infrastructure involved in the generation, dissemination,

and use of technology. The TIS framework is a practical tool for analyzing potential discontinuities and policy development possibilities regarding innovation systems across spatial scales (Lukkarinen et al., 2018).

The SNM perspective is designed to facilitate the introduction and dissemination of new sustainable technologies through protected social experiments. It is considered a research model and a political tool (Raven et al., 2010). It was developed by Kemp et al. (1998) to analyze how technological change and the acceptance of its social impact evolve together (Mirzania et al., 2020).

Transition Management was defined for the first time in 2000, based on the concept of transition, becoming later an operational model and political practice (Raven, 2005). It is a prescriptive framework that suggests policymakers can shape transitions through four sequential steps: (1) Strategic activities in a 'transition arena'; (2) Development of tactical activities for specific pathways while building agendas and coalitions to support such paths; (3) Operational activities on the ground such as innovation experiments and demonstration projects, aimed at learning by doing; (4) Reflective activities that lead to adjustments in visions and the articulation of best practices (Loorbach, 2010).

Loorbach et al. (2017) describe three different approaches in the science of transitions: Socio-technical, socio-institutional, and socio-ecological. The socio-technical approach emphasizes technological innovation, the socio-institutional approach emphasizes political and institutional change, and the socio-ecological approach the ecological thresholds between the extraction of fossil resources to renewable resources within closed cycles through adaptive management (Visser et al., 2019). Table 3 summarizes the socio-technical analysis's conceptual elements or dimensions that share or differ from the main transition analysis frameworks studied here.

In general, the different analytical frameworks presented in the literature can be ascribed to two major ontologies: (1) the Sociotechnical Transition (STT) and (2) the Socio-Ecological Systems (SES; Ollivier et al., 2018). Since socio-technical transitions are multidimensional phenomena and can be studied from various angles by different disciplines, each approach is supported by ontologies (Geels, 2010). Ontology is defined as "the assumptions about the nature of the (social) world and its causal relationships" (Geels, 2010, p. 2) that underpin and frame ways of looking at transitions (Ollivier et al., 2018). The MLP and the TIS approach correspond to STT ontology but in SNM and TM prevail a SES framework (Geels, 2010).

An important consideration is that not all emerging experiments are viable or have proved sustainable (Jurgilevich et al., 2016). There is no guarantee that proposals for implementing sustainable agriculture schemes will be accepted without a basis demonstrating their feasibility for critical actors. How sustainable agriculture practices will impact the relevant environmental indicators cannot be guaranteed. Here, the SES ontology makes a relevant conceptual and methodological contribution. One example is reducing the impact of climate change in a particular region. When agricultural practices in the traditional regime have a minimal impact on climate change, farmers are likely to show more resistance if they do not feel the guarantees that the transition would provide them with the tools to cope with risk.

Concerning SES, Biggs et al. (2012) identify three properties of the socio-ecological system to be managed: (1) biological and social diversity-redundancy; (2) connectivity between biophysical and social entities, and (3) the state of slow variables (organic matter, water, resources, management agencies, social values) that determines the dynamics of rapid variables (field management, water extractions, authorization to access resources) in complex systems.

Several authors have constructed their classifications on socio-technical systems. For example, starting from the approach, different systems are distinguished: socio-technical (energy, mobility, water, and waste), institutional or socio-economic (education, work, finance) and socio-ecological (forestry, fisheries, agriculture, culture). Røpke (2016) distinguishes resource and waste systems, supply or socio-technical systems, distribution and geography, governance, and economic and financial jurisdictions (cities, economies). Patterson et al. (2017) focused on change processes and distinguished four approaches: socio-technical transition, socio-ecological transitions, sustainability pathways, and transformative adaptation (Geels, 2019).

3.2. Understanding transitions

Regions are the source of niche innovations that will eventually transform regimes with actions that, while modest, are essential (Gibbs and O'Neill, 2014). Sustainability transitions are geographical processes: they are not ubiquitous, but rather, they occur in specific places, that is, in real geographical locations with materiality for them (Hansen and Coenen, 2015). The influence of the region can be seen in urban climate change experiments show that the actor constellations behind vary considerable between different parts of the world (Bulkeley and Castán Broto, 2013) or the important of geographical proximity between agents in the development of niches (Truffer and

TABLE 3 Summary of the conceptual elements or dimensions of socio-technical analysis that share or differ from the main frameworks of transition analysis.

Transition analysis framework	Type of cases	Applications	Approach
Multilevel Perspective (MLP)	Historical	Addressing the socio-technical change of large-scale infrastructures.	Socio-technical transitions/Technological transition/Sustainability transitions
Technological Innovation Systems TIS	Contemporary	Study of actors and institutions involved in the propagation of innovations.	Socio-technical transitions
Strategic Niche Management (SNM)	Contemporary	Introduction and dissemination of new technologies.	Socio-ecological system/Socio-technical transitions
Transition Management Approach (TM)	Contemporary	Modeling transitions through strategic, tactical, operational, and reflective activities.	Socio-ecological system/Social transitions

Author's elaboration (2021).

Coenen, 2012). In the case of transition to sustainability of agriculture in LAC, it is a force that comes from outside the niche (international organizations, NGOs, authorities, customers, and others), so the transition depends on the institution's strength that promotes it.

According to Geels (2010), in the regime, the elements can be tangible (laws, regulations, protocols, standards) or intangible (political paradigms, shared visions and beliefs, social norms, cognitive routines; El Bilali, 2019). Of the three types of rules in socio-technical regimes (regulatory, normative, and cognitive), academia focuses on regulatory ones because they are more tangible than the other two categories (El Bilali, 2019). The above characteristic may condition the success of the transition toward sustainability in agricultural practices. In LAC, except for the case of Brazil, is low the presence of a regime successful supported by the government, and the drivers are mostly export markets that condition niches to certain practices. One example is the regulation and standard for organic production.

3.3. Transition to sustainable agriculture

The analysis of socio-technical transitions from the perspective of the four selected frameworks applied in agriculture seeks to identify success stories that serve as models in the transition towards sustainability in agricultural production in LAC in their context, in accordance with the objectives of this SRL. The modernization of agriculture has resulted in a complete disregard for the negative externalities. The multiple ecological crises force us to ponder the transition toward sustainable agricultural systems by identifying alternative models that make them sustainable and exploring how to build them from the existing systems (Griffon et al., 2021). The triple threat of climate change, biodiversity loss, and food insecurity is a significant challenge to food system resilience (Hastings et al., 2021). Nonetheless, environmental issues became public problems, and stakeholders became aware of the connections between what they did and the ecological processes at various spatial and temporal scales (Steyaert et al., 2016). Within this framework, the idea of a 'green economy' emerges, which promises itself as a remedy to the ecological crisis, and is, simultaneously "in favor of growth, employment, and poverty reduction (Gibbs and O'Neill, 2014). According to Cooke, green economic development aims to mitigate the environmental damage caused by the overexploitation of waste and resources and moderate human contributions to climate change (Gibbs and O'Neill, 2014).

Achieving more sustainable food, feed, and bioenergy systems will require interventions such as increased recycling of nutrients and coordination of biomass flows among farms (Fernandez-Mena et al., 2020). Several technologies for sustainable agriculture have been proposed, including green fertilizers (GFT), biodiversity-based agriculture, and recycling. Legume production and consumption have been reinvented in many products and included in conservation agriculture, organic production, intercropping, and crop rotation (Ferreira et al., 2021). Two applications are crop waste as animal fertilizer or fertilizer released from control (Adnan et al., 2018) and biopesticides that act only against the target pathogen (Ram et al., 2018). However, the isolated application of these technologies cannot be seen as a panacea. For example, the adoption rate of GFT is unsatisfactory in most developing countries, given that the cost of production is considerably higher (Adnan et al., 2018). There is increasing interest in agroecology to move toward more sustainable agriculture and food systems, but its contribution to sustainability remains fragmented (Mottet et al., 2020).

4. Results

The selected papers highlighted the consistent increase in research on the transition to sustainable agriculture in LAC after 2016 when 49 of the 63 chosen works were published. Further, only 5 of these works used the framework of socio-technical transitions to analyze these processes. They were all be published in 2020 or afterward. Table 4 shows the distribution of the five papers using the approach to socio-technical transitions.

By examining the contents of the papers, using TM approach, Rossing et al. (2021) focus on co-innovation, governance, and management of ecological intensification in Uruguay and the European Union, showing more significant contributions to sustainability transitions were associated project preparation, a focus at the farm-level, connections with regional actors, and its interactions. Meanwhile, Scotton et al. (2020) investigated the influence of TM on the transition from conventional to organic agriculture in Mogi Guaçú, SP, Brazil, highlighted the influence of the management system employed, contrasting richness and diversity indices were higher under TM versus conventional

TABLE 4 Use of socio-technical transition analysis framework in papers on transitions to the sustainability of agriculture in LAC (2021).

Year	Transition framework	Document type	Reference	Case study	Country
2021	Transition Management (TM)	Paper	Rossing et al. (2021)	Use of co-innovation in eco-intensification projects	Uruguay/European Union
2020	Multilevel Perspective (MLP)	Paper	Schiller et al. (2020a)	Role of agroecology in agricultural transformation	Nicaragua
2020	Multilevel Perspective (MLP)	Paper	Passos Medaets et al. (2020)	Role of Good Agricultural Practices (GAP) and Organic Certification Programs	Brazil
2020	Transition Management (TM)	Paper	Scotton et al. (2020)	Influence of transitional management from conventional to organic agriculture	Brazil
2020	Technological Innovation Systems (TIS)	Paper	Schiller et al. (2020b)	Examining systemic barriers to the agroecological transition	Nicaragua

management. Passos Medaets et al. (2020) used the MLP to examine Brazil's Good Agricultural Practices (GAP) and organic certification programs, founding that GAP compliance programs represent an adjustment to refit modern agriculture to new expectations created at the level of the landscape and of the incumbent regime. Schiller et al. (2020a) used MLP to examine Nicaragua's barriers to agroecological transition, finding that although the term 'agroecology' is used widely by government, incentives for transitions to agroecology are weakly implemented. Also in Nicaragua, Schiller et al. (2020b) highlight the importance of using TIS approach to understand national agroecological transitions, where systemic barriers to the agroecological transition and cycles of blockages caused by barriers' interactions make change difficult. This sample of cases where the four analysis frameworks of sociotechnical transitions selected for the SRL were expressly applied show the potential of their use in the study of the transition towards sustainability of agriculture in LAC, presenting options to the researchers according to the context.

In addition to the four approaches for sociotechnical transitions analysis selected for this SRL, the other articles published between 2010 and 2021 can be associated with several frameworks. Table 5 lists the papers addressing the transition to sustainable agriculture in LAC with their respective associated approaches. For example, social practice approach groups the papers that deal with market concerns related to their own health, social commitment, food and nutrition security, adequate nutrition, alternative agri-food system, sustainable production models and food consumption. While agricultural techniques, soil technologies, software and simulations are referred to the use of different technologies to address transitions towards sustainability in agricultural production, the combined breeding and harvesting and agri-forestry deal with mixed production.

The most considerable number of papers on the transition to sustainability in agriculture, 23, were related to the approach of social practices, a study framework whose application lends itself to low-resource contexts like that of Cuba in recent years. The first of these in this country was by Rosset et al. (2011), which dealt with the impact of agroecology and the Campesino a Campesino movement, where peasants boost food production substituting more ecological inputs for the no longer available imports, making a transition to more agroecologically integrated and diverse farming systems, including additional benefits from resilience to climate change. Leitgeb et al. (2014) examined the themes, resources, sources, motives, methods, and results of farmers' experiments toward sustainable production, where results reveal those are an integral part of farming. Casimiro Rodríguez and Casimiro González (2018) share the experiences of a farm representative in Cuba's cooperative sector in a longitudinal study of the agroecological transition using the Socio-Ecological Resilience Assessment Methodology during three periods of transition between 1995 and 2015. These three papers are a sample of the benefits that the study of sociotechnical transitions to the consolidation of agroecology in each territory can bring.

Also in the approach of social practices group, the role of associativity in the transition to sustainability has some cases, like Mexico, where Rosas-Baños and Lara-Rodríguez (2013) analyze the creation of the Communal Forestry Company in San Pedro El Alto, which proposes a transition from subsistence agriculture to a type of production that would increase the quality of life and achieved a certain degree of development (Rosas-Baños and Lara-Rodríguez, 2013). In Brazil is addressed by Lima and Vargas (2015) a review of the case related to the Association for Sustainable Rural Development in Serra da Baixa Verde, it was observed, the critical importance of the role of the association to the farmers, without which, they could

TABLE 5 Research focuses on the transition to sustainable agriculture in Latin America and the Caribbean from 2010 to 2021.

Approaches	Number of records	Reference
Social practice approach	23	Pompeia and Schneider (2021), de Souza Amaral et al. (2020), Gassner et al. (2020), Gaitán-Cremaschi et al. (2020), Boza and Kanter (2020), Delgado Berrocal (2019), Paiva et al. (2019), Silva et al. (2019), Coquil et al. (2019), Ianovali et al. (2018), Teixeira et al. (2018), Casimiro Rodríguez and Casimiro González (2018), Santamaria-Guerra and González (2017), Reis et al. (2017), Da Silva et al. (2017), Hammond Wagner et al. (2016), Mueller and Mueller (2016), Salvini et al. (2016), Pérez Sánchez et al. (2016), Lima and Vargas (2015), Leitgeb et al. (2014), Rosas-Baños and Lara-Rodríguez (2013), Rosset et al. (2011)
Agricultural Techniques/ Technologies	10	Perillo et al. (2021), Chaibub et al. (2020), Van Loon et al. (2020), Edivaldo and Rosell (2020), Hammond Wagner et al. (2016), Sherwood and Paredes (2014), Ramirez-Guerrero and Meza-Figueroa (2014), Rondon et al. (2013), Lovatto et al. (2012), de Souza et al. (2012).
Transitional management Approach	5	Mottet et al. (2020), Heredia-R et al. (2020), Dominguez-Hernandez et al. (2018), Fernandez et al. (2018a), Fernandez et al. (2018b)
Soil Technologies	4	Cunha et al. (2021), Yagi et al. (2019), Withers et al. (2018), Garrett et al. (2017a)
Sustainability indicators	4	da Silva et al. (2011), Astier et al. (2011), Das Chagas Oliveira et al. (2012), Palestina-González et al. (2021)
Combined breeding and harvesting	3	Bonaudo et al. (2014), Latawiec et al. (2017), Garrett et al. (2017b)
Software and simulations/ Technological Innovation Systems	3	Tejada et al. (2016), Schiller et al. (2020b), Monjardino et al. (2021), Garrett et al. (2017b)
Agri-Forestry	2	Coser et al. (2018), Jacobi et al. (2014)
Strategic Niche Management (SNM)/Niche Studies	2	Benítez et al. (2020), Lucantoni (2020)

hardly make possible their production. Contrast the results of Da Silva et al. (2017) and Coquil et al. (2019) studies. The first reviewed the agroecological transition in France and Brazil where although PAIS can promote the adoption of more sustainable practices, is limited in promoting the agroecological transition, meanwhile two networks studied for the second contribute to the development of agroecological, more self-sufficient farming systems, which demonstrates that not all cases of transition towards sustainability will be successful.

Additionally, another group of papers incorporates the influence that the market can exert in the transition towards sustainability. de Souza Amaral et al. (2020) include an analysis of the impact of the short food supply chain created by the Center for the Marketing of Family Farming in Rio Grande do Norte, highlighting the role of farmers and their organizations in guaranteeing the volume and diversity of products and showing the impact of certification on organic production. Similarly, in Brazil, Salvini et al. (2016) evaluates the application of a role-playing game (RPG) to promote climate-smart agriculture in three groups of farmers in the southern Amazon, demonstrating this practice induced not only technical learning, but also socio-institutional learning and engagement for collective action. Mueller and Mueller (2016) analyze the transition of Brazilian agriculture from low productivity and backwardness to its status as a significant player in international markets, highlight the importance of the underlying institutional setting on the impact of agricultural policy and the need of inclusive and sustainable institutions created a fiscal, monetary, and political environment. Reis et al. (2017) explore the knowledge, attitudes, and practices of women farmers working in tobacco products on this activity's social, environmental, and health impacts, showing that an integrated approach is needed to deal with tobacco farmers' problems, considering a balance between their beliefs and government decisions.

A review of the social aspects of the transition to sustainable agriculture has focused on the issues of nutrition and food security. It includes an analysis of the food security and individual nutritional status based on the Body Mass Index in Antioquia, Colombia, by Pérez Sánchez et al. (2016), which showed agro-ecosystem features could threaten in the medium-term current food security conditions and the need of protection against this eventuality. Cepal (2019) analyze the establishment of the expression "adequate and healthy diet" in Brazil and the transition of the conception of healthy eating, incorporating the understandings and debates in the fields of food and nutrition security. Boza and Kanter (2020), discuss the key drivers of the transition to agroecological food systems through sustainable diets and provide viable solutions based on existing global experiences around the concepts of local diets, sustainable diets and agroecology practice, enhance the synergies between its. Gaitán-Cremaschi et al. (2020) empirically analyze plant food systems in Chile and assess their potential to support transition pathways to sustainability from ecological intensification, concluding that requires actions to remove barriers in the relations with the agri-food regime and among themselves.

Gassner et al. (2020) analyze how the United Nations Convention on Biological Diversity can influence international policy to favor local production and marketing capacity investments to replace imported food and beverages in the Southern Cone, inviting it to recognize the importance of mixed, diverse agricultural landscapes for their contribution to the conservation of wild biodiversity. Similarly, Pompeia and Schneider (2021) analyze how food and nutrition security narratives and adequate nutrition agendas have been mobilized and modified to respond to criticism and legitimize claims about Brazil's public policies and legislative proposals, concluding that commodity chains begin to privilege discourses that stress their contributions to the exports, while food to health gains momentum. Finally, Ianovali et al. (2018) evaluated the productivity and sustainability of different farming systems, including the migratory agriculture system and the economic impacts on Quilombola communities, recognizing that permanent agriculture was more efficient in terms of income and the use of labor than shifting cultivation system, but it is also part of a complex socio-environmental relations.

Also, in Brazil, Teixeira et al. (2018) developed a farm typology that combines participatory and quantitative methodologies to develop strategies to promote agroecological transitions, findings that farmers differ in their management strategies, had stronger engagements in a network composed of farmers' organizations, showed great potential to provide a wide range of ecosystem services and it is crucial to recognize peasant knowledge. Meanwhile, Silva et al. (2019) pointed out the microlearning process's importance in supporting agroecological transitions, showing that ecolearning processes foster robust ecologization processes and reinforce farmers' systemic visions of their activities.

In Panama, Santamaria-Guerra and González (2017) reconstructed the recent past and the current situation of agroecological initiatives, portraying the contribution of the incorporation of agroecological practices to small-scale family agriculture in this country. In Peru, Delgado Berrocal (2019) studied the landscapes created in the central Andes and the exemplary local conservation and territorial management practices that can serve as a model of socio-ecological transition to mitigate and adapt to the negative effects of anthropogenic climate change.

In the 12 years covered by this paper, several works related to agricultural technologies, fertilization and pest control were identified, including one by de Souza et al. (2012), which conducted experimentation in the coffee agroforestry system in Brazil using several technologies, finding agroforestry coffee (AF) was more profitable than sun coffee (SC). Another example can be found in Rondon et al. (2013), who studied the allocation of potato plantings to 1 of 4 transition systems and their impact on beetle control, providing information for growers making transition from conventional to organic potato production. Ramirez-Guerrero and Meza-Figueroa (2014) studied the effects of composting on soil and potato growth, development, and nutrition in Venezuela, finding that the values of phosphorus, calcium or magnesium content in the soil increased with the use of compost (chicken, bovine or and pigs). Sherwood and Paredes (2014) researched the impact of pesticide use on agriculture in Ecuador, showing the study how actors cooperate, collude, and collide in advancing certain technological agenda, even when against public interests. Hammond Wagner et al. (2016) presented a case study on pest management strategies in small-scale agriculture concluding that opportunities to transition to sustainable on this issue at the local level in Latin American through interventions countering the lock-in of synthetic pesticides. Edivaldo and Rosell (2020) studied the use of slash and burn in black bean production in Brazil, to which it corresponds to 30% of the total bean yield in Prudentópolis, playing a vital role for local food production and a sustainable eco-system. Van Loon et al. (2020) applied the Scaling

Scan tool to evaluate agricultural mechanization projects in Mexico, Zimbabwe, and Bangladesh, finding limitations for the development of suppliers of the value chain according to the market. Chaibub et al. (2020) investigated the application of biological pest control in rice production in Brazil, concluding that the treatments, microbiolized rice seeds or plant sprayed facilitate the agroecological transition. Finally, Perillo et al. (2021) focused their study on the GHG estimation of sugarcane cultivation in Brazil, formulated from the transitional management approach, finding that the gradual transition of pre-harvest burning contributes to the reduction of GHG emission.

The application of TM is recent in LAC and began with Fernandez et al. (2018a), who synthesized the successes and deficiencies of agroecology in Cuba, presenting specific information and experiences to discuss successes and challenges of transition to sustainability. Dominguez-Hernandez et al. (2018) evaluated the sustainability of the traditional maize agroecosystem in Ahuazotepec, Mexico, using the Framework for The Assessment of the Sustainability of Natural Resource Management Systems approach, showing that productivity was the most influential attribute. Heredia-R et al. (2020) evaluated the sustainability of smallholder farmers using a traditional agroforestry system (chakra) within the buffer and transition zones and core of the Yasuní Biosphere Reserve in the Amazon.

In the period covered, four papers were found addressing issues related to soil technologies. One corresponds to Garrett et al. (2017a), which addressed the integration of agricultural and livestock systems on the same ground, focusing on how federal policies in Brazil, New Zealand and the United States encourage or discourage this practice. Withers et al. (2018) analyzed Brazil's current and future phosphorus supply and explored the alternative use of livestock manure and residues from sugarcane processing as its substitute. Yagi et al. (2019) addressed soil fertilization using various proportions of bird manure in Brazil, identifying the benefits of the splitting of the poultry litter rate during the rainy season. In soil conservation practice in Piauí, Brazil, Cunha et al. (2021) evaluated the effects of monoculture on the soil organic carbon's microbiological characteristics, finding the transition to agricultural areas caused changes in the soil microbiological indicators.

Papers focusing on sustainability indicators include Astier et al. (2011), who applied a sustainability assessment framework for peasant systems in more than 40 case studies in Latin America, focusing on the choice of indicators, the effects of alternative strategies on agroecosystems' sustainability, and the trade-offs involved. Da Silva et al. (2011) diagnosed the Economic Sustainability of the properties in the Sanga Guabiroba micro-basin in Brazil using sustainability indicators (land and buildings, capital improvements, equity in machinery and equipment, property, and animals in permanent crops). Das Chagas Oliveira et al. (2012) used the MESMIS method to evaluate the degree of sustainability of peasant agroecosystems and their strategies to promote the emergence of innovations in Brazil locally, showing the relevance of local knowledge as a key factor in policies that promote the sustainability of family systems. Finally, in Mexico, Palestina-González et al. (2021) built a Sustainability Index for Traditional Agroecosystems composed of 16 indicators to analyze diversity-resilience, self-management-autonomy, integration, and self-sufficiency finding that these indicators increased the sustainability of home gardens.

Three papers were produced on the transition in activities that combine animal husbandry with agricultural production. Bonaudo et al. (2014) analyzed how agroecological principles can help farmers redesign and improve resilience, self-sufficiency, productivity, and efficiency within integrated crop and livestock systems (ICLC). Latawiec et al. (2017) used focus groups and semi-structured interviews with farmers in the state of Mato Grosso in the Amazon to identify the underlying factors that lead to or inhibit improvements in land management in pursuit of the transition that leads to the expansion of Brazilian agriculture with zero-deforestation. Garrett et al. (2017b) provided a comprehensive historical and international perspective on why integrated crop and livestock systems have declined in most regions and what conditions have fostered their persistence and resurgence.

Regarding using the TIS approach, Tejada et al. (2016) explore land-use modeling to simulate how the growing land demand could affect future deforestation trends in Bolivia. Schiller et al. (2020b) introduced the TIS approach to examine systemic barriers to agroecological transition in Nicaragua and cycles of blockades caused by the interactions of the barriers. Monjardino et al. (2021) applied an integrated framework that combines bioeconomic simulation, risk analysis, adoption theory, and impact assessment to investigate various combinations of conservation agriculture components in a case study from central Mexico.

Two of the papers published between 2010 and 2021 were on SNM. For instance, Location (2020) analyzed the agroecological conversion process implemented by a family farm in Cuba, and Benítez et al. (2020) conducted a case study of Cuba's Local Agricultural Innovation Project, focusing on gender-specific elements. Two papers addressing agroforestry used the SNM approach. The first paper by Jacobi et al. (2014) analyzes aerial and underground carbon stocks and tree diversity in different cocoa farming systems in Bolivia. The second paper refers to a comparison by Coser et al. (2018). They took the native vegetation of the Cerrado in Brazil to conduct a study to evaluate the transition from a low-productivity pasture to an agroforestry system.

The geographical distribution of these academic results can be seen in Table 6. It is noteworthy that 53 of the 63 papers had a single country as an object (84.1%), and nine involved two or more countries or regions (14.3%; see Tables 6, 7). Brazil hosted more than half of them (52.8%), leading the regional production of publications on the subject, followed by Cuba (13.2%) and Mexico (9.4%). The rest of the papers were distributed among Bolivia, Ecuador, Nicaragua, and Peru, with two papers per country and one for Chile, Colombia, Panama, Venezuela, and Uruguay.

Brazil participated in two multinational studies, one with France and another with the United States and New Zealand. Other studies were regional, one in South America and another in South America and Western Europe, including two global research studies. Another involved Uruguay with the European Union and Mexico/Zimbabwe/Bangladesh. Table 7 summarizes the findings of international research conducted in collaboration with LAC countries.

5. Discussion

Only five of the papers published on the transition to sustainable agriculture in LAC used one of the four frameworks for socio-technical transitions selected for this SRL to analyze it. The five papers were published after 2020 and represented 22% of the 23

TABLE 6 Distribution of country where research on the transition to sustainability in agriculture in LAC were developed.

Country	Number of papers	Percentage
Brazil	28	52.8
Cuba	7	13.2
Mexico	5	9.4
Bolivia	2	3.8
Ecuador	2	3.8
Nicaragua	2	3.8
Peru	2	3.8
Chile	1	1.9
Colombia	1	1.9
Panama	1	1.9
Uruguay	1	1.9
Venezuela	1	1.9
Total	53	100.0

TABLE 7 Multinational research on the transition to sustainability in agriculture.

Countries/regions involved	Number of papers
Brazil/France	2
United States/New Zealand/Brazil	1
Mexico/Zimbabwe/Bangladesh	1
South America	1
South America/Western Europe	1
Uruguay/European Union	1
Global	2
Total	9

analyzed papers. They were published in the last 2 years of the analyzed period, of which 17 were published in 2020 and 6 in 2021. It may presage a better future for applying these frameworks with greater rigor. Both the work by El Bilali (2019) and Giganti and Falcone (2022) shows the lag of LAC in using such analytical frameworks to study transition processes. Considering the purpose of facilitating the transition towards sustainability, the strict application of these methodological frameworks could increase their contribution to the transitions underway in contexts like those studied, whether it is addressing the socio-technical change, study of actors and institutions involved, the introduction and dissemination of new technologies or modeling transitions through strategic, tactical, operational, and reflective activities.

Looking at how transitions to sustainable agriculture have been framed within the approaches to studying socio-technical transitions, the 5 cases of stated application correspond to contemporary transitions. There is no historical analysis between them. However, this cannot be seen as a negative fact. According to Genus and Coles (2008), research on transitions has faced two challenges: (i) creating and improving the understanding of historical transitions and (Lukkarinen et al., 2018) (ii) advancing and refining the frameworks and tools used for the analysis of contemporary socio-technical transitions (Papachristos and Adamides, 2016). When the observation is expanded to establish trends, and all the selected papers published since 2016 are considered, some works explore historical-cultural aspects to respond to that first challenge. It includes Heredia-R et al. (2020) (traditional production systems of the Kichwa in Brazil); Garrett et al. (2020) (combined cultivation and livestock systems in Brazil), Delgado Berrocal (2019) (practices and techniques of the Waris and the Incas in Peru) and Ianovali et al. (2018) (Quilombola migratory cultivation system in Brazil). Transition research has a solid analytical core based on historical socio-technical data from the cases studies (Elzen et al., 2004; Geels, 2005). The trend that has followed the application of transitions towards sustainability in LAC is to take advantage of the study of historical cases to facilitate contemporary transitions.

Overall, identifying windows of opportunity and the first signs of an imminent transition is necessary to formulate policies to direct the system toward the desired trajectory, something that does not necessarily apply to historical studies (Papachristos, 2014). The 23 papers addressing social practices (Table 5), of which 19 were published after 2016 (83%), are hopeful signs because experimenting in niches is crucial to learning about social challenges and stimulating transitions (Raven et al., 2010). The SNM, the related approach to social practices, was used in 23 of 63 publications for 36.5% of the total sample.

The results suggest that socio-ecological and socio-technical systems similarly conceptualize their objects of study, showing complex, dynamic, multiscale, and adaptive properties (Smith and Stirling, 2010). Therefore, the leading technologies on which the experiences of technological transitions in favor of sustainable agriculture in LAC are based must include a look at social practices. In agricultural techniques/technologies, there is a wide range of alternatives. Some are relatively inexpensive, such as avoiding burning in cane cultivation to reduce greenhouse gas emissions (Perillo et al., 2021) to slashing and burning in the cultivation of black beans (Edivaldo and Rosell, 2020). Other low-cost technologies include chicken compost, bovine vermicompost, and pig vermicompost (Ramirez-Guerrero and Meza-Figueroa, 2014).

Table 5 shows that works related to agricultural techniques/technologies (10), soil technologies (4), combined breeding and harvesting (3), software and simulations/TIS (3) and agroforestry (2) represent 33% of the total selected cases. Techniques for pest control have high skill requirements, including the use of C24G agent as a biological control in rice plantations (Chaibub et al., 2020), the use of ground beetles in potato production (Rondon et al., 2013), and the use of sustainable pest management strategies (Lovatto et al., 2012; Hammond Wagner et al., 2016). There is also the call to pay more attention to the human face of socio-technical change against the actors cooperating, colluding, and colliding in favor of synthetic pesticides (Sherwood and Paredes, 2014).

As the only case in the SRL, the escalation in agricultural mechanization was seen in three different contexts. Van Loon et al. (2020) recognize that the availability of resources is a handicap in its implementation and propose using providers that offer the service to multiple users. In this way, the organizational point of view takes the technological aspect into the background.

Implementing integrated agricultural production systems is considered a promising strategy for sustainable agricultural intensification (Cunha et al., 2021). Several examples of integrated

agriculture production systems can be found that fit agricultural techniques/technologies and soils. Bonaudo et al.'s (2014) were pioneers with their proposal to combine crops and livestock as an opportunity to improve the sustainability of agricultural systems. They were followed by Latawiec et al. (2017). The latter studied ways to improve land management from a producer perspective to understand better the importance of the underlying factors that lead to or inhibit improvements in land management. Garrett et al. (2020) concluded that combining crops and livestock is an activity that has come and gone in time. Hence, they analyzed the drivers of its decoupling and recoupling throughout history.

Coser et al. (2018) considered the contribution of agroforestry by combining agriculture with livestock. They evaluated the transition from a low-productivity pasture to an agroforestry system that combines two or more species with agricultural practices to potentially increase soil organic matter quality. In Bolivia, Jacobi et al. (2014) conducted a study that compared surface and underground carbon stocks and tree diversity in different cocoa farming systems and their links to tree diversity. They also highlighted the role of organic certification in transitioning from monoculture to agroforestry.

In the SRL, three papers were identified in which simulations were applied to analyze a transition instrument toward sustainable agriculture. Monjardino et al. (2021) lamented that despite the many benefits of conservation agriculture (CA), including land cover, crop diversification, and the cultivation of a new crop or variety, few farmers worldwide have simultaneously implemented all facets of the strategy. They applied an integrated framework to investigate how various combinations of CA components performed over a 10-year period found significant differences in profit, net value, downside risk, and risk-aversion cost between double-component scenarios and all other scenarios. Similarly, Schiller et al. (2020a) applied the MLP to the case of agroecology in Nicaragua, where although the government widely uses the term (agroecology), the transition incentives were weakly implemented. They summarize existing knowledge and gaps around service crops, arthropod-mediated functions, landscape and watershed regulation, graze-based livestock, nature-inclusive landscapes, and policy mechanisms to support transitions. Tejada et al. (2016) used the TM framework to create a land cover change model under different deforestation scenarios to simulate how growing land demand could affect future deforestation trends in Bolivia, beginning with Sustainability scenario, passing to the Middle and finishing at Fragmentation scenario of deforestation expands to almost all Bolivian lowlands. These simulation techniques are scarce in the literature, but they could facilitate and accelerate the transition toward sustainable agriculture by creating what-if scenarios that project the effects of decision making.

Regarding the research agenda, the findings of this SRL indicate that the knowledge gap in LAC is still huge, allowing advancement in regional and national agendas about sustainable agriculture transitions in the zone. At the regional level, although research has been progressing in technologies that improve sustainable soil management practices or pest control, LAC still presents opportunities in these fields, given its importance in terms of biological diversity and the challenges that deal with food safety and security as they are nutrition's, healthy diet and sustainable production and shown Pérez Sánchez et al. (2016), Paiva et al. (2019), and Boza and Kanter (2020).

At the level of national agendas, the challenge is just as complex since each country presents different starting situations and differentiated challenges regarding the sustainability of the rural sector and agriculture. To a considerable extent, the construction of national research agendas linked to public sustainability policy will depend on the type and level of linkage of the agricultural sector to the value chain of each country.

6. Conclusion

This paper has identified the technologies on which the experiences of the transition to sustainability in the region are based, showing a scarce use of the dominant approaches considered as reference (MLP, TIS, SNM, and TM). Results suggest a scenario of more outstanding production in the future where researchers addressing the socio-technical change, with better understanding of the context, introducing more newest and effective technologies and developing models to transitions using the those and other approach. Besides, there needs to be awareness in research on transitions about the diversity of food systems present in countries and how they interact.

The SRL shows a lag in work with an approach associated with TIS, limited by the region's conditions where the use of technologies in agriculture is scarce. The socio-technical transitions general ideas have been present in studies on sustainable agriculture in LAC but more implicit than explicit, with some preeminence of SNM and TM frameworks. Socio-technical transitions as a straightforward approach have been incorporated more clearly starting in 2020, waiting for its increase in the future considering state of the art on frameworks for approaching socio-technical transitions and the diversity of countries and authors who applied them. A stricter use of the analytical frameworks studied will improve the understanding of the analyzed contexts, the identification of more efficient technologies adapted to the specific needs and challenges of regional agriculture, as well as the comparison of research results carried out in this and other regions.

The literature about agricultural technologies in LAC countries dominates the biological control of pests and the fertilization of soils through composting. The evaluation studies in the region about the transition to sustainability are recent but diverse in methodologies. The technologies identified to make agriculture more sustainable have been focused more on reducing environmental impact than on increasing productivity, so social practices such as certifications have had preponderance in this transition.

About the region's countries, Brazil dominates the research on the transition to sustainability in agriculture and highlights the role that socio-technical analysis can play in developing agricultural plantations that harmonize environmental conservation with the satisfaction of developing countries' economic and social needs. Considering the vastness of the body of researchers in this country, the size of its economy, the weight of agriculture in it and the questioning of its impact on the conservation of its natural resources, are reflections of how the analytical frameworks of sociotechnical transitions considered in this SRL and others can facilitate the study of the transition towards sustainability in food production. These factors may influence the fact that Brazil's participation as an object of study for socio-technical transitions continues to predominate and the

availability of resources and knowledge affect the technologies used for this transition.

One limitation of this SRL is the classification made of the selected papers, for which the authors did not refer their ascription to a specific framework of socio-technical transitions.

Author contributions

VG-V contributed to the conception and design of the SRL. VG-V and KR manuscript revision, read, and approved the submitted version. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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