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RESEARCH ARTICLE OPEN ACCESS

The Role of Intermediaries in Sociotechnical Transitions: A Systematic Framework Towards Sustainability Management

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ABSTRACT

Modern society grapples with socio-environmental challenges such as pandemics, climate change, resource depletion, and poverty alleviation. Recent research underscores the crucial role of intermediaries in expediting the shift towards sustainability management. This study examines how intermediaries influence sociotechnical transitions towards sustainability within the biogas technological innovation system (TIS) in Paraná state, Brazil. The relationships between transitions and entrepreneurial innovation, strategy, and ESG were examined in-depth in 27 interviews and then triangulated with historical records, using the case of the International Center of Renewable Energies and Biogas (CIBiogás)—an organization created with the support of the United Nations. Findings indicate that intermediaries are pivotal in facilitating sociotechnical transitions through connections with individuals, networks, and organizations. The paper contributes to the literature on sociotechnical transitions by deepening our understanding of intermediaries' role in transitions towards sustainability and by furnishing a systematic framework to guide future research in this domain.

1 | Introduction

The recent exploration of intermediaries as facilitators of sustainability transitions has been led by researchers such as Van Lente et al. (2003), Kivimaa (2014), Polzin et al. (2016), Hyysalo et al. (2016), and Barrie et al. (2017). These studies illustrate intermediaries as agents that can positively influence the transition to sustainability and how they play a vital role in advancing sustainable processes by connecting diverse stakeholders and leveraging their resources and expertise (Kivimaa et al. 2019). With diverse responsibilities like envisioning new markets and contributing to policy development, intermediaries are recognized as catalysts for sustainable transitions (Kivimaa 2014; Kivimaa and Martiskainen 2018; Kanda et al. 2020).

The intersection of entrepreneurial innovation and the effectiveness of intermediaries in advancing sustainability represents a compelling avenue for exploratory research. Entrepreneurs operating within dynamic and risk-intensive environments are compelled to innovate continuously to remain competitive (Lungu 2022). However, internal resource limitations often impede these efforts, prompting firms to seek external expertise to drive innovation (Eisenreich et al. 2021). Despite notable advancements, the study of intermediaries in sustainability transitions remains in its infancy, revealing significant theoretical gaps and underscoring the need for further inquiry. Köhler et al. (2019) underscore the importance of exploring how intermediaries can accelerate sustainability transitions and the policy frameworks required to support these

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roles effectively. Similarly, Kivimaa et al. (2019) highlight the paucity of research linking the functional roles of technological innovation systems (TISs) with the intermediary perspective, thereby limiting a comprehensive understanding of their interplay. To bridge this gap, Kanda et al. (2019) call for innovative research approaches to evaluate the contributions of intermediaries to the core functions of TIS. Addressing these research priorities could significantly enhance our understanding of how intermediaries facilitate transformative innovations and contribute to sustainable development goals (SDGs).

Given the urgency of global issues like biodiversity loss, climate change, resource scarcity, and uneven economic growth, research on intermediaries' roles in hastening sustainability transitions can offer invaluable insights. Particularly in emerging economies like Brazil, such studies hold the potential to catalyze profound shifts in sociotechnical systems encompassing energy, water, agriculture, and mobility. In the context of Brazil's energy mix, primarily reliant on renewable sources (84%), with hydroelectric power dominating (63.1%), alternative energy sources have gained traction due to rising electricity prices (EPE - Empresa de Pesquisa Energética 2023). Despite biogas' inclusion in the "2050 National Energy Plan" only in 2020, there is a growing interest in leveraging biogas for electricity generation, signifying a move towards decentralizing the electrical grid. As a signatory of global environmental commitments, Brazil aims to reduce methane emissions by 30% by 2030, recognizing the impact of intensive livestock farming in states like Paraná. Utilizing agricultural residues for renewable energy production in rural areas is seen as a strategy to mitigate emissions and environmental impacts.

Our work is situated in the confluence of entrepreneurial innovation, strategy, and environmental, social, and governance (ESG). While there is vast literature on each of these knowledge streams, we have identified a chasm in the convergence of the three streams, a gap that prevents further understanding of intermediaries influence on sociotechnical transitions to sustainability within TISs.

To the best of our knowledge, the current literature on sociotechnical transitions and TISs has not yet addressed the convergence of entrepreneurial innovation, strategy, and ESG considerations. As such, we aim to investigate this convergence using the analytic induction technique. By bridging this gap, system actors will be better equipped to handle the complexities of sustainability transitions and gain a clearer understanding of the function of intermediary organizations. When analyzing possible relationships between ESG, sociotechnical changes, intermediaries' responsibilities, and TISs, we found a promising new area of study by looking into how CIBiogás affected the sociotechnical transition inside Paraná's biogas TIS. Our study offers a systematic framework to evaluate the influence of intermediaries on TISs to facilitate the rapid adoption of new technologies in sustainability transitions. To accomplish this study's aims, our research question is: Within TISs, what is the role of intermediaries in sociotechnical transitions to sustainability in a developing country context? The rationale behind the contribution of this research work lies in addressing this critical gap regarding our understanding of

intermediaries' influence on sociotechnical transitions to sustainability within TISs.

Structured into sections, the article includes a literature review on intermediaries, sociotechnical transitions, and TIS studies in light of ESG and entrepreneurial innovation and strategy. It concludes with a theoretical integration of intermediaries in sociotechnical transition and TIS approaches. The subsequent sections outline research methodology, present analysis results, discuss findings, introduce the proposed systematic framework, and finally, present the study's conclusions.

2 | Theoretical Background

2.1 | The Role of Intermediaries in Sociotechnical Transitions

The study of sociotechnical transitions and the role of intermediaries constitutes a key foundation for this research. Scholars in this field emphasize the critical role intermediaries play in shaping trajectories and guiding transitions by fostering relationships among various stakeholders. For Ehnert (2023), intermediaries act as translators and facilitators in (urban) transitions to sustainability; similarly, Guibentif and Patel (2024) see intermediaries as organizations that seek to foster the transition activities of others. Kivimaa (2014) and Sovacool et al. (2020) underscore the importance of intermediaries in advancing sustainability, noting their pivotal function in connecting actors and resources to facilitate collaboration and drive scientific and technological innovation. For this study, the definition of intermediaries follows Kivimaa et al. (2019, 1072), describing them as "actors and platforms that positively influence sustainability transition processes by linking actors and activities, aligning skills and resources, and bridging transition visions with the demands of actor networks. Intermediaries create momentum for sociotechnical system changes, foster new collaborations across niche technologies, ideas, and markets, and disrupt dominant unsustainable configurations."

Sovacool et al. (2020) offer a comprehensive categorization of intermediary actors in sustainability transitions, including associative organizations, government-initiated agencies, social enterprises, network organizations, local authorities, innovation agencies, technology transfer bodies, and universities. Kivimaa et al. (2019) further propose a typology of intermediaries, suggesting four non-mutually exclusive categories: systemic intermediaries, regime-based transition intermediaries, process intermediaries, and user intermediaries. Systemic intermediaries, as defined by Van Lente et al. (2020, 486), focus on fostering innovation within systems and networks rather than mediating at the individual level, making them central to sustainability transitions. Further, Jain et al. (2024) emphasize links between intellectual property (IP) models and sustainability practices of firms in this context and recommend IP sharing among firms to support sustainability transitions. Additionally, Gaitán-Cremaschi et al. (2024) emphasize the value of collective intermediation to address systemic and interconnected barriers. They highlight the orchestration of diverse intermediaries by pivotal actors to create varied transition pathways.

Manders et al. (2020, 185) stress the importance of intermediaries developing expertise, confidence, and adaptability to navigate evolving circumstances and integrate new insights effectively. Kanda et al. (2020) provide a detailed analysis of systemic intermediation activities, identifying three levels of interaction: (1) between intermediary entities within a network; (2) between networks of entities; and (3) between actors, networks, and institutions. These levels depend on factors such as (a) the entities with which intermediaries interact, (b) the functions performed, and (c) the realization of potential benefits from intermediation.

Transition intermediaries address various challenges, such as unclear direction, ineffective communication, and resistance to change from entrenched actors. Institutional change, shaped by intermediaries, is essential for transitions. To analyze the role of government-linked intermediaries, Kivimaa (2014) developed a typology encompassing functions such as articulating expectations and visions, creating social networks, and facilitating multidimensional learning and exploration. Moreover, intermediaries are key participants in policy-making processes, as noted by Kivimaa and Martiskainen (2018), and policy design depends on the extent to which policymakers understand organizational motives (Magnusson and Werner 2023). This study builds upon the functions of transition intermediaries outlined by Sovacool et al. (2020) and synthesizes them into the analytical model presented in Table 1 below.

Intermediaries are categorized by Fisher and Newig (2016) based on the levels of governance within the social domains in which they operate. Expanding on this, Van der Schoor et al. (2016) emphasize the role of local communities as catalysts for social innovation, particularly in driving efforts towards decentralized and decarbonized energy systems. In the context of net-zero transitions, Cairns et al. (2023) highlight the importance of group intermediaries in collectively diffusing grassroots innovations within the UK's energy community. Similarly, Rosenbloom and Meadowcroft (2022) underscore the vital role of the state, political frameworks, and intermediaries in formulating transformative strategies to accelerate transition pathways. Lastly, a complementary perspective is offered by Sehnem et al. (2022), who explore the organizational competencies required to drive sustainable transformations, shedding light on the internal capabilities needed to support broader transition efforts.

2.2 | TIS and Sociotechnical Transition Convergence

Most studies on sustainability transitions have concentrated on niche intermediaries, while intermediaries within the TIS have received relatively little attention, despite their pivotal role in transition processes (Kivimaa et al. 2019). This gap underscores the importance of TIS as a crucial knowledge stream for the present study. The sociotechnical system matrix provides a comprehensive framework for understanding these transitions, encompassing four fundamental components: institutional, social/cultural, organizational, and technological elements, which together shape the context of sociotechnical transitions (Gaziulusoy and Brezet 2015). The institutional dimension comprises laws, policies, rules, and regulations (Markard, Suter, and Ingold 2016; Markard, Wirth, and Truffer 2016), while the

TABLE 1 | Roles of intermediaries in transitions to sustainability.

Role	Outcomes
Knowledge and learning	<ul style="list-style-type: none"> • Collection, processing, generation, and combination of knowledge. • Facilitation of experimentation. • Aggregation and circulation of knowledge. • Providing advice and support.
Networking	<ul style="list-style-type: none"> • Creation and management of networks. • Translation between actors and interests. • Trust-building and conflict resolution.
Brokerage	<ul style="list-style-type: none"> • Brokerage, representing organizations, and dealings on their behalf. • Brokerage between actors and interests. • Financial brokerage increasing monetary support.
Innovation and diffusion	<ul style="list-style-type: none"> • Management of innovation processes. • Technology transfer. • Connection of new technologies and users.
Vision	<ul style="list-style-type: none"> • Articulation of expectations, requirements, and visions.
Institutional	<ul style="list-style-type: none"> • Conducting political advocacy and lobbying. • Implementation of policies. • Legitimation of institutional change. • Standards development.

Source: Adapted from Sovacool et al. (2020, 3).

social and cultural aspects involve norms, values, and practices that influence actors' behaviors and cognitive processes (Kompella 2019). Geels (2004) links competition and resource scarcity to environmental changes, highlighting the role of co-evolution, where environmental factors drive organizational and technological transformations. This approach emphasizes how social structures, technology, and human agency interact to carry out particular tasks within sociotechnical systems. (Geels 2004). Moreover, low-carbon transitions can be accelerated by coevolutionary interactions between technologies and societal groups (Geels et al. 2017).

Sociotechnical transitions also emphasize societal shifts towards sustainability, where businesses generate innovations within the boundaries of institutions, markets, industries, policies, cultures, and sciences (Kompella 2019). These systems enable instances for short-term innovation and have a long-term impact on society structures by enacting norms, legislation, and technologies and require collaboration among multiple actors (Kemp et al. 2007; Pedersen et al. 2023). Activities fundamental to this process include the formation of networks for knowledge and innovation exchange, fostering innovation-driven learning, and creating new sociotechnical structures. Another important

factor is the dual role of companies in transitions to sustainability: driving both the economy and societal transitions, while they also face the impacts of the transformative changes in these areas (Schaltegger et al. 2023). Green growth, within this framework, emphasizes the role of education and human capital as drivers of sustainable development, linking these factors to economic progress (Ngo et al. 2022). Strategies such as environmental taxation, renewable energy adoption, and agroecological practices have been shown to reduce CO₂ emissions, with economic mechanisms playing a critical role in supporting sustainable agriculture (Hao et al. 2021; Ngo et al. 2021).

The sociotechnical system, with its focus on knowledge production and innovation creation (Geels 2004; Mohr and Dessers 2019), offers a suitable lens for analyzing cases like CIbiogás. Transitions are complex, multifaceted phenomena involving interactions between politics, technology, market dynamics, and culture (Kemp et al. 2007; Geels 2010). Coevolution, characterized by continuous adaptation and change, drives systemic evolution and influences the roles of actors within the system (Geels 2004). Schot and Steinmueller (2018) argue that addressing global challenges, including those outlined in the United Nations' SDGs, necessitates systemic changes in sociotechnical systems. The United Nations Global Sustainable Development Report further highlights this imperative, stating that member states must establish a shared transformation framework to guide the SDGs' implementation across global and local contexts (United Nations 2024, 104). This particularly involves the adoption and implementation of SDGs in supply chains (Agrawal et al. 2022).

Energy supply serves as a quintessential example of a sociotechnical system, comprising networks of individuals, organizations, artifacts, and material knowledge interacting to deliver essential services to society (Markard et al. 2012). For Marcon Nora et al. (2023), sociotechnical transitions in the energy sector call for involving and aligning the interests of multiple actors. The intricate interdependence within this system underscores its critical role in the dynamics of transitions. For instance, in the area of wind power, solar photovoltaics, and biogas, Kriechbaum et al. (2021) find that shared expectations arise from events, actor coalitions, niche traits, and institutions. Theoretical frameworks such as the TIS, strategic niche management, and transition management form the core analytical approaches in sociotechnical transition studies for sustainability (Markard et al. 2012; Kivimaa et al. 2019; Köhler et al. 2019). Building on Carlsson and Stankiewicz's (1991) seminal definition of TIS as "a network of agents interacting within an institutional infrastructure [...] involved in the generation, diffusion, and use of technology," these frameworks have advanced understanding of how innovations evolve and diffuse within broader systems (Carlsson and Stankiewicz 1991, cited in Bergek et al. 2015, 416).

Effective analysis of innovation systems requires mapping their structures, which encompass the agents responsible for innovation creation, application, and diffusion; the institutional frameworks of rules and regulations governing these processes; and the interactions between agents and institutions (Edquist 2001; Hekkert et al. 2007; Bergek et al. 2008). Here, Stalmokaitė et al. (2023) find when studying newcomers and incumbents in the wind power industry that the wider sociotechnical context is

important for companies' engagement in innovation processes in order to bring contributions to sociotechnical changes. Beyond structural analysis, understanding TIS dynamics is equally critical for explaining how transitions unfold and identifying the mechanisms that drive systemic changes. Hekkert et al. (2007) caution that a sole focus on structural aspects is insufficient, emphasizing the need to analyze the system's dynamics to uncover the processes that shape growth, development, and innovation diffusion.

Bergek et al. (2015) propose a functional framework for TIS analysis that has been widely applied to emerging and established technologies. This framework identifies seven core functions of TIS, encompassing all activities related to the creation, dissemination, and application of innovations. Table 2 lists the core functions. These include entrepreneurial experimentation, knowledge development, guidance of the search for innovation directions, market formation, legitimation, resource mobilization, and the development of positive externalities (Bergek et al. 2008). This functional approach not only provides a detailed understanding of innovation systems but also offers actionable insights to direct and accelerate sustainability transitions effectively.

Hekkert et al. (2007) demonstrate that the fulfillment or lack thereof of a single function within an innovation system can significantly influence the performance of other functions. This interdependence underscores the necessity for structural change and transformation within the innovation system, which relies on the dynamic interplay and mutual influence of its roles.

2.3 | Entrepreneurial Innovation and Strategy as Accelerators of Action

In dynamic circumstances characterized by risk and uncertainty, entrepreneurs are required to innovate continuously (Lungu 2022). A certain skill set is needed to deal with innovation, especially in the context of sociotechnical changes. Because internal constraints frequently function as barriers to innovation, firms should leverage specialized talents for innovation driven by external causes (Eisenreich et al. 2021). Thus, it is crucial for ecosystems to combine elements that promote innovation, entrepreneurship, and collaborative strategy (Laceta and Könnöla 2021; Ayoub et al. 2025), on the grounds that sustainable entrepreneurs face market constraints individually but collaboratively influence transformation, overcoming resistance to change (Westman et al. 2023). Combining the complex (co)evolutionary umbrella with the ecosystems's territorial approach, as in the biogas TIS, is also crucial (Scaringella and Radziwon 2018).

According to Autio et al. (2014), entrepreneurial innovation is centered on radical innovation and is propelled by co-creation and ecosystem evolution. Further, Garud et al. (2014) and Ghorbel et al. (2021) add that entrepreneurs interpret invention through narratives, which in turn control the availability of possibilities and/or the feasibility of innovations. Therefore, "effectuation," or the ongoing hunt for chances for innovation, is crucial to innovation (Guerrero and Urbano 2017). More distinctively on the social innovation dimension, Adomako and

TABLE 2 | TIS core functions.

#	Function	Description
F1	Development and dissemination of knowledge	Captures the breadth and depth of the current TIS knowledge base and how it changes over time, including how that knowledge is diffused and blended into the system.
F2	Entrepreneurial experimentation	Reduction of uncertainty from trial-and-error experimentation with innovation, new technologies, applications, and markets.
F3	Influence in the direction of the search	The combined force of factors that induce or pressure companies and other organizations to join TIS and the mechanisms that influence the direction of TIS research in terms of competing technologies, applications, markets, business models, etc.
F4	Market formation	The formation of opening a market space and articulation of demand.
F5	Legitimation	Greater social acceptance and compliance with new technology institutions.
F6	Resource mobilization	Mobilization of competence/human capital, financial capital, and complementary assets (e.g., infrastructure).
F7	Development of positive externalities	Development of free public services in the system (e.g., combined labor markets and specialist component suppliers).

Source: Adapted from Bergek (2019, 5).

Nguyen (2024) demonstrate how social innovation, a byproduct of responsible entrepreneurship, influences entrepreneurial performance. Furthermore, a firm's greater level of commitment to the United Nations' SDGs increases the impact of social innovation on entrepreneurial performance.

Following Khalid et al. (2020), the improvement in innovation performance through R&D cooperation in poor nations is validated by the cooperation of enterprises with the government and universities (triple-helix agents) to gain resources and expertise. The coevolution process was furthered by Znaniecki's (1934) discovery that a firm's energy efficiency and environmental performance were influenced by its environmental strategy, entrepreneurial innovation, and entrepreneurial attitude. In a similar vein, Camilleri et al. (2023) connected open innovation to the triple bottom line of sustainability, arguing that businesses strategic social responsibility initiatives, eco-friendly technologies, and ongoing engagement with internal and external stakeholders can generate long-term economic value.

The actors in CIBiogás consider the strategic implications of their decisions. Furthermore, strategy is what drives transitions. We consider strategy to be entwined with the maintenance of a firm's identity for the sake of continuity in strategic action (Burgelman 1983). According to Burgelman and Grove (2007), only a tiny percentage of companies sustain their independence over time, which lends credence to the sociotechnical system and coevolutionary transitional strategies. The relationship between strategy practices and strategy processes is crucial to a corporation's ability to create a strategy (Burgelman et al. 2017; MacKay et al. 2021). Urbaniec et al. (2021) have identified five core factors related to strategy crafting in the bioeconomy: economic and financial, market, technological, ecological, organization and human resources, and legal. In a related study, Schönwälder and Weber (2023) identified five maturity levels of sustainable corporate entrepreneurship with increasing levels

of collaboration: non-existent, occasional, expert, collaboration, and strategic collaboration. Additionally, Osório de Andrade Guerra et al. (2023) provide a framework based on the balanced scorecard approach to promote sustainability while ensuring companies' growth and environmental responsibility. In a co-evolutionary system, strategy formulation is dynamic and emergent as a result of a learning process (Mintzberg et al. 2008). The fact that emergent strategies are defined in terms of particular content and carried out regardless of intentions may help to explain the strategic implications and coevolution of agents in CIBiogás (Gruba et al. 2022).

Sutherland et al. (2015) introduce emerging transition processes in renewable energy, envisioning the emergence of a "flat" regime focused on producing renewable energy. Hultman et al. (2012) note that non-economic variables significantly influence technological advancements related to energy, with strategy being a supporting component for both approaches. In business, sustainable development thinking considers how strategy can drive profitability through the management of environmental and social responsibilities. It explores how integrating transition management, adaptive planning, and sociotechnical techniques can aid the successful implementation of sustainability-focused innovations in a business environment (Ludovico de Almeida and Campelo de Melo 2017). Similarly, Gruba et al. (2022) present the strategic implications of resource management in circular economy projects, where strategies maximize resource efficiency and technology facilitates successful plan execution. In a similar vein, Bertassini et al. (2021) emphasize the relevance of organizational behavior in transitions to the circular economy, while Ciliberto et al. (2021) propose integrating lean production with circular economy elements, e.g., by investing in reverse logistics. According to Ersoy et al. (2022), transition into circularity for green business growth is a necessity in supply chains. Moreover, Nogueira et al. (2023), in their study of waste valorization, demonstrate that within the circular economy context,

environmental policies spur innovation, with the public sector playing a vital role in their development.

Taking a managerial accounting perspective, Gunarathne et al. (2021, 2023) found that environmental management accounting mediates the relationship between environmental management strategy and the environmental and economic performance of businesses, with statistically significant evidence of a positive association between the two. Further, the authors uncover that environmental management accounting and environmental management techniques were positively impacted by a firm's institutional context.

Sustainability is a key component in the sociotechnical transition perspective addressed in this work. Hence, strategy—and resulting business models—becomes an essential constituent of the transition. Here, Enthoven and Thelken (2023) highlight that niche-level strategies shape consumer culture, fostering protective spaces for sustainability, while Silvestre et al. (2022) address strategic sustainability integration, offering five clusters of key factors for corporate sustainability: strategic alignment with sustainability, stakeholders' engagement, information related to sustainability, innovation for sustainability, and other resources and capabilities (including organization-specific key factors).

2.4 | ESG, Sociotechnical Transitions, and Intermediaries

Despite the limited research on the interplay between TISs, intermediaries, sociotechnical transformation, and ESG principles, this study seeks to bridge these domains. These perspectives are inherently complementary and interconnected, sharing a foundational focus on sustainability and social impact. ESG refers to the integration of ESG factors into decision-making processes across all organizational levels (Camara 2022). Strong ESG performance has been shown to drive innovation in green technologies, particularly when supported by intermediaries facilitating R&D investments (Hu and Zhang 2023). Guo et al. (2023) is more specific, highlighting the relevance of green digitalization on environmental innovation. Moreover, ESG plays a critical role in enhancing technical innovation capabilities across various phases of corporate innovation (Chen et al. 2023). Gargantini and Siri (2022) emphasize the importance of a legal framework akin to financial analysts' models, advocating for greater prominence of disclosure in initial ESG rating methodologies. To Colovic et al. (2025), within the scope of digital transitions, intermediaries carry out a multitude of institutional work at different levels of intermediation. Going further, Bähr and Fliaster (2023) suggest that within digital transitions, companies operating as renewable energy enablers or system supporters add key contributions to energy transitions.

The sustainable growth of biogas requires supportive mechanisms such as national legislation and regulations tailored to the agricultural sector (Thrän et al. 2020). Similarly, Pestalozzi et al. (2019) highlight significant socio-political obstacles to biogas development, including public opposition and insufficient financial incentives. In parallel, Karlsson et al. (2019) underscore the critical role of networks in fostering sustainable business

models for farm-based biogas production. Risk emerges as a pivotal factor in ESG adoption. Singhania and Gupta (2024) explore the relationship between ESG disclosures and firm risk, concluding that idiosyncratic risk, rather than systematic risk, shows a stronger correlation with corporate risk in the context of ESG practices. Biber-Freudenberger et al. (2020) similarly emphasize the need to integrate sustainability risk assessments systematically into technological impact evaluations, particularly for the bioeconomy. Furthermore, Whelan et al. (2021) and Yuen et al. (2022) identify ESG as a positive contributor to financial performance, reinforcing its strategic value.

2.5 | Knowledge Streams Integration

This study integrates knowledge streams from related domains, including sociotechnical transitions, strategy, and ESG, to examine the role of intermediaries in promoting sustainability (see summary table in Data S1). TISs provide a framework for analyzing sociotechnical transitions, while the intersection of transitions, entrepreneurial innovation, strategy, and ESG highlights the intermediary's central role. In this context, CIBiogás serves as a key actor within the Paraná state TIS. Intermediaries facilitate the connection of various sociotechnical levels, driving technological innovation and fostering long-term sustainable change, as depicted in Figure 1.

3 | Methodology

To expand and validate our understanding of the role of intermediaries in sociotechnical transitions to sustainability, we call on the analytic induction paradigm (Robinson 1951; Katz 2001) for several reasons. First, we already have some pre-existing body of knowledge in this area, but that is in need of empirical validation. That is, we do not aim to purely inductively build entirely

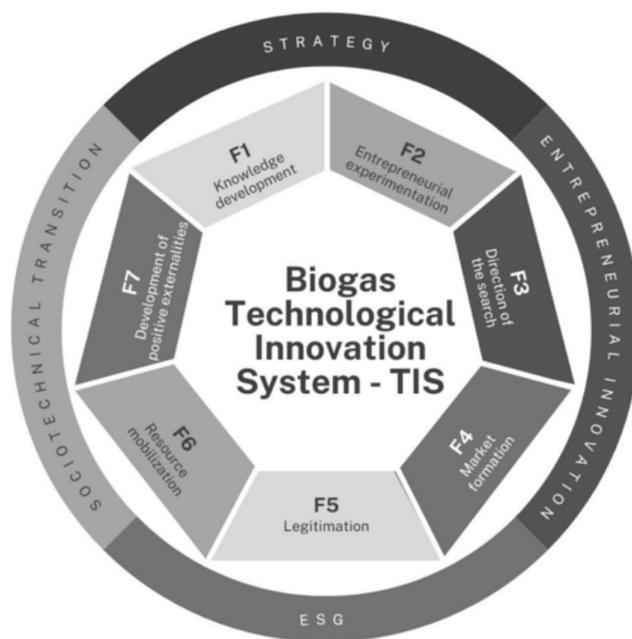


FIGURE 1 | Theoretical background—knowledge streams. Source: The authors.

new theory as is the case with classical theory building from case studies or grounded theory approaches (Suddaby 2006). Rather, our approach uses pre-existing explanations from the literature as scaffolding to guide and structure our initial case work, leading us to iterate through the cases and revisit our understanding in a dynamic feedback process that essentially allows us to qualitatively test existing explanations around sociotechnical transitions. Analytic induction is an attempt to increase rigor in qualitative studies while bridging the qualitative-quantitative divide (Hammersley and Cooper 2012). The objective of analytic induction is causal explanation (Katz 2001:84). Second, it is well suited for use with case studies (e.g., Corley and Gioia 2004). Third, it has previously been used in leading journals in the context of strategic change initiation (Corley and Gioia 2004; Gioia and Chittipeddi 1991), organizational adaptation and responsiveness to environmental disruptions (Busch 2011; Bansal and Roth 2000), and regulatory uncertainty (Hoffman et al. 2009) and even to explore the effects of embeddedness on the entrepreneurial process (Jack and Anderson 2002). Yet it has not yet been applied to the specific context of sociotechnical transitions, allowing us to enrich our knowledge in this area through a novel lens. Therefore, we use concrete case studies from the biogas energy sector to study and validate existing explanations and extend them. Third, in using this approach, we answer a call by Van Burg et al. (2022) for leveraging methodological plurality in entrepreneurship to advance the qualitative side of the field.

Following the analytic induction approach, we initiated the process by formulating a preliminary theoretical explanation of the phenomenon, which was then tested using insights derived from the qualitative data analysis. Iteratively collecting and examining responses, we adhered to the principle of the hermeneutic circle, commencing with an initial set of semi-structured interview questions stemming from this preliminary understanding, which evolved throughout the research process until theoretical saturation was achieved. The systematically coded and presented data are aligned with the theoretical framework, allowing for verification, contestation, or expansion of the generated facts. Thus, the logic of analytical induction guides the process of data collection, analysis, and organizing findings.

Katz (2001, 84) maintains that the objective of analytic induction is causal explanation, “a specification of the individually necessary and jointly sufficient conditions for the emergence of some part of social life,” while calling for a progressive redefinition of the phenomena under study (Ibid). Analytic induction is an attempt to increase rigor in qualitative studies while bridging the qualitative-quantitative divide (Hammersley and Cooper 2012). It has been used in management and entrepreneurship to better explain ecological responsiveness (Bansal and Roth 2000), organizational adaptation to environmental disruptions (Busch 2011), regulatory uncertainty (Hoffman et al. 2009), and the discovery of entrepreneurial opportunities. The logic of analytic induction also underpins emerging methods such as qualitative comparative analysis (Bernard et al. 2016). In using this approach, we answer a call by Van Burg et al. (2022) for leveraging methodological plurality in entrepreneurship to advance the qualitative side of the field. It also strongly suits our research context because there is a considerable preexisting theoretical knowledge base from which we depart to examine our research question, and the complexity of the subject matter and breadth

of stakeholders makes qualitative research better suited to validate and expand our ex-post understanding.

3.1 | Data Collection Instrument Testing and Validation

The process of testing and validating the data collection instrument is linked to the work of Kanda et al. (2019) and Kivimaa et al. (2019), who highlight that intermediaries assume different roles within and between niches and regimes, which should impact sustainability transitions. The connection between the TIS approach and the roles of innovation intermediaries is explained by Kanda et al. (2019) and Lukkarinen et al. (2018), making it relevant for this analysis. According to Kanda et al. (2019, 6), “TIS functions provide a dynamic set of activities through which we can map the roles of intermediaries.” Given that actor interactions are fundamental to the TIS approach, it is essential to analyze how those supporting the innovation system facilitate innovation by adopting intermediary roles within the system. This study builds on the recommendation of Kivimaa (2014), further explored in the work of Lukkarinen et al. (2018).

The similarity between TIS functions and the key roles of innovation intermediaries is addressed by Kanda et al. (2019), who emphasize the importance of knowledge generation and dissemination in both frameworks, as well as the exchange of information among actors. Additionally, both approaches recognize opportunity-seeking and the formation of partnerships as central elements. This study assumes that the functions performed by intermediaries are fundamental to the sociotechnical transition process towards sustainability. The TIS can be influenced by the seven functions of intermediaries involved in sustainability transitions. Specifically, to develop the analytical model for intermediary roles in TISs, this study integrates the TIS functions from Bergek (2019) with the transition intermediary functions compiled by Sovacool et al. (2020). The alignment between these frameworks and the seven TIS functions of Bergek (2019) was assessed. Adjustments were necessary, as Sovacool et al. (2020) and Bergek (2019) identified gaps, particularly in market formation (F4) and the development of positive externalities (F7) within intermediary functions. To address this, intermediary functions were assigned based on Bergek’s (2019) TIS analysis, as these functions are considered essential for TISs in sociotechnical transitions. Furthermore, within the market formation function (F4), activities related to investment intermediation for new businesses, prototyping, and piloting, as highlighted by Lukkarinen et al. (2018) and Kanda et al. (2019), were incorporated.

Thus, the data collection instrument was developed based on this methodological contribution, resulting in a new analytical framework for examining intermediary roles in sociotechnical transitions. This framework can help uncover the role of intermediaries in accelerating transitions. Further, Kanda et al. (2019) acknowledge that analyzing the relationship between intermediary functions and TIS functions is complex due to variations in intermediaries’ capacities, mandates, and normative positions, as well as challenges in determining the ideal level of contribution and contextual factors. Therefore, for instrument validation, a qualitative analysis was conducted with

various innovation system experts, using specific questions to evaluate intermediaries and assess their contributions to each TIS function.

To ensure the quality and reliability of the data collection instrument for the interviews, an initial pilot test was conducted using the first three interviews (see sampling below). These interviews served as a calibration phase, allowing researchers to assess question clarity, relevance, and effectiveness in eliciting detailed responses. Adjustments were made based on participant feedback and observed inconsistencies, refining the instrument to enhance its validity, consistency, and overall trustworthiness for subsequent interviews.

3.2 | Sampling Approach

In alignment with the analytic induction paradigm, we made use of purposeful sampling (Patton 1990), in particular theory-based selective sampling. The logic of criterion sampling is to study cases based on a predefined criterion of importance (Patton 1990). In this process, we defined and followed specific characteristics to reach out to relevant market participants. Given our research question, the targeted organizations span various actors within the sociotechnical system, including industry associations, NGOs, local government, community organizations and cooperatives, and financial organizations. Interviewees were deeply embedded in the biogas industry and up-to-date on current events. Specifically, we reached out to organizational representatives of the biogas industry in Paraná state at the mid- and upper levels of management (e.g., senior engineers, directors) with at least 5 years of industry experience (often more). All interviews were conducted in person online (synchronous online) and lasted between 45 and 90 min with a total of 26 h of audio source material. We triangulate the interviews with the analysis of approximately 30 additional industry reports and internal documents.

We begin with a basic understanding of sociotechnical systems, ESG, and resources in organizational and strategic management. We then develop a preliminary theoretical framework and interview questions (see Data S1 and S2A). Using a three-phase research methodology (Figure 2), we examine the effects of intermediaries in the sociotechnical system for biogas production in Paraná, Brazil, employing analytical induction.

3.3 | Phase I, Sociotechnical System Analysis

In accordance with Gaziulusoy and Brezet (2015), in order to identify the important actors within the sociotechnical system,

the key components of the system were analyzed along the four dimensions of the sociotechnical system matrix (institutional, social/cultural, organizational, and technological) on the coevolutionary dynamic within the sociotechnical system (Gaziulusoy and Brezet 2015, 8).

3.4 | Phase II, Industry Data Analysis

The second phase involved the analysis of the industry reports and internal documents, drawing on insights from a UNIDO project called GEF Biogas Brazil, where CIBiogás was actively engaged. In the GEF project, 75 interviews with industry players aimed to identify challenges and opportunities in the Brazilian biogas and biomethane industries. The interviews, focusing on innovation systems and performance, comprised five open-ended questions and averaged 50 min each and aimed to investigate the role of CIBiogás in the development of the Brazilian biogas sector, as well as find out what is expected from CIBiogás in the next 10 years. Over 60 h of interviews yielded more than 300 pages of material, serving as secondary data for this project. Atlas.TI's categories network results were used for analysis (see Data S3 for qualitative data coding). Thirty documents related to the biogas TIS were examined, and interviews were triangulated. CIBiogás' identification of TIS-related functions in this phase laid the groundwork for the subsequent analysis in Phase III.

3.5 | Phase III, Interview Data Analysis

In the final phase (March–May 2021), a second round of 27 semi-structured interviews (primary data) was conducted based on the findings from the analysis in Phase II, particularly focusing on CIBiogás' role as an intermediary in the TIS of biogas in Paraná (Yin 2009). Participants included representatives from various organizations collaborating with CIBiogás in Paraná, such as financial organizations, associations, energy distributors, rural producers, supply chain participants, biogas industry experts, and CIBiogás members, ensuring diversity in experience, expertise, and performance (see Table 3). These online interviews took place with actors from Itaipu Technological Park in Foz do Iguassu (CIBiogás's location) and the surrounding area of Paraná state, Southern Brazil, lasting 45–90 min each (totaling 26 h of interview recordings). The interview script, with a focus on transition intermediary roles, comprised 17 questions (see Data S2A). Additionally, we included a summary of the documents and papers supporting the research instrument (see Data S2B).

Participants were asked questions organized along the seven functions of innovation systems (Bergek 2019): (1) knowledge development and dissemination; (2) entrepreneurial experimentation; (3) pursuit of shared goals; (4) market formation; (5) legitimation; (6) resource mobilization; and (7) development of positive externalities. Using content analysis and the Atlas.TI software, answers were transcribed and coded based on the seven functions, providing a comprehensive understanding of the sociotechnical system of biogas production in Brazil. The stepwise coding process and organization of emerging themes followed the theoretical framework as a guide to explore the presence of ideas in the instances under consideration.

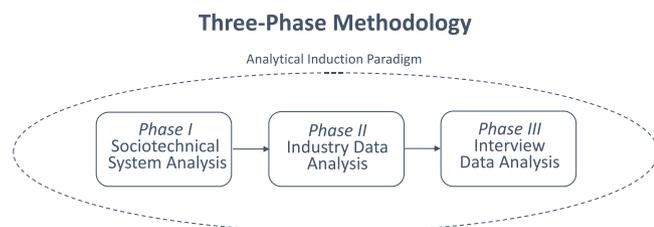


FIGURE 2 | Methodology. Source: The authors.

TABLE 3 | Overview of interviews conducted.

Type of organization	Number of interviews	Respondents coding
Government agents	6	G1 to G6
Industry associations	3	A1 to A3
Power distribution companies	2	CE1 to CE2
Rural producers	2	PR1 to PR2
Supply chain actors	4	SP1 to SP4
Cooperative	1	CO1
Financial organizations	2	B1 to B2
CIBiogás	7	CB1 to CB7
Total	27	

Source: The authors. The interviews were developed during the COVID era. For this reason, they were conducted online via Google Meets between March and May of 2021. Interviewees ranked from analysts to managers. A total of 25 h 57 min of interviews were recorded, yielding 378 transcribed pages.

3.6 | Research Setting

Our research setting is the International Center of Renewable Energies and Biogas (CIBiogás),¹ a science and technology institution dedicated to the development of biogas as a clean and competitive energy resource. CIBiogás has a biomethane demonstration unit in operation at the Itaipu Technological Park (PTI) in Foz do Iguaçu, Brazil, and is responsible for implementation projects, monitoring, and improvements in biogas production systems for the generation of electricity, thermal energy, and biofuel, and also biofertilizers. CIBiogás has already carried out 26 R&D projects, delivered 58 solutions to the market, and trained 4529 students. The projects mostly involve small and medium-sized entrepreneurs, including rural properties, companies, cooperatives, farms, and starch factories. We highlight three projects developed by the entity, such as Granja São Pedro Colombari, a rural property with 5 thousand pigs that generates 35 MW/h of electricity per month in the distributed generation system. The Entre Rios do Oeste Thermolectric Plant brings together 18 rural properties in the municipality, with a 20 km biogas collection network, generating 3000 MW/h of electrical energy per year. And the Toledo Bioenergy Plant, the project is in the assisted operation phase, was developed and managed by CIBiogás, and will supply 1500 medium-sized homes, generating 324 MW/h monthly.

CIBiogás was chosen as the research setting for this work for a number of reasons. First, the state of Paraná, where CIBiogás is located, is one of the largest biogas producers in Brazil, with 198 biogas plants in operation, ranking second nationally, and encompassing 22% of the total biogas producing units (CIBiogás – Centro Internacional de Energias Renováveis – Biogás 2023); therefore, it is representative for the industry at large. Second, the role of CIBiogás, established in 2012 with UN support, in advancing biogas technology in Paraná is pivotal in Brazil's renewable energy transition and provides a rich setting to study sociotechnical transitions within TISs. Its proactive engagement

and partnerships within the biogas sector underscore its significance in driving sociotechnical transitions.

3.7 | Data Processing and Analysis

The 27 interviews were recorded and transcribed. Next, the data was aggregated through coding of the interviewees' statements and semantic networks with the help of Atlas.TI software, with the categories of the proposed model and the creation of networks to better visualize the results. Refinement was then conducted, with an in-depth analysis of each code when subcategories were included and similar content was joined. Finally, a general review was carried out to provide clarity, consistency, and robustness to each category.

For data interpretation and analysis, tables were generated through Atlas.TI and cross-referenced with previously defined categories, according to each function researched, enabling the creation of tables and graphs to demonstrate the results, where compliance of the seven functions by the CIBiogás intermediary was identified, as well as its influence on the diffusion of technology and the factors determining the functioning of the TIS.

To verify the level of intensity of the intermediary and of the functions of the biogas TIS in Paraná, the scale defined by Kivimaa (2014) and Kanda et al. (2019) was adapted for this case when it was found that all functions were present, albeit some with weak intensity. Furthermore, a value from 0 to 3 was defined for each degree of intensity. Both degrees and intensity definitions are shown in Table 4 below.

Our analysis focuses on the actors within the sociotechnical system, with CIBiogás as the unit of analysis. Established in 2012 with United Nations backing, CIBiogás operates mainly from its main office in the Itaipu Technological Park in Foz do Iguaçu. As a scientific and technology organization, CIBiogás, with about 50 staff and researchers, aims to advance the biogas industry in Brazil by developing biogas as a clean, cost-effective energy source. Analyzing the capabilities, mission, and normative position of intermediaries can be challenging. To address this, we utilized the categorization approach of Kanda et al. (2019), aligning with the seven basic functions of TISs and subcategories representing activities within each function. Employing the numerical intensity degree scale (0–3, Table 4), adapted from Kivimaa (2014) and Kanda et al. (2019), we assessed the intensity level of intermediation functions and activities within the functions in the biogas TIS in Paraná. Intensity degree measurements were conducted through quartile analysis, categorized as very weak or 0 (1st quartile), weak or 1 (2nd quartile), medium or 2 (3rd quartile), and strong or 3 (4th quartile). We created a detailed map description of each function and its activities based on the model of Nevzorova and Kutcherov (2019). This mapping revealed barriers and sub-barriers in the biogas innovation process, allowing us to determine fulfilled activities by CIBiogás and showcase the relative intensity of each activity within a specific TIS function.

Lastly, we triangulate our findings from the interviews with archival research, in accordance with Haggarty (1996). In addition, as we mentioned, we looked at a total of about 30

TABLE 4 | Intensity scale for intermediaries.

Level	Description of scale items	Degree of intensity
Strong	The intermediary functions contribute to the fulfillment of the above-median aspects of a particular system function.	3
Medium	The intermediary functions contribute to the median fulfillment of many aspects of a particular system function.	2
Weak	Intermediary roles contribute to the below-median fulfillment of some aspects of a particular system function.	1
Very weak	The intermediary has detectable functions far below the median connected to aspects of a given system function.	0

Source: The authors, adapted from Kivimaa (2014) and Kanda et al. (2019, 13).

documents pertaining to the case and Brazilian biogas sector. We adhered to Bell and Bryman's (2007) guidelines when choosing and evaluating the documents, which included internal documents, laws and regulations pertaining to renewable energy, as well as national and international industry research reports. These guidelines propose four criteria for assessing the quality of documents: authenticity, credibility, representativeness, and meaning. These gave us a comprehensive picture of the main laws and rules that govern this business, both allowing and prohibiting activities that may have an impact on the distribution of resources and the type of competitive strategy.

4 | Results

The knowledge streams we used to comprehend the role intermediaries play in sociotechnical transitions towards sustainability are in line with our findings. We first examined the role of intermediaries in sociotechnical transitions and the intersection of these transitions within the TIS, including entrepreneurial innovation. We then conclude with ESG within the system and offer inputs on the strategies of system actors.

4.1 | The Role of Intermediaries in Sociotechnical Transitions Within Biogas TIS

The analysis of interview data concerning the role of CIBiogás in advancing the biogas sector in Paraná state revealed a shared acknowledgment among all actor levels regarding CIBiogás's pivotal contributions to the industry's development since its inception. Complementary industry data further underscored CIBiogás's exceptional performance in the development and dissemination of knowledge (F1) and in establishing the industry's

legitimacy (F5). As a research and technology institute, CIBiogás is intrinsically positioned to foster information creation and dissemination, a role that aligns with its contractual obligations to Itaipu. Additionally, secondary data highlighted CIBiogás's recognized efforts in advocating for the biogas sector and working to validate the institutional transformations within Brazil's biogas landscape.

When asked about the anticipated role of CIBiogás over the next decade, the data indicated a sustained emphasis on its core function of knowledge development and dissemination (F1). Moreover, an increased focus was observed on market formation (F4) and entrepreneurial experimentation (F2), particularly in fostering new entrepreneurial initiatives along the value chain. While less pronounced, attention was also directed towards CIBiogás's impact on guiding the direction of the industry (F3) and its future role in legitimizing the sector (F5). Analysis of market formation (F4) within the TIS functions revealed that the establishment of new biogas plants stimulated demand across the supply chain, creating business opportunities and encouraging diversification among companies.

To assess the impact of CIBiogás's performance within the biogas TIS in Paraná, aggregated interview data, derived from coding and semantic network categorization using Atlas.TI, were analyzed to calculate the performance intensity of CIBiogás's functions, as presented in Table 5. The scale outlined in Table 4 was employed to aggregate data and define the degree of intensity of intermediary activity. Proportions were calculated based on the percentage of quotes assigned to each scale of intensity. Activities with the highest percentages of quotes were highlighted in bold and italicized. The total intensity of each function was determined by summing the degree of intensity for its constituent activities, serving as the criterion for evaluating functional intensity.

The aggregated data and quartile analysis performed in Atlas.TI revealed that most activities demonstrated very weak performance (Scale 0), with percentages ranging from 0.35% to 2.25%. These were followed by activities classified as weak (Scale 1), with percentages between 2.26% and 4.15%. Medium performance activities (Scale 2) ranged from 4.16% to 6.05%, while strong performance activities (Scale 3) exhibited percentages of 6.06% or higher. Percentages for each function were summed to calculate the proportional intensity within a 100% range.

To ensure the reliability of results and mitigate potential bias, each subcategory underwent independent analysis and grading. The allocation of intermediary activity intensity, measured both on a 0–3 scale and as a percentage, was accompanied by excerpts from the interviews to corroborate the findings. These results, along with the detailed performance analysis, are presented in Table 5.

Table 5 reveals that the function of *Development and Dissemination of Knowledge* (F1) achieved the highest percentage of quotes relative to the total, accounting for 20.86%. This function also represents the most significant aspects of CIBiogás's performance, particularly in the aggregation and circulation of knowledge (8.01%) and the collection, processing,

TABLE 5 | CIbiogás's performance in the biogas TIS functions in Paraná state.

Intermediaries' role in Paraná's biogas TIS functions	Function intensity	Activity intensity	Proportion of quotes (Atlas. TI QDA)	Interview excerpts^a
(F1) Development and dissemination of knowledge	3		20.86	
Gathering, processing, generating and combining knowledge		3	7.74	SP4: "When I worked outside Brazil, the reference for biogas that we had in Brazil was not Embrapa, it was not universities, it was CIbiogás."
Aggregation and circulation of knowledge		3	8.01	
Training and technology assessment		2	4.49	
Technology transfer		0	0.62	
(F2) Entrepreneurial experimentation	0		10.13	
Facilitation of experimentation		1	2.91	PR1: "When you know that there is someone on your side, 'oh you are getting things right, oh you are making mistakes ...' you can do better ... that's what you need, it gives you more confidence, more certainty". CB2: "we, in fact, do what the market is not doing yet, when the market is already doing it, we will undertake other things, because we precisely want to be at the forefront, we want to pull..."
Advice and support		1	2.38	
Innovation process management		0	1.41	
Tests and validations		1	3.43	
(F3) Influence in the direction of the search	1		12.76	
Articulating expectations, requirements, and visions		1	3.43	G6: "Indeed, the influence they have in relation to private actors in the South of the country is undeniable. That, for me nowadays is really the biggest benefit, it is the biggest function that they have". "They were also able to incorporate the Federal Government into the actions that are also being developed within the scope of states and municipalities".
Strategy development		0	0.70	
Advancement of sustainability goals		1	2.55	
Identification of challenges and opportunities for strategic planning		0	1.50	
Policy implementation		2	4.48	
(F4) Market formation	1		18.75	
Advice and support for new business opportunities		1	2.99	A1: "it is growing because they are partnering with companies, offering the possibility for companies to use CIbiogás to develop technology". SP3: "The maintenance of the demonstration units for visitation allowed this exchange of knowledge in a broader way, on how to run a biogas plant. [...] one of the first biomethane plants in the country, came from there too".
Brokerage, representing organizations, and dealings on their behalf		0	0.62	
Brokerage between actors and their interests		0	1.50	
Connecting new technologies and users		0	1.94	
Financial and regulatory instruments/public procurement policies		2	5.02	
Development of awareness mechanisms		0	0.70	
Encouraging the establishment of installation and after-sales service companies		0	0.52	
Investment in new business		0	1.76	
Prototyping and piloting		1	3.61	
(F5) Legitimation	1		13.03	

(Continues)

TABLE 5 | (Continued)

Intermediaries' role in Paraná's biogas TIS functions	Function intensity	Activity intensity	Proportion of quotes (Atlas. TI QDA)	Interview excerpts ^a
Trust-building and conflict resolution		2	4.31	SP1: "In small businesses, regional businesses, it no longer has to solve anyone's problem here, the actors here have already suffered together and have already learned, now they find a way. [...] "Best of all, CIbiogás is respected". PR1: "Even the IAP itself is already starting to talk about biodigesters, not that it is obligatory, but it is suggesting that the biodigester be made, even to eliminate the manure problem".
Gatekeeping and brokerage (defense and lobby)		1	2.64	
Accreditation and setting of standards		0	0.62	
Arbitration based on neutrality		0	1.06	
Assessment of the breadth of environmental and social impacts on society		0	0.79	
Setting and aligning interests for regulation		0	1.67	
Legitimation of institutional change		0	1.94	
(F6) Resource mobilization	3		15.85	G6: "They run after projects, they develop projects, they are a scientific and technological institution, but their partners are always private institutions, they are always a company".
Creation and facilitation of new networks		1	2.82	
Financial brokerage increasing monetary support for equity financing		3	7.13	
Identification and management of human resource needs (skills)		0	1.50	
Project design, management, and evaluation		2	4.40	SP3: "Today we have a company that serves the entire national territory, which is Biokohler. Then it came from there". "[...] Enermac itself emerged from this market that was dropped by companies in the industry, which was after-sales service". CB2: "The quantity of entrepreneurs, including people who left CIbiogás, are in other companies, are entrepreneurs in other companies. Then, new businesses emerged. [...] a project that we planned 3 years ago, and we did not consider some suppliers, and that we did not have at the time, now we have".
(F7) Development of positive externalities	0		8.63	
Creating opportunities for other actors to access highly specialized knowledge		1	2.20	
Dissemination of best practices		0	1.59	
Generation of specialized suppliers		1	2.73	
Generation of combined labor markets		0	1.76	
Generation of complementary technologies		0	0.35	
Total			100	

Source: The authors, based on collected data. Intensity scale according to Table 4.

^aRespondents as listed in Table 3.

generation, and combination of knowledge (7.74%). These findings indicate that CIbiogás's performance in this function can be classified as strong.

The second most frequently cited function, *Market Formation* (F4), accounted for 18.75% of the total quotes. However, within this function, only activities related to regulatory, financial, and public procurement instruments exhibited average performance (5.02%), while the majority of activities were categorized as very weak (Scale 0).

Resource Mobilization (F6) was the third most cited function, with 15.85% of quotes, and financial brokerage for capital financing emerged as a notable highlight within this function (7.13%). Meanwhile, the functions of *Legitimation* (F5) and

Influence on the Search Direction (F3) accounted for 13.03% and 12.76% of the quotes, respectively. Despite these percentages, their activities were generally weak, with the exceptions of *Building Trust and Resolving Conflicts* (4.31%) and *Implementing Policies* (4.48%), which demonstrated slightly better performance.

The functions of *Experimentation with Entrepreneurial Activity* (F2) and *Development of Positive Externalities* (F7) were classified as very weak (Scale 0) due to the minimal percentages associated with their activities.

The analysis of industry data underscores CIbiogás's substantial contributions since its inception, with particular emphasis on the *Development and Dissemination of Knowledge* (F1)

and the *Legitimization of the Sector* (F5). CIBiogás's foundational role as an ICT institution clearly aligns with its mission to generate and disseminate knowledge, as established in its agreement with Itaipu. Furthermore, CIBiogás's efforts to legitimize the biogas sector in Brazil have been recognized, particularly in advocating for the sector and pursuing institutional transformation.

The functions of *Market Formation* (F4) and *Entrepreneurial Experimentation* (F2) demonstrate medium levels of recognition, reflecting the historical progression of CIBiogás's operations. Conversely, functions such as *Influence on the Search Direction* (F3) and *Resource Mobilization* (F6) show lower levels of recognition, while *Development of Positive Externalities* (F7) was notably absent.

As Wiczorek and Hekkert (2012) assert, structural elements, such as the presence and interaction of actors, play a critical role in shaping the *Knowledge Dissemination* function. CIBiogás's collaborations with other stakeholders, particularly rural producers, have been fundamental to facilitating knowledge exchange. Secondary data emphasize the necessity of continuing these efforts to further consolidate the biogas sector. Additionally, according to interviewees, the functions of *Market Formation* (F4) and *Entrepreneurial Experimentation* (F2) have significant potential for enhancement, with CIBiogás's actions positioned to encourage the entry of new entrepreneurs across the value chain (Bergek 2019).

4.2 | TIS Actors' Entrepreneurial Innovation

Regarding the management of innovation processes, interviewee G6 comments that "in this area of technological development, innovation, structuring of business models, CIBiogás, yes, is responsible for a large part of the activities," which is also reported by Interviewee A2: "this entire part, from project presentation, studies and then development to implementation, is all through CIBiogás." R&D projects and ventures that emerged in the western region have as a reference the knowledge developed at CIBiogás, because, as reported by interviewee CB2, "we, in fact, do what the market is not doing yet, the When the market is already doing it, we will undertake other things, because we just want to be at the cutting edge, we want to pull..." Hence, the collaboration of actors is paramount to entrepreneurial innovation, within uncertainty scenarios, suggesting firm-level and systemic transformation within sustainability-oriented innovations. Furthermore, uncertainty in the evolution of markets, technologies, and applications of a TIS leads to external factors to reduce uncertainty. Within the CIBiogás TIS, the combination of experimentation and subsequent innovation is posed by transition intermediaries who can act to facilitate entrepreneurial experimentation and minimize the uncertainties of new businesses.

However, the weak performance of entrepreneurial experimentation and following innovation is due to additional challenges in the system, such as R&D partnerships, the focus of rural properties on animal protein, and the implementation of electricity micronetworks by ANEEL (Electricity Energy Brazilian Agency), which did not favor radical innovation in the system,

therefore limiting possibilities of entrepreneurial innovation and impacting the local producers' efficiency.

4.3 | TIS Actors' Strategy

Entrepreneurial entry into a market is influenced by factors such as the promise of market growth, national and international policies, and shared expectations among various actors, according to TIS studies (e.g., Bergek 2019). Stable and shared expectations, especially among different stakeholders, played a crucial role in encouraging entrepreneurs, highlighting the role of intermediaries in guiding the direction of change and addressing institutional issues. The analysis underscores CIBiogás's proactive role in clarifying objectives, influencing policy discussions, and supporting strategic alignment in the biogas TIS, particularly in the institutional, technological, and legal domains.

CIBiogás's proactive roles are fundamentally tied to its strategy of promoting and expanding the biogas sector. By clarifying objectives, influencing policies, and ensuring strategic alignment across various domains, CIBiogás advances its mission to develop a sustainable and robust biogas TIS, contributing to energy security, environmental sustainability, and economic development. Interviewee CB2 stated, "management of the institution as a whole and attracting new members, innovation strategies, technological development, relationships with stakeholders, institutional relationships, both national and international" when describing his function within the organization. Further, CIBiogás incorporated a subsidiary devoted to renewable energies whose strategy is to provide support for entrepreneurial ventures in transitions towards renewable energy (Interviewee CB2).

Recommendations suggest that stakeholders in the biogas TIS should focus on altering regulatory, normative, and cognitive perceptions to enhance societal acceptability. CIBiogás, as an intermediary, can play a crucial role in this process by assisting in contextual changes, monitoring sentiment during standard development, advocating for regulatory changes, forming alliances, and instilling confidence in overcoming challenges, ultimately mitigating resistance to change.

4.4 | ESG, Sociotechnical Transitions, and Intermediaries

CIBiogás's active involvement in policy discussions within the biogas sector has significantly influenced various functions, including market formation (F4), legitimization (F5), and the development of positive externalities (F7). The findings highlight that stakeholders in the biogas TIS of Paraná recognize the importance of environmental and social sustainability, even though economic considerations frequently dominate decision-making processes. Interviewee A3 emphasized that CIBiogás has successfully demonstrated the economic value of addressing environmental liabilities, thereby shifting the cultural orientation of rural producers towards income diversification. This shift not only enhances sustainability performance but also facilitates compliance with environmental regulations, as

noted by Interviewee A2, who observed improvements such as reduced odors, fewer vectors, and the transformation of biogas emissions into valuable assets.

In the context of environmental performance, a gradual but notable increase in awareness of environmental management was evident. Interviewee B1 remarked, “Over time, people are becoming a little more aware of environmental and sustainability issues, but this is a transformation, and it is a very slow transition.” This perspective ties the evolution of environmental awareness to education and generational cultural shifts. The interviewee further noted that “projects that reduce the production of greenhouse gases and that have a sustainability footprint can be financed by international partners,” underscoring the availability of international funding opportunities for sustainability-oriented projects through CIBiogás’s extensive stakeholder network. These partnerships significantly benefit sociotechnical transitions by aligning financial incentives with sustainability goals.

This gradual transformation highlights the increasing recognition of sustainability issues by intermediaries within the TIS, propelled by educational initiatives and cultural evolution. Furthermore, the ability of projects to mitigate greenhouse gas emissions while demonstrating a sustainability footprint has enabled access to international funding, reinforcing the critical role of CIBiogás in facilitating environmentally beneficial initiatives. Through its comprehensive engagement with stakeholders and its capacity to drive both environmental and economic advancements, CIBiogás has cemented its position as a pivotal force in steering the biogas sector towards greater sustainability and economic viability.

5 | Discussion

The exploration of intermediaries and their role in advancing TISs underscores their significance in driving sociotechnical transitions. This study contributes to prior research in three key domains related to the functional methods of innovation intermediaries in TISs. Firstly, by scrutinizing the performance and intensity of intermediaries, this study enhances understanding of their roles in sociotechnical transitions. The systematic framework expands on earlier research by examining the influence of intermediaries within the biogas TIS in Paraná, Brazil. Additionally, it broadens the scope by identifying more actors, organizations, and networks involved in sociotechnical transition processes within the Biogas TIS.

Secondly, it sheds light on the crucial elements of strategy and environmental, social, and governance (ESG) in facilitating sociotechnical changes within TISs. Intermediaries’ functions, particularly in the biogas TIS of Paraná, are exemplified through various performance highlights. For instance, CIBiogás excels in knowledge development and dissemination (F1) during the structuring phase of the biogas TIS, pivotal for its emergence. Similarly, resource mobilization (F6) through network formation and funding distribution stands out as a key function of CIBiogás. However, despite these strengths, certain functions require improvement. The influence on policy implementation (F3) displays varying intensities, indicating opportunities

for refining strategies. The legitimization function (F5) showcases CIBiogás’ strength in building trust among system actors yet underscores the need for further institutional validation. Entrepreneurial experimentation (F2) remains a weaker aspect for CIBiogás, impeding the acceleration of the shift through innovation. Moreover, intermediaries’ reliance on entrepreneurial innovation, strategic planning, and adherence to ESG practices for driving sustainability within TISs is paramount. Their well-defined strategies encompass addressing industry complexities, regulatory environments, and technological advancements. They facilitate sustainable innovation by developing roadmaps, understanding market dynamics, and engaging key stakeholders.

Lastly, in the journey towards sustainability, intermediaries bridge the gap between novel technologies and widespread adoption, again spotlighting the importance of entrepreneurial innovation. They cultivate emerging technologies, facilitating their transition from niche markets to mainstream acceptance. Integrating ESG principles into their operations and supported technologies ensures adherence to responsible practices, fostering trust among stakeholders, consumers, and investors.

In essence, this study underscores intermediaries’ pivotal role in driving sustainable transitions within TISs, highlighting the importance of entrepreneurial innovation, strategic planning, and ESG principles in this journey, filling the gap on the confluence of these knowledge streams as proposed in the study’s aims. In addition, it emphasizes the need for continued efforts to overcome challenges and foster a robust ecosystem for sustainable innovation and adoption within Brazil’s Paraná state and beyond.

5.1 | Systematic Framework Proposal

This research makes a fundamental contribution through the introduction of a systematic framework for evaluating the intensity of intermediaries’ activities within TISs. This model offers a valuable tool for scholars examining sociotechnical transitions towards sustainability. The framework integrates functions of transition intermediaries outlined by Sovacool et al. (2020) with the seven TIS functions identified by Bergek (2019), ensuring their alignment. Adjustments were made to address gaps in the market formation (F4) and the creation of positive externalities (F7) functions, necessitating the addition of more functions, as shown in Table 6 below.

These features are thought to be necessary for the TIS to operate during sociotechnical transitions. Additionally, Lukkarinen et al. (2018) and Kanda et al. (2019) found (highlighted with two asterisks) the intermediaries’ activities for investments in new firms as well as for prototyping and piloting in the market formation function (F4).

6 | Conclusion and Implications

This study underscores the critical role that intermediaries play in navigating complex and challenging landscapes within the renewable energy sector. CIBiogás exemplifies how intermediaries adeptly maneuver through multifaceted institutional,

TABLE 6 | TIS intermediaries' functions in sociotechnical transitions.

TIS functions	Intermediaries' functions (Lukkarinen et al. 2018; Kanda et al. 2019; Sovacool et al. 2020)
(F1) Development and dissemination of knowledge	<ul style="list-style-type: none"> • Gathering, processing, generating, and combining knowledge • Aggregation and circulation of knowledge • Training and technology assessment • Technology transfer
(F2) Entrepreneurial experimentation	<ul style="list-style-type: none"> • Facilitation of experimentation • Advice and support • Innovation process management • Tests and validations
(F3) Influence in the direction of the search	<ul style="list-style-type: none"> • Articulating expectations, requirements, and visions • Strategy development • Advancement of sustainability goals • Policy implementation • Identification of challenges and opportunities for strategic planning
(F4) Market formation	<ul style="list-style-type: none"> • Advice and support for new business opportunities • Brokerage, representing organizations, and dealings on their behalf • Brokerage between actors and their interests • Connecting new technologies and users • Financial and regulatory instruments/public procurement policies • Development of awareness mechanisms^a • Encouraging the establishment of installation and after-sales service companies^a • Investment in new business^b • Prototyping and piloting^b
(F5) Legitimation	<ul style="list-style-type: none"> • Trust-building and conflict resolution • Gatekeeping and brokerage (defense and lobby) • Legitimation of institutional change • Accreditation and setting of standards • Arbitration based on neutrality • Setting and aligning interests for regulation • Assessment of the breadth of environmental and social impacts on society
(F6) Resource mobilization	<ul style="list-style-type: none"> • Creation and facilitation of new networks • Financial brokerage increasing monetary support for equity financing • Identification and management of human resource needs (skills) • Project design, management, and evaluation
(F7) Development of positive externalities	<ul style="list-style-type: none"> • Creating opportunities for other actors to access highly specialized knowledge^a • Generation of combined labor markets^a • Generation of complementary technologies^a • Generation of specialized suppliers^a • Dissemination of best practices^a

Source: The authors, based on Bergek (2019), Sovacool et al. (2020), and Pigatto et al. (2023).

^aAdditions from TIS theory: Bergek (2019).

^bBased on Lukkarinen et al. (2018) and Kanda et al. (2019).

technological, and market conditions to drive sustainable innovation. In this context, intermediaries serve a dual role: firstly, as facilitators of renewable energy production, and secondly, as technology enablers, fostering interactions between these and the broader institutional actors.

As facilitators of renewable energy production, intermediaries like CIbiogás serve as catalysts for the advancement and adoption of renewable energy technologies. They navigate regulatory

frameworks, secure funding and resources, and facilitate partnerships between stakeholders to overcome barriers to entry and promote the deployment of renewable energy solutions. Simultaneously, intermediaries empower technological niches within the renewable energy sector by providing support, expertise, and networking opportunities. By nurturing emerging technologies and facilitating collaboration between niche actors, intermediaries enable the development and diffusion of innovative solutions that contribute to the broader goals of

sustainability and energy transition. In addition, intermediaries bridge the gap between emerging innovations and mainstream adoption by facilitating dialog, knowledge exchange, and collaboration between actors and policymakers. This interaction helps to shape regulatory frameworks, promote supportive policies, and create enabling environments for the scaling up of renewable energy technologies.

The CIbiogás case illustrates how intermediaries serve as key drivers of change within the renewable energy sector, leveraging their expertise, networks, and resources to navigate challenges and promote sustainable innovation. By playing a dual role in facilitating renewable energy production and empowering technological niches, intermediaries contribute to the advancement of sociotechnical transitions towards a more sustainable energy future. Given how crucial change is for business strategy, the findings herein have clear implications for strategic policy making, through valuable insights for sociotechnical transition processes and strategic decision-making, as well as showcasing that intermediaries contribute significantly across the seven functions, particularly on knowledge development and dissemination (F1) and resource mobilization (F6). In addition, our findings suggest that policymakers should be cognizant of the key functions and closely involved with intermediaries to drive sociotechnical changes towards sustainability.

Generalizing from this study, it becomes transparent that intermediaries serve as crucial facilitators in renewable energy production and technological niche empowerment. They secure resources, navigate regulatory landscapes, and foster stakeholder partnerships, enabling the deployment of renewable technologies. Additionally, they support emerging technologies by offering expertise, networking opportunities, and collaboration, thus promoting the development and diffusion of innovative solutions. Within the biogas sector, this work is potentially generalizable to comparable TISs and niche renewable technologies, such as biomethane and other biogas association partners around the world.²

6.1 | Theoretical Implications

This study has several theoretical implications. First, the case underscores the pivotal role of intermediaries in facilitating sociotechnical transitions, particularly in the renewable energy sector of a rapidly developing economy. Intermediaries, such as CIbiogás, are adept at navigating complex institutional, technological, and market conditions, which are often characterized by regulatory barriers, technological uncertainties, and market dynamics. They act as connectors between various stakeholders, including governments, research institutions, private companies, and local communities. Their ability to bridge gaps and foster collaboration helps streamline the processes needed to drive renewable energy initiatives. For example, CIbiogás not only promotes the development of biogas technology but also facilitates knowledge transfer and builds networks that connect producers, consumers, and policymakers. Such connections create an ecosystem that supports the advancement and acceptance of renewable energy technologies.

Second, intermediaries like CIbiogás play a dual role in socio-technical transitions. On the one hand, they facilitate the development and deployment of renewable energy technologies, such as biogas production. On the other hand, they empower technological innovation by fostering interactions with existing institutional regimes, thereby creating opportunities for innovation and diffusion. By engaging with regulatory bodies and advocating for supportive policies, intermediaries help shape the regulatory environment to accommodate and accelerate technological advancements. Additionally, their collaborations with academic institutions and private sector enterprises drive research and development, resulting in new technologies and innovative solutions.

Furthermore, the study highlights how intermediaries contribute across the seven functions identified in sociotechnical transition frameworks, in line with Bergek (2019). These functions are critical for understanding how transitions unfold and how different actors contribute to this process. In particular, we found that intermediaries play a key role in two functions, (F1) and (F6). They contribute to knowledge development and dissemination (F1) by sharing information, best practices, and lessons learned across stakeholders. This function is vital for building collective understanding and reducing uncertainties, which can otherwise hinder the adoption of new technologies. Intermediaries organize workshops, seminars, and knowledge-sharing platforms that bring together stakeholders from diverse backgrounds to exchange insights and experiences. Such initiatives enhance learning, promote technological improvements, and accelerate the diffusion of innovations. Additionally, intermediaries play a significant role in resource mobilization (F6). They facilitate access to funding, infrastructure, and other resources needed for innovation and deployment. For instance, CIbiogás assists project developers in securing financial support from government grants, international organizations, and private investors. They also help to identify and leverage existing resources such as technical expertise and physical infrastructure, ensuring that projects are implemented effectively and efficiently.

Intermediaries often act as advocates for the renewable energy sector, influencing policy agendas and promoting regulatory frameworks that support innovation and the sector at large. By representing the collective interests of stakeholders, they help shape policies that address market failures, reduce investment risks, and create a more favorable environment for renewable energy projects, driving innovation, shaping policy environments, and creating networks that sustain long-term transitions. The case of CIbiogás illustrates how intermediaries address barriers and unlock opportunities for technological advancement. As the renewable energy sector continues to evolve, recognizing and supporting the role of intermediaries will be essential for achieving sustainable transitions and addressing global energy challenges.

6.2 | Practical Implications

The findings from the CIbiogás case offer valuable insights for strategic decision-making within the renewable energy sector and beyond. Organizations and policymakers can draw lessons from the experiences of intermediaries like CIbiogás in

navigating complex transition processes, overcoming barriers, and seizing opportunities for innovation and sustainability. One key insight is the critical role of collaboration and networking in driving sociotechnical transitions. Intermediaries such as CIBiogás act as vital connectors, fostering cooperation among diverse stakeholders, including government agencies, research institutions, industry players, and local communities. These collaborative efforts accelerate the development and implementation of renewable energy projects, enhancing their impact and scalability.

CIBiogás' approach demonstrates how intermediaries facilitate multi-stakeholder partnerships through knowledge-sharing platforms, joint research initiatives, and policy dialogs. Such efforts not only bridge gaps between sectors but also drive collective problem-solving and innovation. For instance, by connecting researchers with industry experts, intermediaries help translate scientific advancements into practical solutions that address real-world challenges in the renewable energy sector and related industries. Further, the case highlights how intermediaries support sustainable transitions by aligning stakeholder interests and advocating for supportive policies. They play a pivotal role in ensuring that projects are inclusive, addressing the needs and concerns of local communities while fostering long-term stakeholder engagement. This inclusive approach builds trust, secures community buy-in, and enhances the resilience of transition efforts.

Finally, the case illustrates that successful sociotechnical transitions require more than technological innovation—they demand robust networks, collaborative ecosystems, and inclusive practices. The lessons derived from this case underscore the importance of intermediaries in coordinating efforts, sharing knowledge, and driving collective action. Policymakers and organizations aiming for sustainable transitions should prioritize fostering strong intermediary roles and relationships, recognizing their potential to unify diverse actors, catalyze innovation, and sustain progress in renewable energy development.

6.3 | Limitations and Future Research Suggestions

The study was conducted in Brazil, a single (rapidly) developing country. While the findings are also relevant for other emerging economies with similar cultural and institutional contexts and may extend to other industries, additional studies in comparable TISs are needed for further validation and exploration of potential limitations in the presented model. Future research could delve deeper into the strategies employed by intermediaries like CIBiogás to navigate challenging institutional, technological, and market conditions. Understanding how intermediaries identify opportunities, overcome barriers, and build networks can provide valuable insights for other transition contexts. Additionally, research could focus on examining the nature and dynamics of relationships between intermediaries, technological niches, and institutional regimes. This could involve analyzing the role of intermediaries in mediating interactions, facilitating knowledge exchange, and fostering collaboration between diverse stakeholders. Lastly, investigating the policy implications of intermediary interventions in sociotechnical

transitions can help inform decision-making and policy design. Research could explore how policymakers can leverage intermediaries to accelerate the transition to renewable energy and foster innovation in other sectors. This could involve analyzing the role of intermediaries in mediating interactions, facilitating knowledge exchange, and fostering collaboration between diverse stakeholders.

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Endnotes

¹ In Portuguese, the name is CIBiogás: Centro Internacional de Energias Renováveis – Biogás.

² <https://www.worldbiogasassociation.org/partners/>, as accessed on May 17, 2024.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.