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Technology and Innovation: A Systematic Literature Review on Sustainability Research in the Amazon

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ABSTRACT

Society relies on technology and innovation (T&I) to tackle some of its great challenges, and it has been given even more importance since the increasing concern over sustainability issues. A particular concern is the Amazon rainforest's impact on sustainability and what this means for the planet. The paper analyzes how research on technology and innovation in the Amazon region is addressing sustainability issues. This wide-ranging intentional approach has led to an integrative picture, providing the first systematic literature review that connects these themes within a specific region, resulting in 222 academic publications from 1992 to 2020. The main findings indicate that: (1) 40.1% of the studies relate to the management field, which percentage increased significantly after 2015; (2) the dispersion of the studied themes confirms the plurality of Amazonian environmental wealth, but their lack of integration represents a constraint to the development of public policies; (3) market and public policies are both powerful but conflicting innovation drivers; (4) although studies on innovations address greenhouse gas emissions, innovation also includes forest degradation activities; and (5) there are different drivers and applications behind initiatives in technology and innovation, which depend on the local context.

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INTRODUCTION

Society relies on technology and innovation (T&I) to tackle some of its great challenges and needs. Moreover, T&I promotes not only economic growth (D'Agostino & Moreno, 2019; Linton, 2017), but it also offers a key to changing the economic, political, technological, social, and cultural environments (Fagerberg & Srholec, 2017; Utterback, 1971). The acknowledgment of the importance of T&I to sustainability issues is not new: it is seen as a possible solution for the so-called Malthusian trap, and it has been given even more importance since the increasing concern over sustainability issues at the end of the twentieth century (Jacomossi et al., 2021; VonWeizsacker et al., 1997; Walsh et al., 2020). It is commonly understood that T&I is a critical lever to help firms' competitive advantages (Nidumolu et al., 2009). T&I is also seen as essential to the development of sustainable communities (D'Agostino & Moreno, 2019; Jiménez & Zheng, 2018; Seyfang & Smith, 2007), civil society, and non-governmental organizations (NGOs) (Tang et al., 2011).

However, Biggi and Giuliani (2021) state that innovations do not self-regulate. T&I development and use depend on regulators, senior executives, and employees who can make bad decisions. Although many scholars (Ambec & Lanoie, 2008; Bansal & Grewatsch, 2020; Franceschini & Pansera, 2015; Hellström, 2007; Pansera, 2011) note that innovations may have downside effects in the short term, they believe that these issues can be offset by the positive long-term impacts of innovations and technological development on economic growth and value generation for society as a whole. As society becomes more aware of the major sustainability challenges faced by contemporary civilization, it becomes increasingly clear that this perspective needs to change (Biggi & Giuliani, 2021).

If we go further on sustainability issues, a particular concern is the Amazon rainforest's impact on the environment and what this means for the planet. The Amazon is one of our planet's most important resources when it comes to world sustainability and global warming. The Amazonian territory encompasses 7.8 million km^2 and 1,497 municipalities within nine countries: Bolivia (6.2%), Brazil (64.3%), Colombia (6.2%), Ecuador (1.5%), Guiana (2.8%), French Guiana (1.1%), Peru (10.1%), Suriname (2.1%), and Venezuela (5.8%) (Rede Amazônica de Informação Socioambiental [RAISG], 2012). With its unique ecosystem, the Amazonian biodiversity includes approximately one-fourth of the world's living species, and the region contains one fifth of the planet's drinking water (Food and Agriculture Organization [FAO], 2012).

The Amazon region is home to the largest tropical forest in the world, corresponding to about one third of the planet's humid tropical forests, with an incalculable number of plant and animal species. Although its natural heritage is imprecise, it is estimated that the Amazon Forest has the highest biodiversity in the world (Instituto Brasileiro de Geografia e Estatística [IBGE], 2011). Also, the Amazon plays a critical role in reducing global warming, since the area plays a major role in capturing and storing global anthropogenic CO_2 emissions (Saleska et al., 2003).

Research on T&I and sustainability, as they relate to the Amazon, may become increasingly critical for providing alternatives to local (and global) problems. The maintenance of the Amazon area in all of its abundance and the sustainable use of its resources are challenging (Becker & Stenner, 2008). Despite being very rich in terms of natural resources, the Amazon region is economically underdeveloped, offering an excellent opportunity to pursue new technology implementation (Arruda et al., 2019). Nevertheless, there is a need for a new paradigm for sustainable development in the Amazon, based on the forest bioeconomy, consisting of using technology and innovation to develop new solutions, to keep the forest standing (Abramovay, 2020; Barroso & Mello, 2020). Therefore, proposing to transform its natural resources into high-added-value products, which are generated and consumed in a sustainable way (Barroso & Mello, 2020; Nobre & Nobre, 2019).

Businesses and market-driven innovation facing sustainability long-term challenges should comply with environmental and social requirements (Hall & Vredenburg, 2003). The productive dynamics in response to market demands created pressure for the intensive use of Amazonian natural resources (Jimenez et al., 2020; Nagatani et al., 2009). Therefore, technology in the Amazon is considered decisive for maintaining the forest standing and preventing the destruction of the ecosystem services on which the whole world depends, including the climate system (Abramovay, 2020). This study sought to problematize (Sandberg & Alvesson, 2011) these assumptions, through the analysis of topics that had not previously been researched together in a specific region. Thus, this paper analyzes how academic research on T&I, as it relates to the Amazon, addresses sustainability issues. The research question posed is:

(RQ) How has academic research bridged technology, innovation, and sustainability in the Amazon?

To answer this question, we use the systematic literature review (SLR) method, which is based on bibliometric and content analysis to bridge theories and blend literature across these different domains of knowledge (Breslin & Gatrell, 2020). SLRs are appropriate when mapping areas where there is a high level of uncertainty and new studies are required (Petticrew & Roberts, 2006).

This paper consists of six main sections. Following the introduction, we present the main theoretical foundations that guide the study. In the methodology section, we describe the methodological procedures. The results section presents the SLR results and analysis, followed by the discussion. Finally, the conclusions and final remarks present the main contributions and research implications

THEORETICAL FOUNDATIONS

Several authors study the different types of innovation (Becheikh et al., 2006; Damanpour, 1991; Mothe & Nguyen-Thi, 2010; Organisation for Economic Co-operation and Development [OECD], 2018) and consider product and process innovations as technical ones, distinguishing them from non-technical or administrative ones (such as organizational, marketing, and strategic).

Thus, innovation entails the improvement or development of something new and valuable, and this can also cover research methods (Fields, 2015). Jewitt et al. (2017) define methodological innovation as a "novel research practice outside of the mainstream" and point out that "the transfer of concepts and practices across contexts and disciplines is central to how methods are adapted and adopted in innovative ways and thus a significant dimension of methodological innovation" (Jewitt et al., 2017, p. 107). Technical (products or processes), administrative, and research-method innovations are developed by different types of organizations, such as corporations and institutions. These innovations are driven by 'internal factors.'

Regarding 'external factors,' the names and classifications of the factors concerning the physical or institutional environment vary, on a theoretical basis, according to where one's business takes place. External factors can influence the types of innovations, challenges, opportunities, activities, capabilities, and outcomes that can occur (OECD, 2018; Pérez et al., 2019) as organizations react to the environments in which they are embedded (Becheikh et al., 2006; D'Agostino & Moreno, 2019). As the production and diffusion of innovations are not isolated processes (Montresor, 2001), any analysis of the external factors must include assessing the interactions between these organizations and their environments (Becheikh et al., 2006; Dziallas & Blind, 2019).

These external factors can have different classifications. Table 1 shows the categories used to classify the internal factors, innovation types, and external factors affecting T&I.

Table 1. T&I categories.

Aspect	Category	Definition	Source
Internal factors and innovation types	Technical (Product/ Service)	New or significantly improved goods or services.	Damanpour (1991) Becheikh et al. (2006) Mothe and Nguyen-Thi (2010)
	Technical (Process)	Improvements to business functions related to the production of goods or services.	Becheikh et al. (2006) OECD (2018)
	Administrative	Innovations encompassing organizational structure, marketing, and administrative processes such as strategic business management, corporate governance, human resources, advertising, partnerships, and after-sales activities.	Damanpour (1991) Mothe and Nguyen-Thi (2010) OECD (2018)
	Research method	Research methods using technological innovations, crossing disciplinary frontiers, or mixing and applying existing methodologies in new and different ways.	Fields (2015) Jewitt et al. (2017)
External factors affecting T&I	Public policies	Regulations, policies, and government programs; business region, stakeholder networks, culture, knowledge, and technology context.	Becheikh et al. (2006) OECD (2018) Pérez et al. (2019) D'Agostino and Moreno (2019)
	Market/Society	Market forces and pressures from consumers, competitors, business industry, civil society, NGOs, class entities, and communities.	Becheikh et al. (2006) OECD (2018) Dziallas et al. (2019) Pérez et al. (2019) D'Agostino and Moreno (2019)

Note. Source: Research data.

Dodgson et al. (2014) determined six distinct processes employed to coordinate assets to conceive, produce, and acquire innovation, each requiring key management capabilities. Type 1 processes focus on the selection, conducting, and application of research and technology projects. Type 2 processes require collecting, analyzing, and responding to information related to markets, users, and consumers, as well as

the capacity to lead markets ahead of demand. Type 3 processes focus on communication and feedback between internal organizational contributors to accomplish an innovative outcome. Type 4 processes involve collaborating with external parties and using the capacities to select partners in value chains and maintain strong collaborations. Type 5 processes require the formulation and implementation of innovation strategies to support overall organizational objectives. Type 6 focuses on building awareness of and responsiveness to changes and potential disruption that affect the business, such as regulations and sustainability, thus preparing organizations for the future.

Sustainability is a popular concept, probably due to its vagueness and ambiguity (Manderson, 2006). It is much disputed and regularly confused (Jamieson, 1998). So far, experts' efforts to produce a generally agreeable definition of sustainability are controversial. Manderson (2006) understands sustainability as "the changing ability of one or many systems to sustain the changing requirements of one or many systems, over time" (p. 96). His conceptual framework uses systems principles to explain why sustainability is a universal principle that can be validly applied in a multitude of situations and contexts. It follows the systemic roots of the World Commission on Environment and Development (WCED) (Bansal & Song, 2017; WCED, 1987) presenting the global issues in the interconnection of six main systems: population, food security, ecosystems, energy, industry, and urban system.

Several fields of knowledge increasingly address sustainability as well, reaching debates on the role of technology and innovation (Walsh et al., 2020). Innovations are also novel bottom-up solutions that respond to the interests of involved organizations and communities in the pursuit of sustainable development (Seyfang & Smith, 2007), social and economic well-being (Adams et al., 2016; Jacomossi et al., 2021), and inclusive growth (George, McGahan et al., 2012; Jiménez & Zheng, 2018). To maximize the potential benefit of T&I, governments, and businesses must invest in research and education. Companies need to work with universities to gain access to scientific and technological knowledge that can then be used to develop new products, processes, and services (McKelvey, 2014).

The environmental benefits of innovations surpass the firm's boundaries as they can trigger changes in social, cultural, and institutional patterns (OECD, 2009), thereby leading to the current trend of combining technology, innovation, and sustainability. Sustainability encompasses great challenges for society (George, Howard-Grenvill et al., 2016). The environmental challenges, together with increasing social inequalities, have led to large-scale discussions over the necessity to develop new corporate approaches to innovation and technology. These approaches must go beyond operational optimization and move toward a systemic, revolutionary innovation that changes institutions, social relationships, behaviors, lifestyles, and even companies' core businesses (Adams et al., 2016).

However, Walsh et al. (2020) argue that although T&I is a driving factor for economic growth, most science and innovation investments are not oriented to the worldwide public good but to economic and market interests. Current technology is not necessarily the most appropriate in terms of sustainable, inclusive, and environmentally responsible development. Besides, "technological, economic, and scientific growth are necessary but not sufficient for sustainable growth" (Cancino et al., 2018, p. 39).

In that regard, the development of innovations framed as eco-efficiency does not guarantee both economic growth and environmental sustainability. The efficiency increment in extraction and use of natural resources can increase their consumption. This 'rebound effect' undermines the positive impacts of innovations, and therefore policies are needed to hinder demand growth (Franceschini & Pansera, 2015; Røpke, 2012). For instance, the enhanced efficiency of new lighting technologies is not enough to compensate for the increase in light consumption (Franceschini & Pansera, 2015). Another case is ICT-related innovations, including consumer electronics that demand the use of bigger amounts of materials and energy to be produced and have caused a considerable impact on household electricity consumption. Besides, the production of ICT equipment also involves other critical issues, such as the mining of scarce metals, the employment of toxic materials, and the disposal of electronic waste (Røpke, 2012). Even the stage-gated process of product innovation development is inherently prejudicial to society and the environment. As it is customer-centric, the focus is on future sales and profits, rather than seeking positive social and environmental impacts (Bansal & Grewatsch, 2020). Demand-side measures become even more critical if we take into account that natural resources are limited and it is necessary to accommodate a consumption rise in underdeveloped countries (Røpke, 2012).

Biggi and Giuliani (2021) also observed that innovations may cause impacts opposite to those originally planned or may have negative side effects on the environment and society. The authors classified the noxious consequences of innovation in five clusters: (1) work-related consequences, such as psycho-

logical effects linked to job dissatisfaction after technology adoption, work-life balance problems, and burn-out; (2) unsustainable transitions that can give rise to a rebound effect; for instance, energy efficiency gains generated by new technologies supplanted by increased residential energy consumption; more efficient production processes and materials enhancing consumption and the generation of waste and pollution; agricultural-improving technologies causing negative externalities in the long run such as effects on human health, poor labor conditions, loss of control over seeds by farming communities, and environmental degradation; (3) downside effects of innovation and growth, such as technological changes that can enhance trade and firm profits but, at the same time, increase unemployment, wage inequality, and pollution; (4) dangers of emerging technologies; for example, possible unintentional negative consequences for the health, environment, and society of nanotechnologies, the internet of things, cognitive computing, big data, and social media, among others; and (5) open innovation's negative side, related to the damaging impacts on the performance and survival of companies and potential negative effects on society caused by fewer job opportunities and less wealth creation. Thus, managers must be aware of the potential for negative effects of science-based innovations that can shift society into new, unsustainable directions.

When studying a specific territorial context such as the Amazon, there are additional factors concerning the potential impacts of technology and innovation. The knowledge generation and the transfer of technology and innovation rely on five dimensions of proximities: cognitive (absorptive capacity open to new knowledge), organizational (integration of agents within and between organizations), social (relations between actors at the micro level), institutional (stable framework at the macro level), and geographical (physical distance between economic actors) (Balland et al., 2015; Boschma, 2005). The ability of organizations to connect with stakeholders enabling knowledge spillover (Howells, 2002) depends on those proximity dimensions.

In a macro context, Audretsch and Belitski (2021) study the relationship between technological and innovative industries, entrepreneurship, and regional economic development. In areas where creative industries prevail, there is a positive influence on the increase of entrepreneurial initiatives and economic development. Otherwise, agricultural and manufacturing areas reduce the attraction of entrepreneurial activities that negatively impact the regional economy.

To address this, more public and private investment is needed, with the development of green technologies being a particularly prominent example. Alongside sustainable entrepreneurial activities, there is the potential to produce positive impacts in a region (Audretsch & Belitski, 2021). Ultimately, a careful balance must be struck between finance and knowledge to reap maximum benefit from the investments made in science, technology, and innovation (McKelvey, 2014).

Taking these issues into account, the unique characteristics of the Amazon region in terms of sustainability (Saleska et al., 2003) require the understanding of how research has bridged technology and innovation with sustainability, having the Amazon as a research context. Despite the existence of studies on the intersection of these topics, this literature is not unified or homogeneous, and there is no integrative framework comprising the themes mentioned above. This study attempts to fulfill this gap, combining literature and concepts within a multidisciplinary approach (Breslin & Gatrell, 2020).

METHODOLOGY

Procedures of the systematic literature review

This research used the ISI Web of Knowledge/Web of Science (WoS) database, as per previous studies that focused on sustainability research (e.g., Cook et al., 2013; Lunde, 2018). The selection of the date range included all years available in the database. The SLR followed the three stages of planning, implementation, and reporting and dissemination (Petticrew & Roberts, 2006; Tranfield et al., 2003). An overview of the article selection process can be viewed in Figure 1.

An analysis of 222 papers provided an overview of studies on technology, innovation, and sustainability as they relate to Amazon. This classification identified sustainability studies related to technology and innovation in the Amazon. This step involved two different authors, and, in case of a deadlock, a third researcher made the decisive vote.

The final sample of 222 presented a variety of journals publishing on technology, innovation, and sustainability in the Amazon. To address the studies in the business domain, an additional categorization considered the listed journals in the business, management, and accounting fields of Scimago Journal & Country and *Qualis Periódicos* classification. It resulted in 89 papers published in journals that are related to management studies.

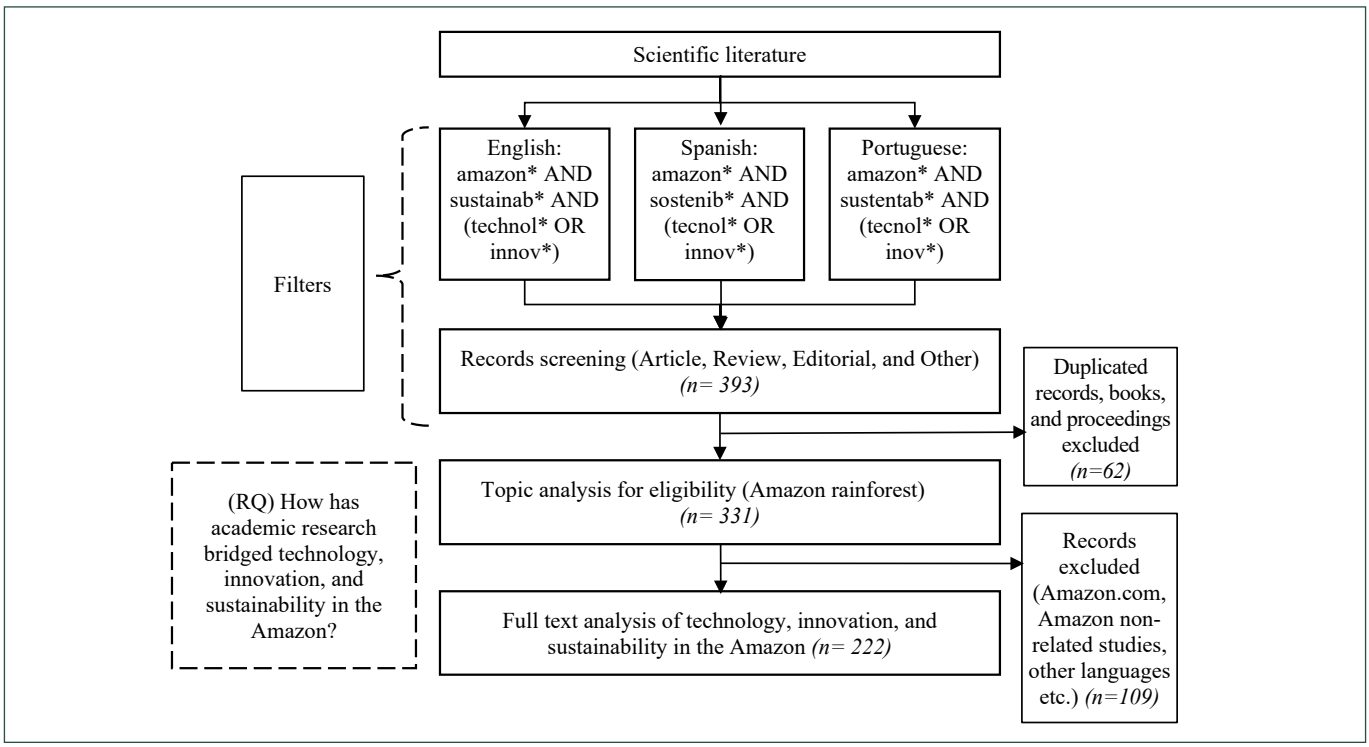

Figure 1. Article selection process.

Analytical categories

Classifying the Amazon-related themes represented a qualitative content analysis of the papers found in the WoS database. This phase of the work addressed the identification of the main subjects of the research, according to the procedure of Ciarli and Ràfols (2019). The identification of main topics and their relations employed the bibliographic data to produce a co-occurrence analysis. The analysis employed the software VOSviewer 1.6.19 to retrieve terms from the abstract, keywords, and publications' years.

The first analysis through association mapped five main clusters. These clusters represented the thematic categories of community; energy, oil, and gas; farming; forestry; and tourism. During the classification process, five categories emerged from the data: biodiversity; health and medicine; mining; government; and water resources. The relevance of those themes illustrated the diversity of the scientific knowledge domains studying technologies and innovation in the Amazon. The papers related to the research question were additionally analyzed and classified through the theoretical concepts of T&I (see Table 1) providing the innovations-related categories.

Analytical framework

The identification of the Amazon studies' themes clarified the interconnection between the concepts of innovation, technology and sustainability, and their characteristics in the Amazon. To do so, firstly, we identified the T&I types, and the external factors driving T&I, which included the T&I categories. Second, to acknowledge the sustainability themes, we performed a thematic analysis similar to Ciarli and Ràfols (2019). Figure 2 illustrates this analytical framework.

RESULTS

Bibliometric analysis

The studies on the Amazon comprise a variety of themes. The criteria for each paper's selection — that they are based on sustainability and technology and innovation — meant also finding papers devoted to different disciplines and sciences that cover basic and applied research on the region. The first paper in the sample was published in 1992. This year was a milestone for the theme of sustainable development due to the Rio Earth Summit. After the event, there was an emergent production of sustainability studies, particularly on the topic of the Amazon. During the summit, the United Nations Framework Convention on Climate Change was adopted and opened for signatures. There is a trend of growth in the number of publications after international agreements addressing global warming.

Specifically in the business domain, results showed 89 papers representing 40.1% of the total sample. Table 2 presents the 10 journals with the highest number of publications. The investigations were related to the management field with interdisciplinary characteristics.

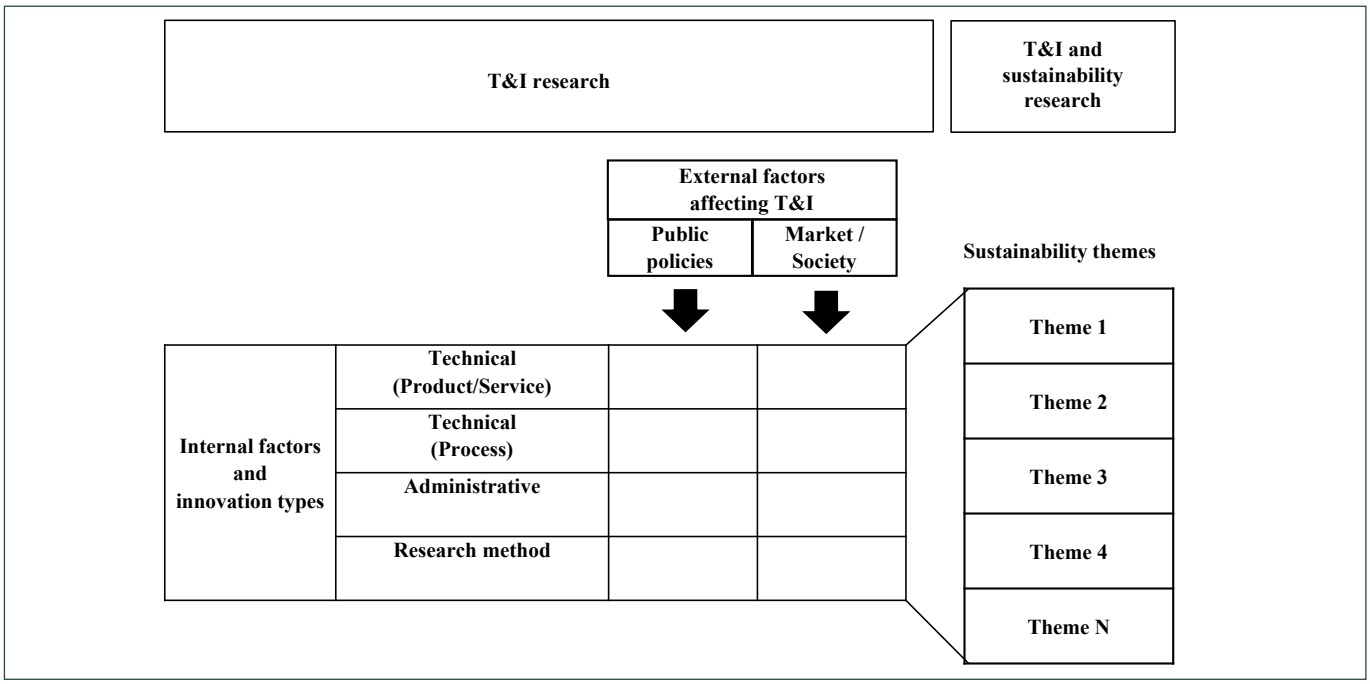

Figure 2. Analytical framework.

Table 2. Journals in the management field.

	% papers	Number of papers
Land Use Policy	8%	7
Acta Amazonica	4%	4
Energy Policy	4%	4
Journal of Cleaner Production	4%	4
Renewable & Sustainable Energy Reviews	4%	4
Agricultural Systems	3%	3
Ecological Economics	3%	3
Novos Cadernos NAEA	3%	3
Economic Development and Cultural Change	2%	2
Ecosystem Services	2%	2

Note. Source: Research data.

As of 2008, there was an expansion in the number of investigations related to T&I and sustainability concerning the Amazon (Figure 3). Nonetheless, the IPCC's 4th Assessment Report (Intergovernmental Panel on Climate Change [IPCC], 2007) and its shared Nobel Peace Prize represented a landmark for the theme of global warming, and publications about the Amazon until 2010. Following this trend, in the management field, academic production started fairly small in 1996. There was a slight and inconstant increase in 2009-2011. After 2015, the number of publications in general and in the business domain presented notable growth.

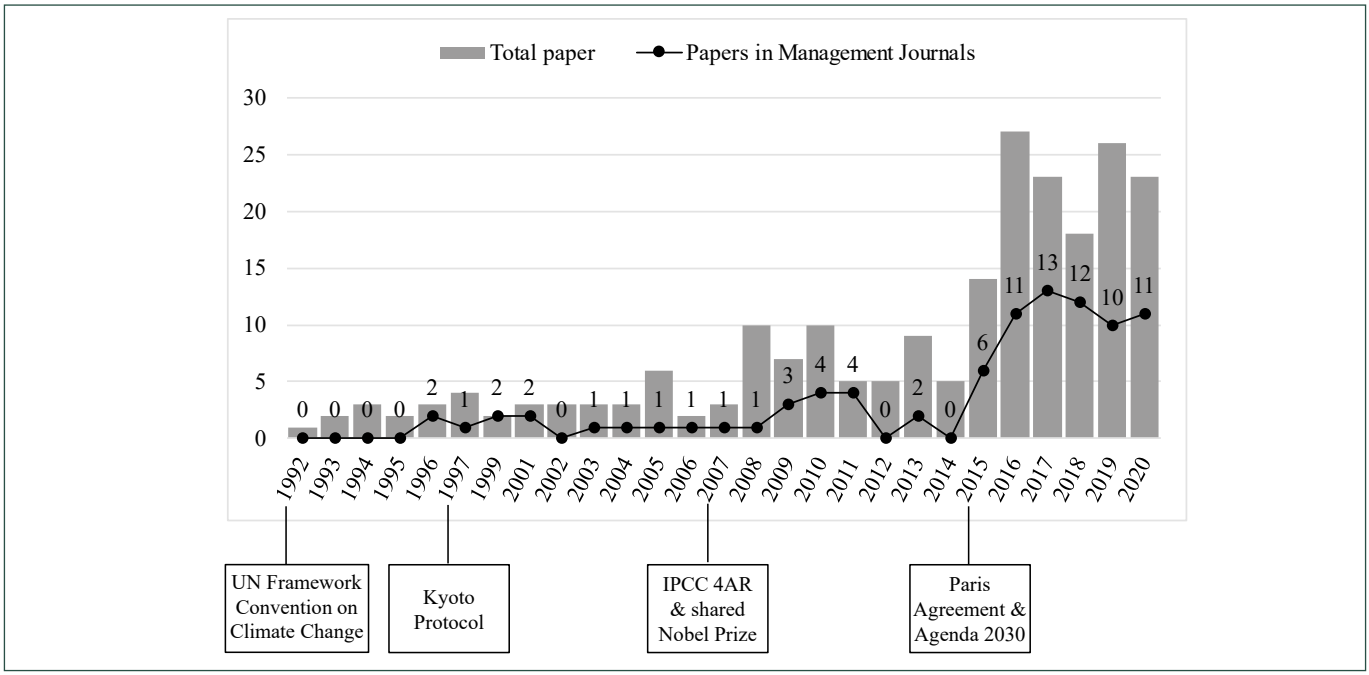

Figure 3. Publication timeline.

The results show further development and rising interest in studies concerning the T&I in the Amazon. In September of 2015, global leaders adopted the United Nations' proposed Agenda 2030, and the Sustainable Development Goals (SDG) were launched. A few months later, 196 parties showed their commitment to addressing global warming and set nationally determined contributions (NDCs) by signing the Paris Agreement. The increase in the number of papers after these events shows the possible effects of the SDGs on scientific investigations in several fields, including business.

Content analysis

Amazon themes

The identification and visualization of the Amazon themes were used to compare the distribution of the publications and the salience of the socio-economic issues, similar to the analysis of Ciarli and Ràfols (2019). According to what was done by those authors, 11 themes emerged from the analyzed sample, as presented in Table 3. The most relevant Amazon themes were then analyzed according to their relationship with studies on technology, innovation, and sustainability as they related to the research question (RQ).

Table 3. Amazon themes.

Amazon themes	Definition	Source	Main topics (examples)	Selected references
Biodiversity	"Biodiversity is the variety of life and its processes" (Noss & Cooperrider, 1994, p. 5).	Noss and Cooperrider (1994)	Genetic diversity of cacao (*Theobroma cacao*) in Bolivia	Zhang et al. (2012)
Community	A community represents a collective response to life conditions in a determined territory that shares a delimited space for sustenance and living purposes and meets common needs by establishing particular forms of social action.	Reiss (1959)	Mapping and monitoring of indigenous groups	Paneque-Galvéz et al. (2017)
Energy, oil, and gas	There is a complex social meaning of energy as a resource base; therefore, it is "not for its own sake but as part of, and in the course of, accomplishing social practices" (Shove & Walker, 2014, pp. 41-42). Energy is considered here in a broader sense, encompassing its various forms of generation and its products, such as oil and gas.	Shove and Walker (2014)	Usage of wood-fuel biomass as an option for sustainable electricity production in Brazilian Amazon	Bacellar and Rocha (2010)
Farming and fishery	Farming, according to Balmford et al. (2012, p. 2714), is the action "to produce food crops, animal feed, meat, eggs, milk, fibers and biofuels" and fishery represents the capture "of aquatic wildlife" (Pauly et al., 2002, p. 689).	Balmford et al. (2012); Pauly et al. (2002)	Land use correlates of agricultural technology adoption in Brazilian Amazon	Perz (2003)
Forestry	According to Helms (2002, p. 17), forestry definition is "the science, art, and business of creating, managing, and conserving forests and associated resources in a sustainable manner to meet desired goals, needs, and values."	Helms (2002)	Forest conservation incentives in the Peruvian Amazon	Börner et al. (2016)
Health and medicine	Health as defined by the World Health Organization (WHO) is the state of physical, mental, and social well-being. Medicine and medical care focus on individuals with diagnosis, treatment, relief of suffering, and rehabilitation.	Mann (1997)	Scenario and challenges dealing with *Plasmodium vivax* and Malaria in Brazil	Siqueira et al. (2016)
Mining	The mining sector, as the starting point of most product value chains, is responsible for the dissipation of non-renewable mineral resources in various ways.	Lèbre et al. (2017)	Artisanal and small-scale gold mining practices in the Brazilian Amazon	Massaro and Theije (2018)
Government	The government is responsible for public administration that represents the administrative rules, procedures, and routines that characterize the public service in action.	Minogue (1983)	Environmental benefits and challenges of waste management in Peru	Ziegler-Rodriguéz et al. (2019)
Tourism	"The action and activities of people taking trips to a place or places outside their home communities for any purpose, except daily commuting to and from work" (Smith, 1988, p. 182).	Smith (1988)	Eco and sustainable tourism in Peruvian Amazon	Calderón-Vargas et al. (2019)
Water resources	Surface waters (rivers, lakes) together with groundwater constitute water resources.	Angheluță et al. (2018)	Strategy for protection and conservation of marine and coastal areas in Brazil	Maretti et al. (2019)
Others	Papers that were not eligible for any category above.	-	-	-

Note. Source: Research data.

Analytical categories

Figure 4 shows the papers' classifications according to the analytical categories of internal factors and innovation types and external factors that affect T&I. The numbers in black circles refer to the 222 papers related to the RQ.

A review of the 222 papers concerning RQ shows 104 related only to external factors, 79 only to internal factors, and 39 to external and internal factors. The sum of 118 papers on internal factors has the preponderance of technical innovations (75) studies whose major focus is process innovations (52 articles). Half of them address the theme of farming and the fishery. The focus of innovation is on increasing crop yields and cattle productivity and decreasing any negative impacts on sustainability. In the research methods category, forest-

ry is the most discussed theme, mainly addressing data science. The sum of 143 papers covering the external factors presents a majority of papers (60) jointly discussing the drivers of market/society and public policy.

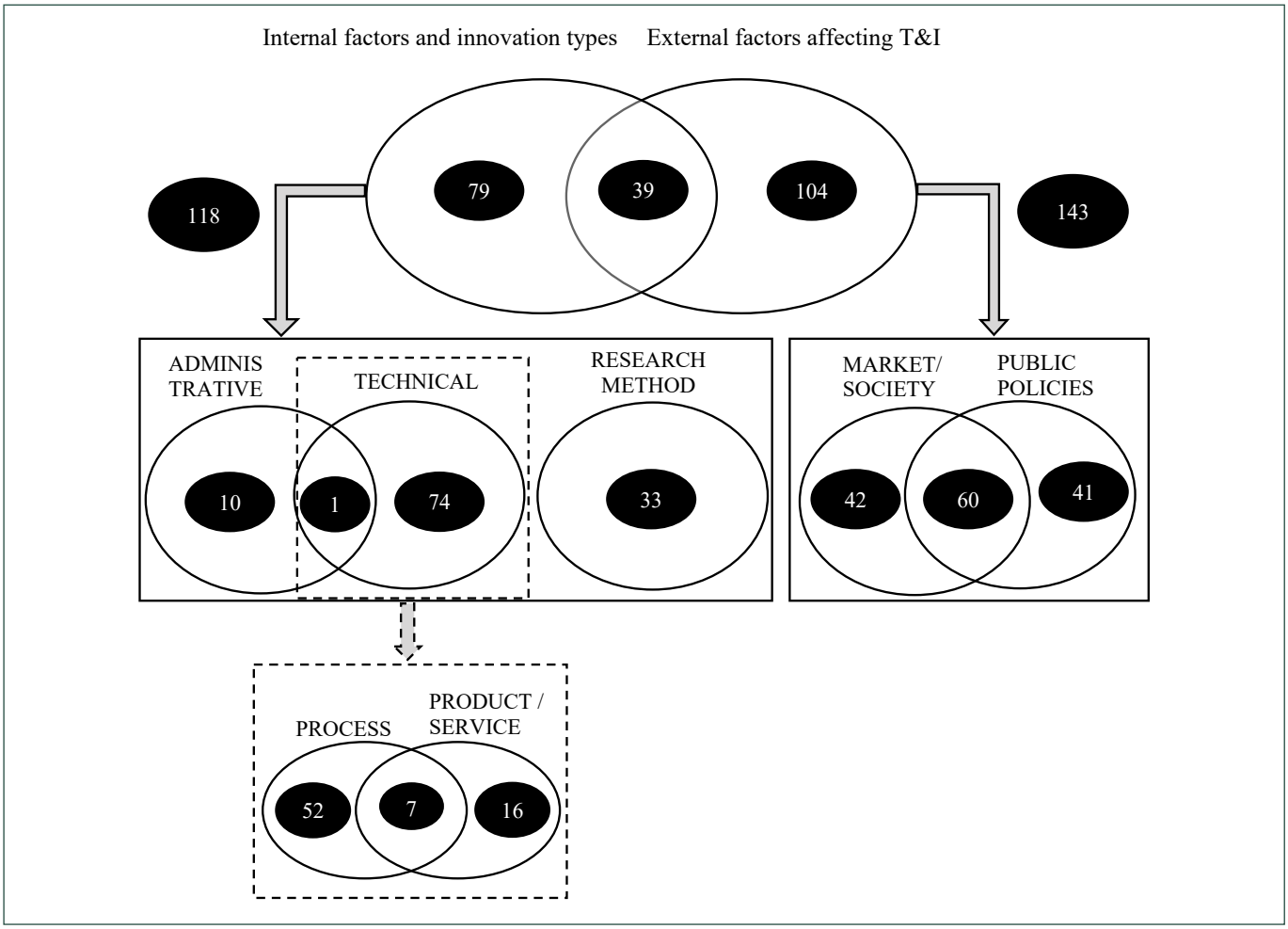

Figure 4. Paper's distribution in innovation and technology.

The papers addressing the market/society external factors of farming and the fishery remark on the characteristics of production in the Amazon. The innovation and technology drivers are intricately connected to the category of process innovation. An analysis of papers on intensive and extensive production shows that there is heterogeneity in (a) accessing knowledge on innovations and technologies and (b) in the market forces that lead to the adoption of these practices and the generation of reliable information on their impacts. Table 4 presents the frequency of each T&I category and Amazon theme.

DISCUSSION

Technology, innovation, and sustainability issues in research in the Amazon

Regarding the RQ, the sample was divided into T&I categories according to the Amazon themes. Additionally, the T&I categories were crossed with the Amazon themes to offer an overview of the main investigation and its interests and innovations drivers. Table 5 shows a summary of the findings.

Many articles in the sample discuss the external and internal factors together, demonstrating the close connection between organizational issues and their contexts. Along with the Amazon themes, it is possible to provide an overview of the intercorrelations among the concepts of innovations, technology, and sustainability as they relate to the Amazon.

The existing extensive and intensive production affects environmental conservation and may cause degradation according to the available knowledge of technologies and their implementation. It demonstrates the relevance of information access (Perz, 2003; Sarmento et al., 2010) as a determinant for the proper adoption of innovations.

When analyzing the external factors — public policy forces that drive innovation —, forestry has the most significant representation among the Amazon themes (Carvalho, Mustin et al., 2019; Schielein & Börner, 2018; Tejada et al., 2016).

Table 4. T&I categories and Amazon themes.

T&I categories			Biodiversity	Community	Energy	Farming and fishery	Forestry	Government	Health and medicine	Mining	Public Policy and Govern.	Tourism	Water resources	Other	Total
Internal factors — Innovation type	Tec	PS	1.8%	-	-	-	1.4%	-	-	-	-	-	0.9%	0.5%	4.5%
		Pc	3.6%	0.5%	0.9%	7.7%	1.4%	-	-	-	-	-	0.5%	1.4%	15.8%
		PS&Pc	-	0.5%	-	0.5%	0.5%	-	-	-	-	-	-	-	1.4%
	Adm		-	0.9%	-	0.5%	-	-	-	-	-	0.5%	-	-	1.8%
	ReM		1.8%	4.1%	0.5%	1.8%	2.7%	-	-	0.5%	-	-	0.5%	0.5%	12.2%
Internal factors — Innovation type and External factors	Tec PS	MkS	-	-	-	0.5%	0.5%	-	-	-	-	0.5%	-	-	1.4%
	Tec PS	MkS&PP	-	0.5%	0.9%	-	-	0.5%	-	-	-	-	-	-	1.8%
	Tec Pc	MkS	-	-	-	1.4%	0.9%	-	-	0.5%	-	-	-	-	2.7%
	Tec Pc	PP	-	-	-	2.3%	0.9%	-	-	-	-	-	-	-	3.2%
	Tec Pc	MkS&PP	-	-	-	-	1.4%	-	-	-	-	-	-	-	1.4%
	TecPS&Pc	MkS	-	0.5%	-	-	-	-	-	-	-	-	-	-	0.5%
	TecPS&Pc	PP	-	-	0.5%	-	-	-	-	-	-	-	-	-	0.5%
	TecPS&Pc	MkS&PP	-	-	0.5%	-	-	-	-	-	-	-	-	-	0.5%
	Adm	MkS	-	-	-	0.5%	-	-	-	-	-	0.5%	-	-	0.9%
	Adm	MkS&PP	-	0.9%	-	0.5%	-	-	-	-	0.5%	-	-	-	1.8%
	Adm-TecPS&Pc	PP	-	-	-	-	-	-	-	-	-	-	-	0.5%	0.5%
	ReM	PP	-	-	0.5%	-	0.9%	-	-	-	-	-	-	-	1.4%
	ReM	MkS&PP	-	0.5%	-	-	0.9%	-	-	-	-	-	-	-	1.4%
External factors	MkS		2.3%	2.3%	0.5%	6.8%	1.4%	-	-	-	-	-	-	0.5%	13.5%
	PP		0.9%	0.5%	2.7%	0.5%	3.2%	3.6%	0.9%	-	0.5%	-	0.5%	-	13.1%
	MkS&PP		3.6%	2.3%	1.8%	4.5%	5.9%	1.8%	-	-	-	-	0.5%	-	20.3%
			14.0%	**13.1%**	**8.6%**	**27.0%**	**21.6%**	**5.9%**	**0.9%**	**0.9%**	**0.9%**	**1.4%**	**2.7%**	**3.2%**	**1**

Note. Tec = Technical / PS = Product and service / Pc = Process / Adm = Administrative / ReM = Research method / MkS = Market and society / PP = Public policy.

Table 5. Amazon themes by T&I categories.

T&I categories		Topics (e.g.)	Amazon themes	Selected references
Internal factors and innovation types	Technical innovation (Product/Service)	Simplified chlorinator on potability standards for turbidity, fecal coliforms, and *Escherichia coli* in rural schools of the Western Amazon.	Water resources	Ribeiro et al. (2018)
	Technical innovation (Process)	Innovative construction process using thin reinforced concrete flat plates as permanent formwork with structural function to avoid wood extraction from the Amazon forest by the civil construction industry.	Forestry	Oliveira et al. (2010)
	Administrative innovation	The traditional community of São Francisco village organized its members around a production cooperative in 1992. In 2004, an innovative partnership was established between the Brazilian cosmetics company Natura and the village of São Francisco.	Farming and Fishery	Le Tourneau and Greissing (2010)
	Research method innovation	Innovative modular indicator library-based approach for the assessment of the multi-hazard risk of social-ecological systems across and within coastal deltas globally.	Water resources	Hagenlocher et al. (2018)
External factors affecting T&I	Public policies	Innovative policies for moving the sectors of agriculture, cattle raising, and forestry toward a sustainable path.	Biodiversity	Scarano and Silva (2018)
	Market/Society	The process of strategic intervention for sustainable innovation and the need to involve the Amazon people, in particular the local entrepreneurs.	Community	Pedro et al. (2017)

Note. Source: Research data.

Hence, it is necessary to consider the significant role public policy plays in this matter. Many adequate technologies already exist that can help control agreements and legislation regarding deforestation. However, what is still necessary is to make proper use of these available tools (Carvalho, Isabella et al., 2019). This situation requires the type 6 (future ready) innovation processes. These processes ensure that organizations are made

aware of and are able to respond to any potential changes in technologies, regulations, markets, sustainability needs, and other business aspects. Spotting signs of potential disruption ahead of time is immensely useful, which requires a lot of openness, extensive integration with the research community, observance of plans and initiatives from newer companies and competitors, and direct involvement in the policymaking process (Dodgson et al., 2014).

The papers show that the Amazon's natural resources are mainly used for producing agricultural crops, cattle pastures, or logging. However, Amazon offers benefits to society in that it provides ecosystem services in terms of carbon storage to avoid global warming through the greenhouse effect (Fearnside, 1997). Considering this factor, forest maintenance is more socially relevant to society than the individual and landholder's activities (Carvalho, Mustin et al., 2019). The Amazonian forest's carbon-storage ability (Sommer, 2020; Stavi, 2013) provides worldwide benefits due to the mitigation effects on global warming. Simultaneously, papers on the current agriculture practices in the region focus on private benefits and their indirect relation with the macro environment.

Implications to the businesses in the Amazon

The geographical location has positive and negative effects on entrepreneurial activities in the area. Due to the limitation of employment options and the constraints on availability and access to the job markets, the main entrepreneurial opportunities rise in sectors based on natural capital such as agriculture, tourism, and the extraction of natural resources. The risk of overexploitation of natural resources increases, jeopardizing the availability of economic alternatives (Anand et al., 2021).

In many parts of the Amazon, living conditions in isolated rural communities are harsh because of the lack of access to essential services such as electricity, water, sanitation, health, and education. In this context, it is an emergency to properly combine appropriate low-cost technologies with innovative business models that align with strategies of public investment and financing aimed at promoting local development (Prieto-Egido et al., 2020).

Geographical proximity enables inter-organizational learning and innovation, most likely by stimulating the other dimensions of proximity, but it is not sufficient or even a necessary condition to enable learning or the creation of innovations. It demands at least the cognitive proximity dimension (Balland et al., 2015; Boschma, 2005). Actors that are close together will be more likely to cooperate and more successful at doing so since closeness reduces the expense and encourages the organization of collective innovative efforts (Balland et al., 2015).

The Amazon is considered the greatest reservoir of organic diversification in the world. Besides its global relevance, it becomes evident the need to enhance productive projects that link income growth, social inclusion, and adequate use of natural resources to local needs (Mandarino et al., 2019). Futemma et al. (2020) studied hybrid arrangements that contrast with the long history of clientelist relations, boom-and-bust economic cycles, successive failures of development programs, and deficient institutional support that have limited the social capital of rural areas in the Brazilian Amazon, fostering distrust regarding external actors.

Market and public policies are powerful innovation drivers that are not necessarily synergic. As stated in several studies, demand growth and government policies have significant positive effects on innovation (Becheikh et al., 2006). Nevertheless, in analyzing the external factors that affect technology and innovation, it is possible to note a fundamental difference between the two main Amazon themes found in the sample (farming and fishery, and forestry). Both themes have a higher concentration of market/society drivers, while forestry also has a high concentration of public policy drivers. There is a mismatch between the market drivers and public policy in Amazon. The results suggest that, despite public policies to stimulate the exploitation of natural resources through the standing forest, market drivers' focus is the use of Amazonian lands for farming, mainly through the intensification and productivity increase of agriculture and livestock. Therefore, any discussions around farming and fishery in the Amazon address how these sectors' needs relate to market demand for profitable production systems in the region.

This article builds on the premise that technology and innovation initiatives have different drivers and applications, depending on the local context. The importance of the context in innovation development corroborates the premise that some of the driving forces behind technological innovations are specific to their contextual determinants, as the context has a significant impact on the innovative capacity (Becheikh et al., 2006; D'Agostino & Moreno, 2019). The institutional context and the local setting also play essential roles in determining innovative behavior; they can also discourage other kinds of innovative activities (Blake & Hanson, 2005). Each locale has its own characteristics, needs, and priorities, especially those related to sustainability issues (Simões-Coelho & Figueira, 2021). For example, the traditional debate around reducing greenhouse gas emissions to address global warming

is less significant in the Amazon context, where carbon storage is seen as more relevant (Carvalho, Mustin et al., 2019; Fearnside, 1997; Fearnside et al., 2009).

The papers demonstrate that innovations have been developed through collaborative processes within and among different types of institutions, such as universities, NGOs, research institutes, and others, and also within and among countries. Firstly, this fact clarifies the global concern about the Amazon rainforest. Second, the dispersion of the themes found in this study confirms the plurality of Amazonian environmental wealth. The lack of integration of information sources also represents a constraint to the development of public policies.

Amazonian territorial planning affects several areas of public action that are strictly interrelated to the private and/or third sectors. Thus, the demand for an integrated approach also includes investigating the multi-stakeholder partnerships that can mobilize and share technology, expertise, knowledge, and financial resources to develop the Amazon or any other region (e.g., Martins, 2011). Type 4 processes, related to external collaboration, are needed in this case. These processes link companies with outside actors as they search for, select, develop, and implement innovations. The aptitude to pick partners within legitimate value networks and cooperate effectively with them is a necessary management capability (Dodgson et al., 2014).

In the Amazon context, territorial and socioeconomic factors play significant roles in producing, adopting, and disseminating innovations. The spatial distance between the producers, users, and other agents of these innovations (Montresor, 2001) poses challenges to their implementation. These issues require the involvement of public representatives to bridge these barriers. Due to the extent of its geography and transportation issues, the mapping, measurement, and monitoring of human-affected areas in the Amazon are often costly and difficult to operationalize. All these aspects influence the transfer of local knowledge of sustainable production practices but also the access to external new technologies. These problems point to the degree of social complexity involved and the chronic failure to design policies that attempt to solve them, as well as the lack of appropriate institutional mechanisms (Ackoff, 1979), thereby reinforcing issues related to the Amazon as a super wicked problem (George, Howard-Grenvill et al., 2016).

Research agenda

First, regarding innovation and technology in a broader sense, further research could address whether it is possible to apply T&I development to increase Amazonian production and resilience whilst also considering the restraints on sustainability (Rockström et al., 2009). Exploiting Amazon's existing capabilities is essential to a comprehensive perspective of technology and innovation opportunities for sustainable development and should be given attention. Future research could employ theoretical lenses such as natural resource-based view (NRBV) (Hart, 1995), considering that those theories argue that businesses will be constrained by and dependent upon ecosystems, to study the level of strategies and organizational dependency on Amazonian natural resources.

Second, concerning the external factors of the market and society, some additional insights can be observed. Future studies could focus on analyzing the innovation and technology needs and the government's initiatives to reduce unsustainable practices, such as 'slash and burn' (Caviglia-Harris, 2003). Furthermore, studies measuring the global warming impacts of technologies (e.g., Sykes et al., 2020) and their scalability in the Amazon should balance the analysis of sustainable production and economic development to mitigate climate change. Moreover, given the characteristics of the population, market studies could be developed considering the base of pyramid (BoP) (Hart & Christensen, 2002; Prahalad, 2005) approach to the development of micro-entrepreneurship in remote areas (Chelekis & Mudambi, 2010).

Third, concerning public policies and regional development, several studies in our sample presented isolated interventions to tackle local issues. These issues, however, are dynamically connected to systemic problems. System dynamics can generate tensions (Schad & Bansal, 2018) through complex interconnections and interrelations (Carvalho, Isabella et al., 2019; Lewis & Smith, 2014). Therefore, studies aiming to understand these dynamics and using a systems perspective could clarify the technology and innovation drivers and tensions related to regional development, Amazon limits, and sustainability impacts.

Finally, this study analyzed academic publications indexed in the Web of Science database. The use of this specific database may cause the omission of other investigations developed in Amazon. Therefore, future studies could include other databases, possibly local or dedicated to publications in Portuguese and Spanish — the predominant languages in the region, to include studies that may have been overlooked.

CONCLUSIONS AND FINAL REMARKS

To our knowledge, this is the first systematic literature review that connects the research on innovation, technology, and sustainability within a specific region

of the globe. Understanding the relationships among those subjects becomes more relevant when considering that the Amazon has a significant global impact in terms of water resources, biodiversity, and climate regulation, among other relevant topics.

Some of the findings of this study should be highlighted. First, when referring to the diversity of the research on technology and innovation and sustainability in the Amazon, the multiplicity of topics that are addressed indicates that, on the one hand, the options for research are limitless but, on the other hand, the existence of so many topics may also imply a barrier to establishing a clear focus not only in terms of choosing 'what to research' but also in defining the types of investments required. Second, technology and innovation studies on sustainability issues (RQ) exhibit a trend in a significant percentage of papers. Researchers have increasingly addressed this theme. Third, the way important events leverage the almost immediate publication of studies is remarkable. These events, such as the IPCC's reports, the UN's announcement of the Sustainable Development Goals, and the protocol signatures, demonstrate the relationship between the stimuli of these events and the concomitant increase in research. Fourth, from the sample of 222 papers, it was also possible to identify that one quarter of the studies on technology and innovation are related to global warming and the other three quarters refer to other aspects of sustainability. This proportion may imply that, despite the certainty of its significance as carbon storage, the role of the Amazon concerning global warming is not viewed as important as other sustainability topics about the region, its resources and capacities.

In terms of the practical implications of this study, although the studies on innovations point to solutions that are capable of reducing the impact of greenhouse gas emissions, innovation also includes activities that are degrading the forest. Studies propose incremental innovations for agricultural and livestock activities that could be developed in other geographic areas where the soil and climate conditions would represent an advantage. The Amazon does not present the best conditions for agriculture, whereas its biome offers benefits that are not yet fully measured. Research points to the existence of the Amazon's underexploited potential if compared to other tropical forests over the planet. The region's biodiversity can provide income generation and development through the standing forest.

It is possible to note that the dispersion of themes found in this study confirms the plurality of the richness of the Amazon, with studies portraying aspects related sometimes to the management of resources, and sometimes to the performance of regional actors. As a recommendation, the study suggests that research institutions should be able to commit to the drafting of integrated planning of science, as well as a compilation of the results reached.

Finally, the findings of this study can be used by public policymakers as a way of diagnosing what has been done (or not) in terms of research on the Amazon. These subsidies can help us understand how the existing research fits with the current legislation and how to boost the focus on themes that can be considered the most important for this region. In short, the outcomes of this investigation can support the identification and prioritization of research on Amazon to promote initiatives that have more effective impacts among all stakeholders.

As a methodological implication, this study proposes an overview of the main categorizations of the aspects of technology and innovation relevant to sustainability issues, as summarized in Figure 2. The lack of an integrated analytical framework can hinder the development of studies that integrate innovation and sustainability concerning specific contexts such as the Amazon region. We believe that this proposal is a methodological contribution to this research. This framework could also be applied in studies involving other contexts by generating a new set of themes and a completely new map of integrated elements.

In short, the Amazon-related studies that address the region's sustainability role through technology and innovation development face multidisciplinary challenges at both micro and macro levels. From a micro-level perspective, there is community subsistence and the need for technical information and awareness to access technologies and innovation for the sustainable use of natural resources. The macro-level approach includes research and development of Amazon's biodiversity and the technological infrastructure required to bridge sustainable development limitations. Jointly, these challenges require the balance of economic growth, social development, and environmental preservation.

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