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RESEARCH ARTICLE

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Bioeconomic innovations breeding more sustainable innovations: A value chain perspective from Argentina

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Abstract

Innovations are crucial for the transition to a sustainable bioeconomy. They are embedded in and linked to complex value chains, but these interrelationships have not received much attention in the empirical literature yet. Using current typologies of four bioeconomic innovation types and six value chain models, this case study analyzes detailed data from 11 companies in Argentina to identify the drivers of sustainable innovations, their linkage to different value chain characteristics, and the main innovation types. The results show that certain factors such as supply and demand, interindustry cooperation and R&D, diversification strategies, personal values and the search for sustainable solutions particularly shape certain types of innovation. The structure and governance of the value chains influence the type of sustainable innovation. Innovations take place at different levels, and in succession, they complement each other and can thus make the bioeconomy more sustainable. Therefore, appropriate policies to promote the bioeconomy in Argentina and beyond should consider the type of value chains and specific innovation systems involved.

KEYWORDS

biofuels, biomass, biotechnologies, food industry, governance, incremental innovations

1 | INTRODUCTION

Technological innovations play a central role in economic growth and have the potential to contribute to the transition toward a sustainable bioeconomy. By replacing fossil resources with renewable, biological materials, the bioeconomy is expected to contribute to the achievements of the SDGs (Biber-Freudenberger et al., 2020). In addition to the direct replacement of fossil resources, biomass production can be made more sustainable, biogenic waste be reused, and low volume to high value biobased products can be created (Dietz et al., 2018).

However, the introduction of these innovations and the transition to a bioeconomy are not sustainable per se. Bröring et al. (2020) show that various possible bioeconomic pathways (Dietz et al., 2018) can be shaped through different types of innovations and lead to different sustainable outcomes. Since innovations take place in mostly complex

Abbreviations: CONICET, National Council of Scientific and Technical Research; EU, European Union; GM, genetically modified; INTA, National Institute of Agricultural Technology; IT, innovation type; R&D, research and development; RQ, research question; SDGs, sustainable development goals; SME, small and medium-sized enterprises; SOI, sustainability-oriented innovation.

value chains and can simultaneously affect and be affected by their organization, it is important to analyze the connection and codetermination between the type of bioeconomic value chains and innovations (Mac Clay & Sellare, 2022).

Despite the lack of empirical evidence, some typologies and conceptual frameworks have been proposed to understand these relationships between technological innovation, bioeconomic pathways, and value chain governance (Bröring et al., 2020; Dietz et al., 2018; Mac Clay & Sellare, 2022). Although useful for developing new hypotheses about how the transition toward a bioeconomy may affect different sustainability dimensions, they are often not empirically validated. Moreover, most of the literature on sustainable innovations has not yet considered supply chain aspects (Neutzling et al., 2018). According to Mac Clay and Sellare (2022), while many papers seek to portray innovations in the bioeconomy, few of them explore in depth which value chain aspects may be more conducive to triggering bioeconomy innovation.

In this paper, we attempt to address this research gap using a case study approach that is particularly suitable for answering "how" questions (Rowley, 2002). Our objective is to find out how value chain characteristics and sustainable innovations are interlinked and how this connection works. We use company-level data from 11 enterprises in Argentina and analyze them through the lens of existing typologies and conceptual frameworks to answer the following research questions: (RQ 1) What are the drivers of sustainable innovations?; (RQ 2) How are innovations linked to different features of the value chains?; and (RQ 3) Which types of sustainable innovations play which role in different value chains? Besides, we will also evaluate to what extent the innovation and value chain typologies proposed for the bioeconomy are a valid analytical tool, and what policy implications arise from our research questions.

Argentina has an ideal setting to study these processes of bio-based technological innovations. While its bioeconomy is still dominated by applications based on high volume-low value-oriented value chains (e.g., for the production of biofuels based on soy and maize), biotechnology is becoming increasingly important, and with it, low volume-high value chains, as in the pharmaceutical industry. Other bioeconomic value chains, such as those related to the food industry and alternative bioeconomic initiatives that are locally embedded, are also gaining attention (Dürr & Sili, 2022). On the political level, the bioeconomy is considered a concept that will promote the development of the economy and improve its environmental performance (MINAGRO, 2016).

To characterize the innovation process in these companies, we combine the typologies developed by Mac Clay and Sellare (2022) of bioeconomic value chain models with the typology of sustainable innovations (IT) in the bioeconomy, developed by Bröring et al. (2020). Based on detailed evidence from biocononomy companies, our analyses contribute to a better understanding of the dynamics of innovations in bioeconomic value chains. Furthermore, our study shows that innovations take place on different levels, which complement each other and only together are able to make the bioeconomy more sustainable. The distinction between primary and secondary innovations is an important conceptual contribution of this paper to the discussion on a sustainable bioeconomy. This will also help formulate appropriate policies that address the different challenges of a sustainable bioeconomy and better determine which policies could promote sustainability-oriented innovations.

2 | TYPOLOGIES OF SUSTAINABLE INNOVATIONS AND VALUE CHAINS IN THE BIOECONOMY

2.1 | Sustainable innovations

Eco-innovations mainly refer to new products or processes that reduce negative impacts on the environment (Kemp & Pearson, 2008). In contrast, sustainable innovations or sustainability-oriented innovation (SOI) (Adams et al., 2016) consider both environmental and social aspects (Silvestre & Ţîrcă, 2019). Triguero et al. (2013) distinguish eco-innovations into product, process, and organizational innovations, based on Schumpeter's (1934) classic innovation concept, which also included new sources of supply and opening of new markets. Eco- and sustainable innovations can be incremental to gradually improve existing businesses or lead to radical changes in products and processes (Donner & de Vries, 2021). However, the concept of eco- and sustainable innovation appears to be aimed primarily at incremental improvements to processes, for example, the elimination of "dirty" product components, rather than radically new technologies and production systems (Hellström, 2007). Varadarajan (2017) further divided sustainable innovation into different types depending on whether resource use is reduced, eliminated or substituted, and on the stage of the supply chain (upstream, production, downstream, and consumption).

It is assumed that drivers of "traditional" innovations, such as technology push and demand pull factors, are also relevant for eco-innovations but that additional factors, such as environmental policies and regulations, have to be taken into account (Horbach, 2008). In this sense, Horbach (2008) differentiated between supply, demand, and environmental policy factors that influence eco-innovations. Similarly, Rabadán et al. (2019) summarized the drivers for eco-innovations by dividing them into market demand, regulations, incentives, technological level, resources and capabilities of enterprises, and their collaboration with partners. Yet different types of eco-innovations can be influenced differently by these factors (Horbach et al., 2012). There are various studies on drivers for sustainable innovations conducted mainly for European countries, but there is still a knowledge gap concerning developing and emerging economies. Besides, the question whether specific innovation types relate to certain drivers is still underresearched (Kiefer et al., 2019).

Moreover, Bröring et al. (2020) note that these innovation concepts have not yet been adapted for the bioeconomy. This is necessary because the bioeconomy has particular characteristics and faces specific challenges, such as a complex knowledge-base, not fully developed technologies, competition with long-established fossil-based industries, and incohesive policy schemes. Furthermore, the requirements for innovations to ensure a transition toward the bioeconomy may be very specific, requiring more radical innovations, often of an interdisciplinary character and facing market entrance barriers. Furthermore, a typology of innovation types that goes beyond the classic distinction between product and process innovation is considered necessary to monitor the development and dissemination of different innovation types in a bioeconomic transition while comparing the challenges, goals, and outcomes of different bioeconomic innovations.

For this purpose, Bröring et al. (2020) utilize existing SOI typologies and connect them with the specific characteristics and challenges of innovations in the bioeconomy, identifying four innovation types (ITs). *IT I*: substitute products; *IT II*: new processes; *IT III*: new products; *IT IV*: new behavior. *IT I* relates to the substitution of fossil-based products by bio-based ones (e.g., bio-fuels or bio-plastics), resulting in lower exploitation of fossil resources and lower carbon emissions. This means that the products, especially their resource base, are new but they do not offer new functions. Therefore, existing value chains can normally be preserved, and no disruptive changes are to be expected. *IT II* includes innovations that improve processes in bio-based firms and value chains for sustainability, through incremental changes that make established processes more efficient, or disruptive procedural transformations that lead to entirely new value chain connections and processing options. New processes comprise the replacement of chemicals by biological processes in bio-refineries, or new and more efficient biomass conversion techniques (e.g., ethanol from lignocellulose waste, or advances in breeding and plant cultivation through genome editing). These innovations might improve resource efficiency and reduce greenhouse gas emissions and pollution. *IT III* refers to new bio-based products with new functions, and as such, it is expected to be disruptive and open up radically different applications and value chains (e.g., bio-degradable stands for medicine, biopharmaceuticals, and specialty chemicals for the construction sector). *IT IV* is about new ways of doing business more sustainably, for example through circular systems or cascade use. A fundamental rethink and a realignment of the business model are necessary here. Examples include the reuse of already exploited biomass, the use of biomass for energy after extraction of more valuable compounds, or new combinations and value chain connections for cascade use that can improve resource efficiency and waste generation and provide a solution between food and fuel conflicts.

2.2 | Bioeconomic value chains

A rich body of literature on value chains has sought to understand the relationship between value chain governance and change (Gereffi et al., 2005; Zilberman et al., 2019), how their organizational structure can affect knowledge transfer and technological adoption (Janssen & Swinnen, 2019; Kuijpers & Swinnen, 2016), and how the integration of smallholder farmers into global value chains can affect their livelihoods (Feyaerts et al., 2020; Van den Broeck et al., 2017). When it comes to the literature on the bioeconomy, previous studies that have a value chain perspective have mainly focused on describing the design of specific value chains and sectors (Carraresi et al., 2018; Cerca et al., 2022) and on the concept of value-webs centered around specific biomass sources (Lin et al., 2019; Scheiterle et al., 2018). However, there is a lack of in-depth empirical examination of how value chain organization relates to technological innovations during the transition to a bioeconomy. This focus is crucial because value chain organization has the potential to drive sustainable technological innovations (Swinnen & Kuijpers, 2019) and affect the equitable distribution of benefits within the value chain (Sellare, 2022).

Mac Clay and Sellare (2022) propose a typology of six value chain models in the bioeconomy and characterize them in terms of the complexity of the innovation process involved and the prevailing value chain features of governance schemes, industrial structures, collaboration among firms, and core innovation capabilities. Value chain governance describes the way of interaction between value chain actors through market mechanisms, contracts, and rules. The structure is characterized by the size and number of firms, the length of the value chain, and so on. Collaboration among firms can take the form of alliances and partnerships, knowledge sharing, or joint ventures. Innovation capabilities mainly rely on the promotion of innovations, research capacities, and the tradition of innovation in the value chain.

The first three models presented by Mac Clay and Sellare (2022) are intensive in biomass requirements and rely on mature technologies. These models are based on the diffusion of available technologies, which in most cases can be acquired on a turnkey basis. In this type of model, the main challenges seem to be related to organizational or management aspects rather than dealing with new or unknown technologies. Therefore, the prevailing governance structures tend to rely on market principles and require contracting or integration only to a limited extent. Examples of these models are first-generation biofuel value chains or biogas production from agricultural or industrial residues. The last three value chain models proposed by Mac Clay and Sellare (2022) are biotechnology intensive, such as second-generation biofuels or bioplastics, meat substitutes based on cellular agriculture, or agricultural inputs based on new gene editing techniques. These models hold a promise from the environmental point of view, as they either reduce the biomass needs or rely on biomass sources that are less land-intensive, thereby mitigating pressures for land-use change and several environmental side effects resulting from increased biomass production. In this second set of value chain models, the main technologies involved are not yet mature, so bringing them to the market implies intensive research and development (R&D). Scaling these products and processes until they reach a profitable scale entails high capital expenditures and risk of failure, both at the development and commercial stages. As the systemic characteristics of the innovations increase, these models require more coordination between value chain actors and the involvement of large industrial players to facilitate the journey of these innovations to markets. Therefore, partnerships between technological and industrial firms in the development of these technologies are common.

2.3 | Framework for linking innovation with value chain types

For our empirical approach, we start by linking the main concepts described above to our research questions. Figure 1 shows that different factors influence (different types of) innovations (RQ 1); varying value chain features influence innovations (RQ 2); and different innovations impact on the sustainability of value chains, depending on the pathway followed ("primary innovations") and other ("secondary") innovations (RQ 3).

In order to develop an analytical framework combining the two typologies described above, we used the typology of Mac Clay and Sellare (2022) to describe the value chain structure of different actors and their interactions, that is, the flow of biomass and products between clients and customers. We start from the analytical unit of our case study, which is either a bio-based processing company (in green), or a biotech/R&D-centered company (in blue), both of which are in the center of the models presented by Mac Clay and Sellare (2022) (Figure 2). Depending on the type of value chain, only one or both of these might be present. The same holds for all other actors: Only some or all of them might exist in a particular chain. There might also be enterprises which exercise various functions, for example, farmers that process the biomass they produce. Note that to keep the framework simple, we have not included traders (wholesalers and retailers). Each arrow denotes a flow of biomass, bio-based products or (biotechnological) services between the value chain actors. The solid lines represent the flow of biomass produced and transformed or services provided, while the dashed line represents reused biomass or biomass that is not processed in the strict sense but used as a medium for biological processes. Again, these are supposed to be specific, so only some of them might be present depending on the value chain. We hypothesize that in each value chain point, that is, where biomass is produced and used or where products and services are generated, there are opportunities for sustainable innovations, classified according to the four types (*IT I* to *IV*) described in Bröring et al. (2020).

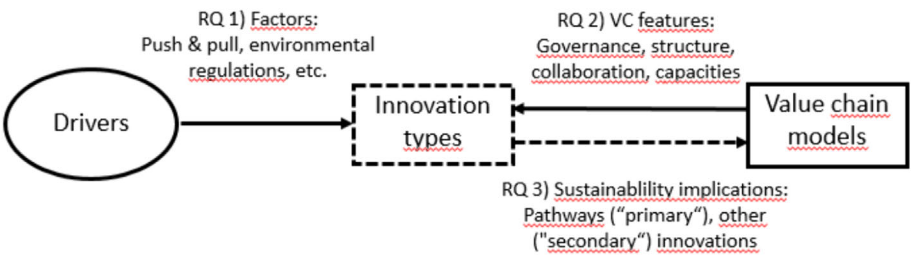

FIGURE 1 Conceptual framework.

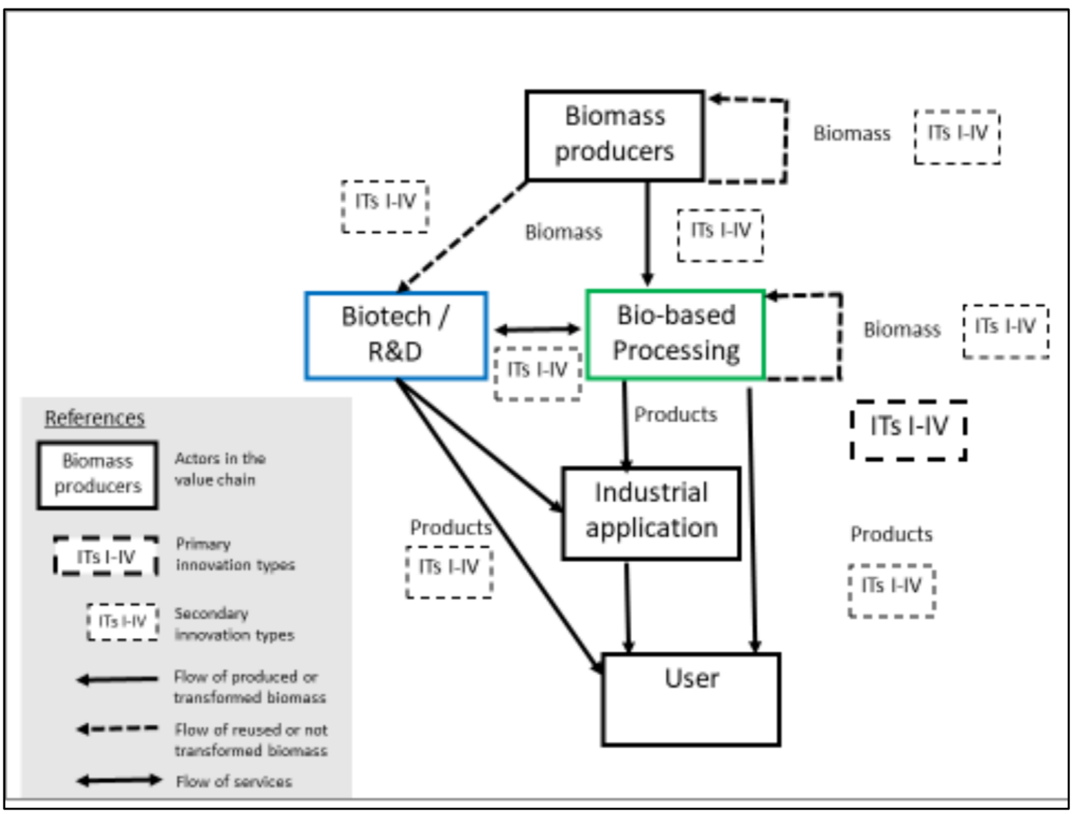

FIGURE 2 Analytical framework based on Mac Clay and Sellare (2022) and Bröring et al. (2020).

3 | METHODS

3.1 | Data collection

Based on the analytical framework, our aim was to gather information from biomass processing as well as from biotech companies. We concentrated on these two types of actors for two reasons. First, they are considered the key players in the value chain models. Second, given our limited time and resources, this procedure allowed us to get information on the whole value chain. In order to be able to include a wide range of possible value chain and innovation types in the study, purposive heterogeneous sampling was considered an approriate nonprobability technique (see Etikan et al., 2016) in order to select as different bioeconomic companies as possible within the regional focus of the study (see Table 1), which includes both very dynamic territories that form the basis of the Argentine bioeconomy as well as more marginal regions (Figure 3).

Semistructured interviews with 11 bioeconomic enterprises representing different sectors and sizes were carried out in November 2022 and lasted around 2 h each. The interviews were conducted with the company management. These companies were chosen from a list of 28 enterprises linked to the bioeconomy, generated with the information provided by the National Institute of Agricultural Technology (INTA), Universities, and the Argentinean Science and Technology Agency (*Agencia CYT*). Of the 28 companies contacted, 11 responded positively to the interview. The companies are located in a vast area of 1000 km from south to north in the Argentine provinces of Santa Fe, Chaco, and Formosa (Figure 3), allowing for diverse environmental conditions and production situations.

3.2 | Data analysis

Using the semistructured questionnaire, we compiled information on the history of the company, its size, business model, biomass used, market channels, main suppliers, and customers, as well as detailed information on the factors that contributed to and hindered its innovation processes. We analyzed the type of actors and their linkages for the 11 cases and examined which of the value chain models developed by Mac Clay and Sellare (2022) they fit under. We then examined which innovations occur in the different cases and types of value chains. In each case, we have defined a primary innovation type

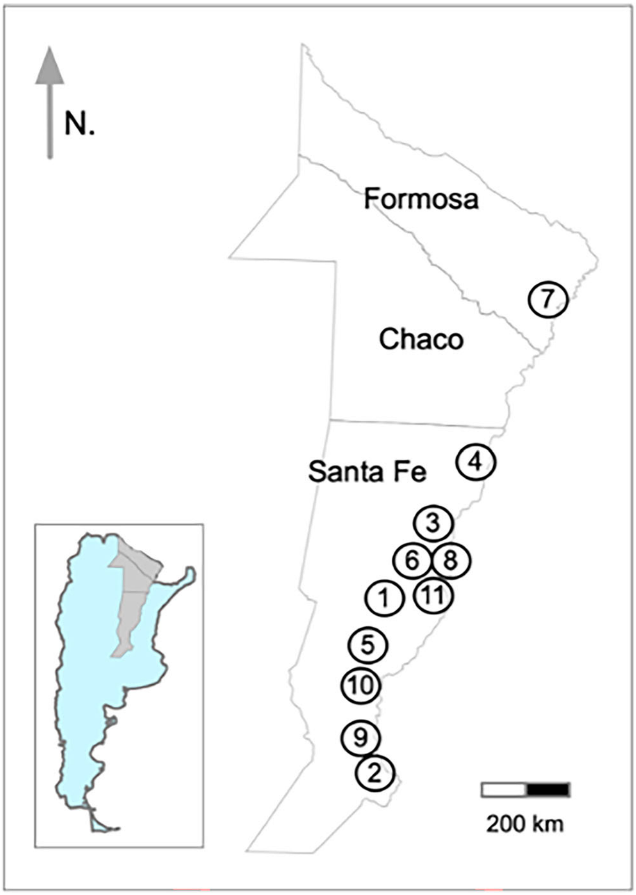

FIGURE 3 Localization of bioeconomic companies interviewed.

TABLE 1 Bioeconomic enterprises interviewed.

Case		Location (city/province)	Number of employees	Biomass used	Tons per year
1	Dairy	Crespo/Santa Fe	500	Milk	300,000
2	Biofuel (diesel)	Rosario/Santa Fe	600	Soybeans	600,000
3	Biofuel (ethanol)	Avellaneda/Santa Fe	200	Corn	240,000
4	Rum & Sugar	Las Toscas/Santa Fe	5	Sugar cane	300
5	Rendering	Recreo/Santa Fe	200	Slaughterhouse waste	80,000
6	Food (rice flour)	Malabrigo/Santa Fe	5	Broken rice	400
7	Tannin	Formosa-Resistencia/Formosa-Chaco	600	Wood	30,000
8	Feed	Reconquista/Santa Fe	20	Sugar, starch	n.d.
9	Seed traits	Rosario/Santa Fe	10	Seed DNA	n.a.
10	Bio-pharmaceutics	Santa Fe/Santa Fe	200	Blood cells	n.a.
11	Agricultural devices	Avellaneda/Santa Fe	50	-	-

Abbreviations: n.a., not applicable; n.d., no data.

(*I* to *IV*, shown in bold in Figure 2) that forms the core of the whole value chain and defines the basic pathway of the bioeconomic transition. In addition, we examined other supplementary ("secondary") innovations that accompany the more fundamental innovation.

4 | RESULTS

4.1 | Model 1: Traditional and high volume biomass use

Case 1 is a medium-sized, family-run company from the "traditional bioeconomy", because its dairy products such as milk, yogurt, and cheese are not new, and hence, no bioeconomy transition pathway is being pursued. But, this does not mean that there are no innovations in this direction in this traditional food sector. In fact, there are secondary products (*IT III*) and process innovations (*IT II*), such as new whole fruit yogurt varieties, lactose-free milk, or better methods for stabilizing cocoa in milk drinks. In addition, the company tries to encourage farmers to produce high-quality raw materials by making the price dependent on the fat milk content. This, in turn, gives producers incentives to improve their feed and herd management and animal welfare in general. Moreover, the company provides technical assistance to dairy farmers. These "secondary" innovations lead to new and better quality products and enable competition in a difficult market dominated by large multinational companies on the one hand and many informal artisanal cheese makers on the other.

For Cases 2 and 3, two grain-exporting companies, one multinational and the other national, were interviewed. *Case 2* started producing biodiesel, and *Case 3*, producing bioethanol when there was high demand in international markets, so fuel substitution (*IT I*) was the main innovation. Both companies mainly export their production, as the national market for blends is reserved for small and medium-sized enterprises (SME). In addition, *Case 2* innovates continuously in the field of energy, water, and waste reduction (*IT II*), mainly at the initiative of employees who suggest improvements to reduce costs. Higher-quality by-products such as glycerin and lecithin, which are primarily used in the feed industry, are also increasingly being marketed. In addition, the company's strategy is to purchase soybeans only from non-deforested areas (*IT IV*). The main drivers of innovation were the reduction of energy consumption in the processes, the possibility to provide higher value products and the international demand for deforestation-free soybeans.

In *Case 3*, similar innovation types were introduced, such as energy saving by producing biogas, electricity, and bio-fertilizer from the largely existing organic waste (*IT I*). The company also sells by-products such as distiller grains to the feed industry or bio-fertilizers to farmers (*IT IV*). Moreover, it is flexible in its alcohol production, that is, when bioethanol demand is low, it can also produce alcohol used as a beverage or disinfectant. In general, the company has highly diversified its bioeconomic activities. As most technologies are turnkey, no big innovations are taking place, but there are still continuous improvement processes, the main driver being energy saving. Moreover, sustainability aspects play an important role in the company's strategy, coupled with the technical capacity to optimize internal processes (Figures 4, 5, and 6).

4.2 | Model 2: Integration of biomass production and processing and adoption of circular principles

Case 4 is a local producer trying to integrate a silvopastoral system with sugar cane production and processing to achieve a more sustainable, circular system (*IT IV*) and new products with higher added value. The artisanal rum and sugar are marketed locally and the by-products (vinasses and molasses) are fed back into livestock and sugarcane production, allowing integrated, circular systems to emerge. Moreover, wood production (from eucalyptus) is designed to solve problems of local energy supply (*IT I*). Other innovations come from improved sugar cane varieties (*IT III*), with higher productivity and suitable for direct livestock feeding in the fields (*IT IV*). The idea for the future is to involve more sugar cane producers, forming an association to scale up production. The main drivers of innovation stem from searching for sustainable solutions to local economic and environmental problems, technological advances in sugar cane breeding, commercial opportunities, and availability of information from technical agencies and networking with other small processors in Brazil. However, a lack of financing, a lack of support policies, bureaucracy, and high requirements to create new processes are hindering the expansion of this alternative model of integrating biomass production and processing (Figure 7).

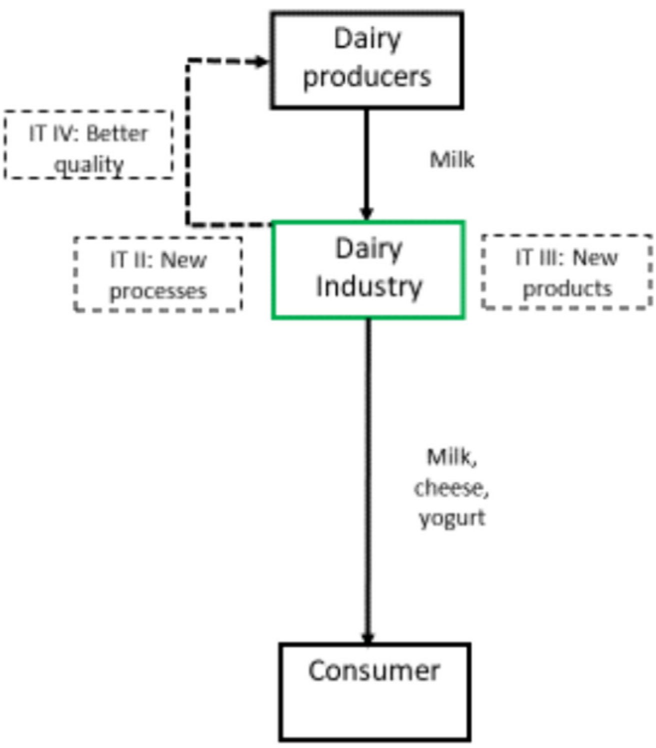

FIGURE 4 Case 1 (dairy industry).

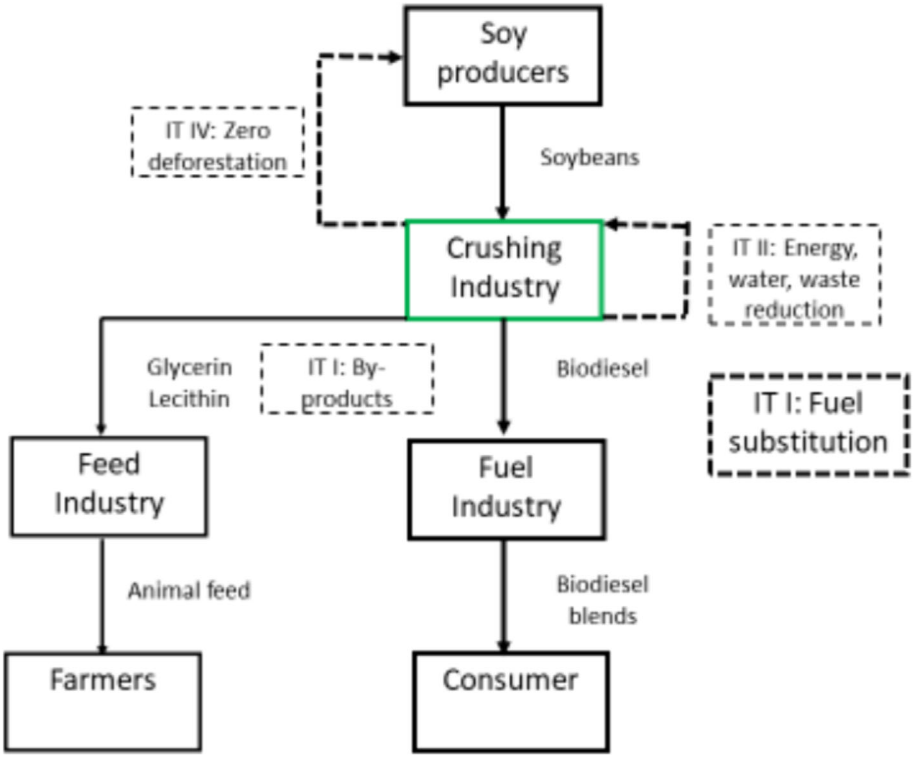

FIGURE 5 Case 2 (soy crushing industry).

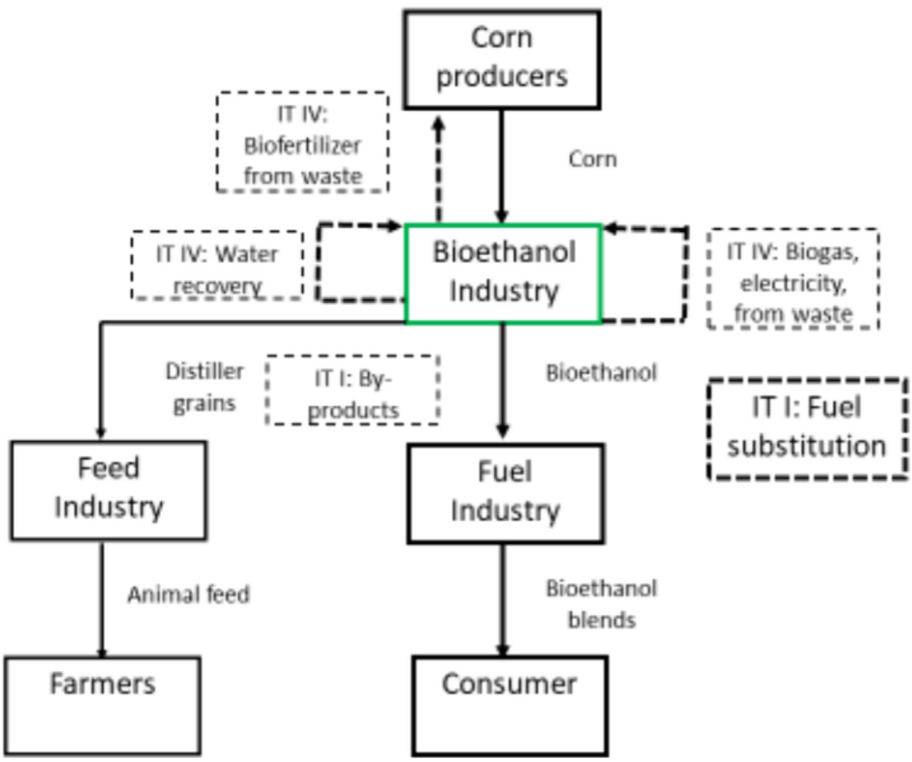

FIGURE 6 Case 3 (bioethanol industry).

4.3 | Model 3: Transformation of biomass residues into products with value-added

The two companies examined in Cases 5 and 6 convert biomass residues into higher value products. Therefore, the primary innovation type consists of re-using already exploited biomass, which enables cascading use of biomass, reduces waste, and leads to higher resource use efficiency (*IT IV*). *Case 5* transforms slaughterhouse waste into new products for human consumption and animal feed, but also for the cosmetics industry and biodiesel production. Secondary

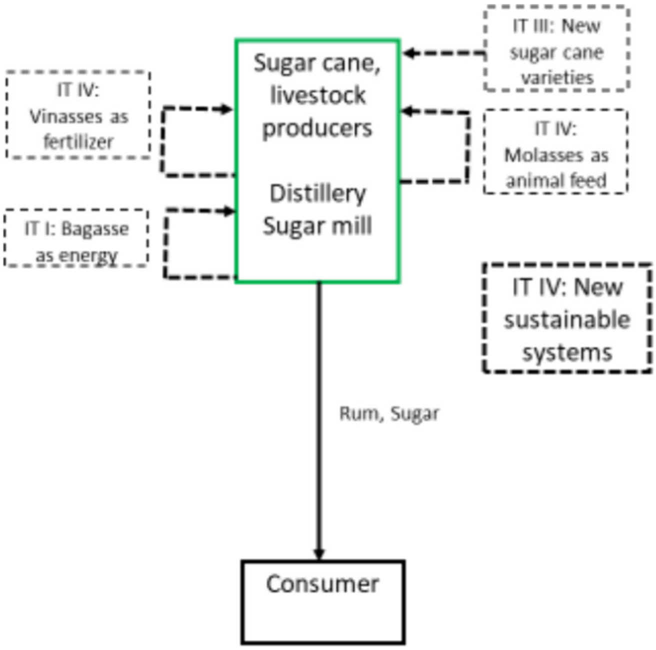

FIGURE 7 Case 4 (small scale sugarcane processing).

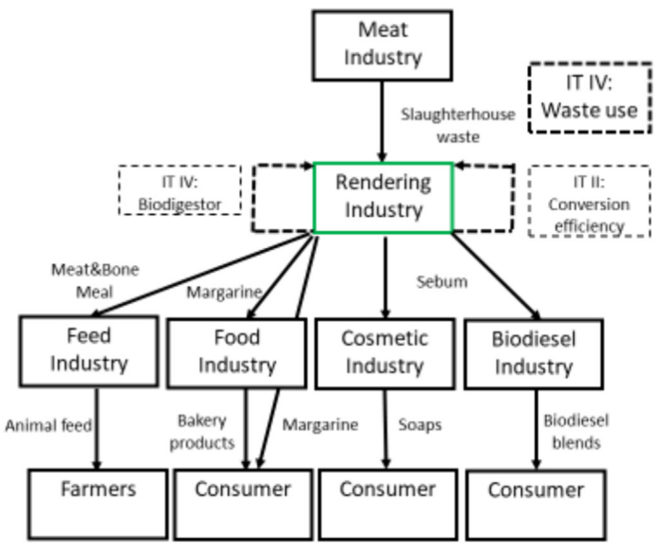

FIGURE 8 Case 5 (rendering industry).

innovations concern the installation of a new continuous refinement plant to improve the quality and conversion efficiency of biomass (*IT II*). In addition, a biogas plant is operated from organic residues, generating heat for the company's production processes. The drivers of innovation are the search for better quality and environmental conditions, which are requirements of clients and of the territory, learning from experiences in other countries on environmental issues, the available human resources, and the willingness of entrepreneurs to change. There is also an agreement with the local university to improve processes.

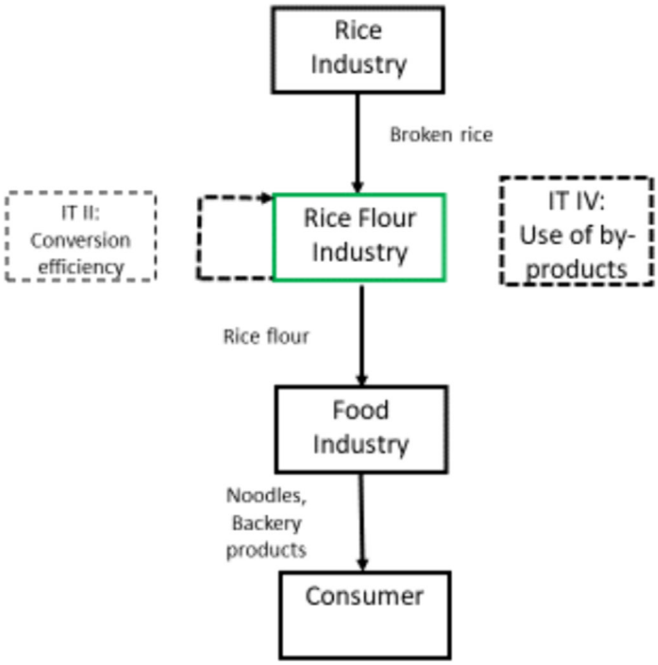

FIGURE 9 Case 6 (rice flour industry).

The main innovation of *Case 6* is related to the better use of biomass, as the company uses broken rice from the rice industry, which cannot be sold to consumers, and new products with higher value-added, such as micro-flour, used as an input in different food industries (*IT IV*). The main drivers are the entrepreneurial spirit of the founder, the availability of biomass and the interest of food industries in developing new products, the trend toward organic and more natural products, as well as the possibility of integrating the chain and adding something new to a traditional activity, with low transaction costs, based on the availability of local science and technology. Here too, secondary innovations affect conversion efficiency (*IT II*) (Figures 8 and 9).

4.4 | Model 4: Feedstocks and advanced technologies for high value products

Case 7 belongs to the "traditional" bioeconomy and produces tannins for leather tanning. But it also uses technologies to create new, innovative products for different purposes (*IT III*). The 'Quebracho Colorado' tree (*Schinopsis lorentzii*) is used for tannin extraction. To ensure the availability of raw materials, the company reforests several thousand hectares every year. The wood waste generated during processing is used to produce energy (*IT I*). There is a diversification of the product range and continuous development of the products in coordination with customers. For example, polyphenols can be used in the feed industry and, thanks to their antibacterial effect, can replace antibiotics in animal husbandry. In addition to the wine industry, another customer is the cardboard and the ceramics industry, which can thereby replace chemical products (e.g., formaldehyde or acids) with natural ones. The company has a laboratory that develops and improves product lines. The driver behind the innovations is the search for diversified, quality products with increased added value, as well as the interest in secure energy and more sustainable use of biomass, including residues from other companies. A key issue is the availability of raw materials, as only Quebracho trees aged 40 to 50 years develop significant amounts of tannin (Figure 10).

4.5 | Model 5: Low volume, high value biomass

The innovation in *Case 8* consists in the development of bio-nutrition products for ruminants (*IT III*), which are elaborated out of biotechnological (enzymes), organic (i.e., sugar and modified starch), and inorganic (chlorine, calcium, phosphorus, nitrogen, etc.) ingredients that are used directly or mixed with other livestock feed. It was developed by the company combining enzymology, micronutrition of the ruminal biota, and microbial ecology, leading to more sustainable and productive animal feeding by optimizing the digestibility of fibrous grasses or deficient grains. The drivers of innovation are the existence of an R&D department of 15 people and the cooperation with the local university, with which the enterprise is jointly developing five different research lines. The business model is to sell innovative solutions for livestock production, an important sector in the country, and to strengthen itself as a company that generates new products. As the products are relatively new, the company is trying to achieve exposure through social media and has set up its own distribution network (Figure 11).

4.6 | Model 6: Biomass-free biotechnologies and high-tech solutions for biomass production

In *Case 9*, the innovation is the development of special seed traits through gene editing for soybean, sorghum, cotton, rice, alfalfa, peanuts, maize, and sunflower, thereby introducing resistance into the seeds, allowing the use of the least toxic herbicides on the market (*IT II*). The drivers of innovation of the gene editing company consist of its own biology labs, plant growth facilities in Argentina, and a lab in the US, in one of the main international agro-biotech hubs. Additionally, there are not only many companies in Argentina that can propagate seeds with the new gene edition but also pro-innovative producers. Furthermore, the regulatory framework for this kind of

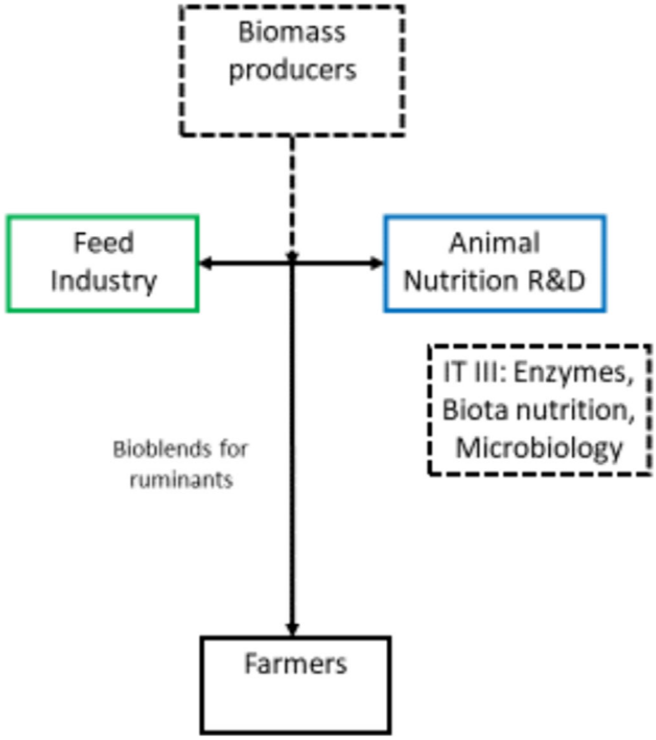

FIGURE 11 Case 8 (bio-nutrition for ruminants).

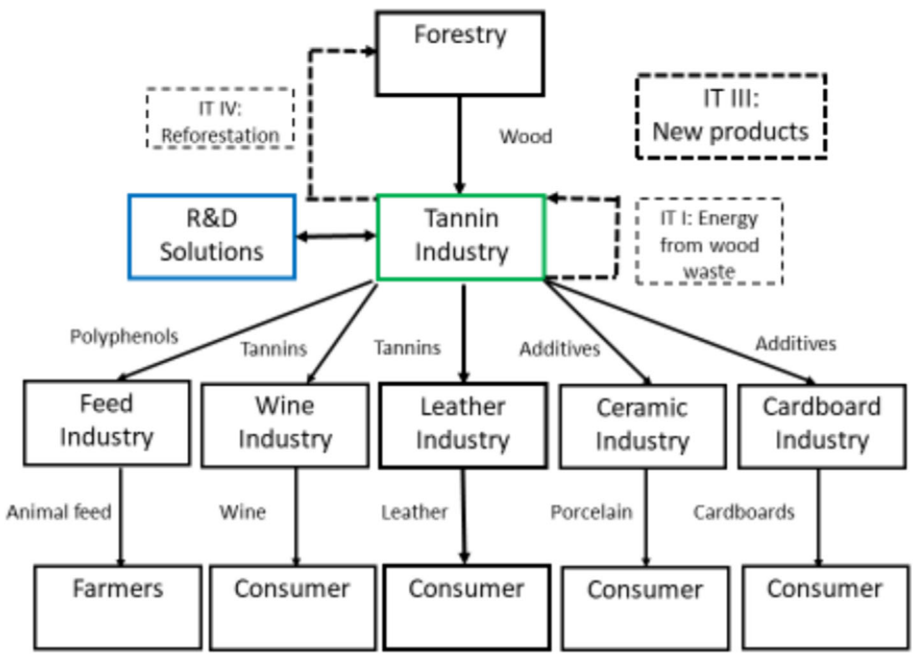

FIGURE 10 Case 7 (tannin industry).

technology is already well established. However, the lack of infrastructure, difficult access to finance and difficulties in importing inputs make business challenging. Due to the lack of specific policies and the Argentine bureaucracy, the company has to spend a lot of time solving logistical and commercial problems.

In *Case 10*, the pharmaceutical company produces biosimilars (recombinant proteins) using rodent cells to produce drugs for different uses (*IT III*). Large investments in R&D facilities and skilled workforce are required. Locally available human resources and an innovation ecosystem with a university business incubator favored the company. Barriers are seen in the general difficulty of long-term investments (the development of a new biosimilar takes 8 to 9 years) given the unstable conditions in Argentina (Figures 12 and 13).

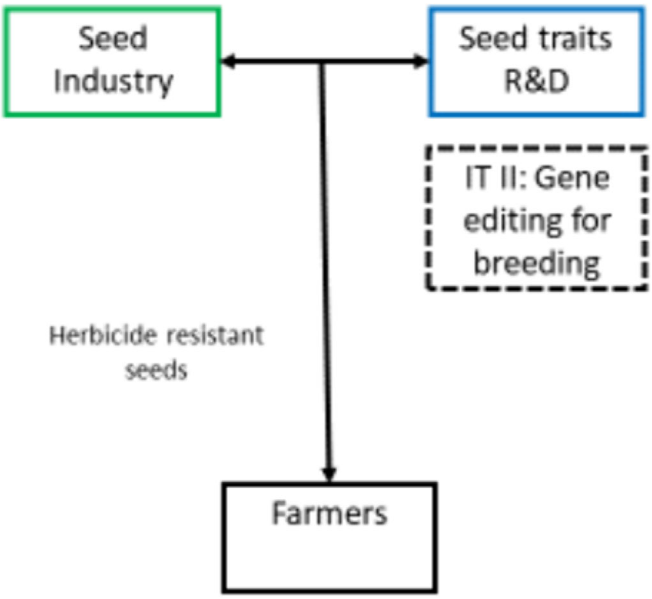

FIGURE 12 Case 9 (biotech seed traits).

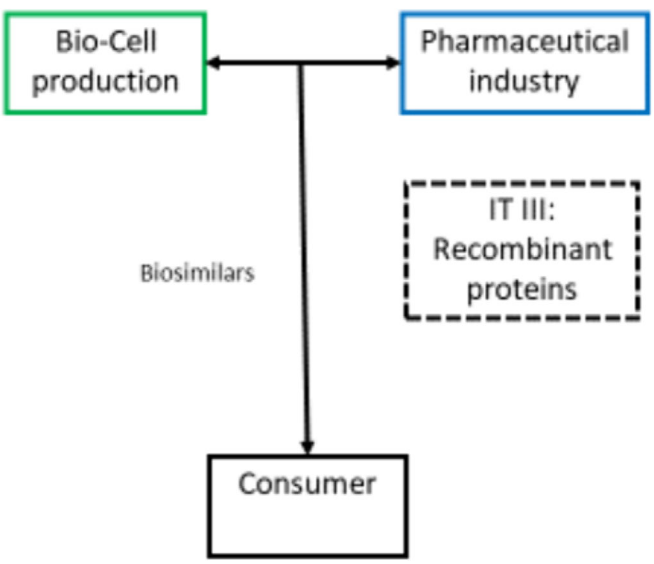

FIGURE 13 Case 10 (bio-pharmaceuticals).

Case 11 is a national company that develops high-tech solutions for the agricultural sector. By combining information technologies with advances in engineering capabilities, the company is a leader in various innovations in the field of high-precision farming (*IT II*). The company sells monitors and devices for sowing, spraying and fertilization, contributing to optimize these activities with less inputs and therefore less environmental damage, lower costs and higher profitability for farmers. The innovation drivers are cooperation with R&D organizations, the availability of human and technical resources, and the high demand from Argentine producers for advanced technology products. Close cooperation with providers of technical equipment is also crucial for the business. The company has a large national and international distribution network for its clients (Figure 14).

Tables 2 and 3 highlight the key findings per case in terms of primary and secondary innovations and their drivers, as well as value chain structure, governance, collaborations, and capacities.

5 | DISCUSSION

5.1 | Typologies used

Although the number of cases studied seems low, we still could observe all the prominent innovation types and VC models discussed above, highlighting the diversity of bioeconomic enterprises in Argentina (Dürr & Sili, 2022; Lachman et al., 2020). Given this diversity, the typology proposed by Mac Clay and Sellare (2022) proved to be valid to synthesize and categorize different bioeconomic enterprises into six value chain models. There were only slight modifications in Model 1 and Model 6, where we included a "traditional" food

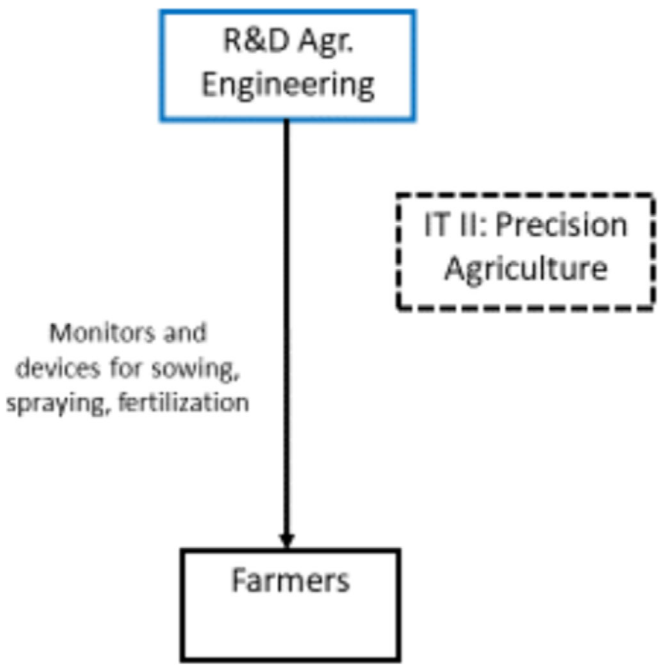

FIGURE 14 Case 11 (agricultural engineering).

TABLE 2 Overview of cases: Innovation types (IT) and its drivers.

Case	Model	Industry	Primary IT	Drivers for primary IT	Secondary IT	Drivers for secondary IT
1	1	Dairy	(Traditional bioeconomy)	–	II: New processes III: New products IV: Better quality	Competition, demand, search for quality, sustainable supply
2		Biofuel (diesel)	I: Fuel substitution	International demand, availability of biomass	I: By-products II: Energy reduction IV: Zero deforestation	Efficiency, energy saving, demand, search for sustainability
3		Biofuel (ethanol)	I: Fuel substitution	International demand, availability of biomass	I: By-products IV: Biogas, fertilizer from residues	Efficiency, energy saving, demand, search for sustainability
4	2	Rum and sugar	IV: New sustainable products	Search for sustainable solutions	I: Energy from residues III. New varieties IV: Feed, fertilizer from residues	Breeding, commercial opportunities, information sharing
5	3	Rendering	IV: Use of slaughterhouse waste	Availability of biomass	II: Conversion efficiency IV: Biodigestor	Knowledge sharing, requirements of clients, search for sustainable solutions
6		Food (rice flour)	IV: Use of by-products (broken rice)	Search for new opportunities, interest of other industries	II: Conversion efficiency	Better use of biomass, cost saving
7	4	Tannin	III: New bio-products for industrial use	Search for diversified, high value products	I: Energy from wood residues IV: Reforestation	Energy saving, sustainable use of waste, sustainable supply of wood
8	5	Feed	III: Bio-nutrition for livestock	Search for sustainable solutions for livestock feeding	–	–
9	6	Seed traits	II: Gene editing for plant breeding	Highly qualified personal, international cooperation and investments, ecosystem of innovation	–	–
10		Bio-pharmaceutics	II: Biosimilars for cancer treatment	Highly qualified personal with international cooperation and investments, ecosystem of innovation	–	–
11		Agricultural devices	II: Precision agriculture	Producer willingness to invest in technological advances	–	–

industry (Case 1) which does both the biomass processing and the industrial application, and a high-tech precision farming company (Case 11), not working with biotechnologies.

The "traditional" food industry is often described as low technology intensive with low innovation rates (Bigliardi & Galati, 2013). However, since it is dependent on natural raw materials, it affects the environment both indirectly through the production of these materials and directly through its own processing activities. For example, food companies can encourage eco-innovations in their supply chains by inducing more sustainable agricultural practices (Blasi et al., 2015), as shown in Case 1. Another possibility consists in converting food waste and by-products into value-added products, such as food ingredients, biochemicals, biomaterials, or biofuels (Diakosavvas & Frezal, 2019). In our study, however, these activities have not been developed by the traditional food industry itself, but by specialized enterprises (Cases 5 and 6).

It is debatable whether industries producing agricultural devices or machines should be considered part of the bioeconomy, as we did in Case 11. In attempts to quantify the economic importance of the bioeconomy, it seems that the input sectors for agriculture, forestry, and fisheries are not included (see, e.g., Kuosmanen et al., 2020; for the case of Argentina, see Wierny et al., 2015). However, "the technology sector (R&D) which provides inputs to production" is included in the definition of an OECD paper (Diakosavvas & Frezal, 2019, p. 12). Regardless of whether this input sector is included in the concept of the bioeconomy or not, it can have an important impact on

TABLE 3 Overview of cases: Value chain characteristics.

Case	Model	Governance	Structure	Collaboration	Capacities
1	1	Cooperation with producers, rules	Multinationals, SMEs, artisanal producers	Strong competition in the market	Good technical, human resources, cooperation with local universities
2		Markets, standards	Big national and multinational firms, SMEs (national market)	Collaboration with other grain companies in the territory	High financial, technical, human capacities
3		Markets	Big national and multinational firms, SMEs (national market)	Collaboration with other grain companies in the territory	High financial, technical, human capacities
4	2	Local embeddedness of artisanal production	Local association of farmers (in the future)	Information sharing with other SMEs, horizontal cooperation of farmers	Human resources, low financial capacity, cooperation with R&D
5	3	Agreements with suppliers and clients	Few national industries	With local technical suppliers	Human resources, technical know-how, cooperation with local university
6		Agreements with suppliers and clients	Local industry	With local technical suppliers, with supplier and user industries	Human resources, cooperation with local universities
7	4	Cooperation with user firms, own resource base	Very few enterprises in Argentina	Partnerships with (international) clients	Own R&D
8	5	Markets, own distribution network	Very few companies in Argentina	No collaboration with other companies	Own R&D, cooperation with university
9	6	Agreements with seed industry	Specific start-ups	Cooperation with seed industry	Own labs in Argentina and USA, human resources, cooperation with universities
10		International markets	International competition of big enterprises	Cooperation with local technical providers	Own labs, human resources, cooperation with universities
11		Competitive markets, own distribution network	Few companies in Argentina	Collaboration with technical providers	Human and technical resources, cooperation with R&D centers

the development of a sustainable bioeconomy. This is especially relevant in a country rich in biomass production such as Argentina, where innovations for the primary sector such as digitalization are critical for better resource utilization and reduced environmental impacts (Vargas-Canales et al., 2022).

The typology proposed by Bröring et al. (2020) helped to cluster what we refer to here as "primary" innovations. Moreover, "secondary" innovations can also lead to more sustainable production systems. We found this differentiation helpful for bioeconomic innovations, as the "primary" innovation defines the main transformation pathway (Dietz et al., 2018), while the "secondary" innovation represents an additional improvement of the products or processes already defined by the primary innovation. Bröring et al. (2020) also gave an example of the interrelatedness of different innovation types. For instance, when bioplastic products are introduced (*IT I*), this might require innovation from *IT II* to allow scaling-up of processes, and these processes can become more circular through *IT IV*, and *IT III* will enable the development of other bioplastic products with value added.

The primary innovation is the starting point for a bioeconomic pathway, and secondary innovations are introduced on the basis of the original innovations and can be carried out gradually over time to achieve more and more improvements. This distinction is related to what is often discussed as the dichotomy of "incremental" versus "radical" innovations. The former is about innovations that do not bring so much novelty with them, but rather improve already existing products or processes, and the latter is about high novelty features and a break with previous structures, products or processes (Donner & de Vries, 2021), in other words, "incremental innovations is about doing things more efficiently, whereas radical innovations is about doing things entirely differently" (Bosman & Rotmans, 2016, p. 2). Nevertheless, as defined here, "primary" and "secondary" innovations are not identical with radical and incremental innovations. While secondary innovations often only affect (technological) processes within the company, primary innovations frequently also influence parts or even the entire value chain, that is, they have an impact on customers and/or suppliers or are dependent on them, as seen in Case 6. Furthermore, primary innovations can entail a complete transformation of the value chain toward a more sustainable system (Case 4).

The fact that after a "primary" bioeconomic innovation has been introduced, further "secondary" sustainable innovations are likely to take place might be explained by the fact that bioeconomic entrepreneurs with an orientation toward making their businesses more sustainable keep searching for even more sustainable solutions. For example, the attitude of entrepreneurs has been found as a key driver of eco-innovations in the bioeconomy sector in Poland (Sołtysik et al., 2019). Also, when an innovative culture exists in a company, this leads to constant further innovations, as innovative enterprises remain innovative, or "innovation breeds innovation" (Baumol, 2002, p. 284). This was confirmed by a study using panel data, which concluded that eco-innovations implemented in the past significantly influenced those implemented later (Horbach, 2008). In general, the innovative feature of bioeconomic enterprises is emphasized by many authors (e.g., Bröring et al., 2020; Urbaniec et al., 2022). Furthermore, there seems to be a strong link between different forms of eco-innovations in firms. For example, SMEs in the EU that introduce eco-innovation in one area are likely to do so in other areas, that is, product, process, and organizational eco-innovations are somehow correlated (Triguero et al., 2013).

5.2 | Drivers of sustainable innovations

The search for sustainable solutions seems to be one of the main driving forces of entrepreneurs in the bioeconomy. This is an overarching motivation, irrelevant of the specific VC model. Business leaders are key players to positively influence sustainable innovations in their companies (Najib et al., 2021; Rosário et al., 2022). Besides, there are also concerns that the bioeconomy might lead to unsustainable outcomes, such as soy expansion in Argentina which has led to land use change, air and water quality deterioration, and human health problems (Phélinas & Choumert, 2017) and which might undermine the legitimacy of the bioeconomy. Legitimacy is considered a key driver for the further promotion of the bioeconomy, both for biomass as well as the biotech-based sectors. But while in sectors with high biomass use (Model 1), social and ecological impacts are vital for its acceptance, in biotech sectors (Models 4–6), the used technology as such is important for a positive attitude of the general public and consumers' toward bioeconomic products (Wydra, 2019). For example, for biosimilars (Case 10), there may not be major concerns, while with the generation of special seed traits through genome editing (Case 9) acceptance may not be taken for granted.

It appears that certain factors particularly drive certain innovation types: *IT I* is mainly driven by the international demand for biofuels and local biomass availability (Cases 2 and 3). For *IT II*, international collaboration and cooperation with R&D institutions and other enterprises are important (Cases 9, 10, and 11). Behind *IT III* is the search for diversified, high value products with positive ecological benefits for their users (Cases 7 and 8). Finally, *IT IV* is moved by the search for social, economic, and ecological local development solutions (Cases 4, 5, and 6). This is not to say that the particular drivers, for example, availability of raw materials or demand, have not also played a role in various innovation types. But a rough classification emerges.

Surprisingly, none of the enterprises mentioned environmental regulatory or policy measures that incentivized or boosted their innovations. This might be partly due to a lack of such environmental measures or the lack of effective enforcement in Argentina. However, there exist a variety of policies to promote a sustainable bioeconomy, just to mention a few (see Testa et al., 2021): the Law 26093 of 2006 to promote biofuels, which was replaced by a new law, Law 27640, passed in 2021; the law to promote renewable energies (Ley 27191) of 2016, and a new bio- and nanotechnology law approved in 2022 (Ley 27685). But it seems that these measures did not have a direct impact on the innovations of the companies in our case study.

The other main strategy in Argentina consists in promoting the biotech sector through public–private partnerships involving various public R&D centerss, such as the National Council of Scientific and Technical Research (CONICET) and the National Institute of Agricultural Technology (INTA) as well as public universities (Deciancio & Siegel, 2022). Most of the interviewed companies cooperate in one way or another with local universities and some with R&D institutions. However, there are also complaints about poor cooperation with public R&D centers. Moreover, companies using advanced or cutting-edge bio-technologies (Cases 7, 8, 9, and 10) have their laboratories to develop innovations and are therefore more independent of public institutions in their R&D activities (Sili & Dürr, 2022).

Owner-managed businesses tend to have a strong stewardship toward their company, the territory where it is located, and the environment (Barth et al., 2017). For example, stewardship is a fundamental value intention of owners of Swedish agri-food companies (Ulvenblad et al., 2019). This driver of innovations could be detected both in the family-owned businesses with a long tradition in their territories (Cases 1, 4, 5, and 7) and in the local start-ups (Cases 6, 7, 8, and 9).

The reasons for utilizing organic waste to produce biogas, heat, electricity, feed, and biofertilizers are both economic and ecological: energy cost saving and creation of economic values as well as a quest for more circular systems with less fossil energy use (Models 1–4). Even if most of the technical solutions for waste use are already mature, they still require technical feasibility on site, with the involvement of service providers and, in some cases, cooperation with local authorities. The increased development of by-products (Cases 2, 3, and 7) can also be attributed to both economic and environmental factors: increased added value and a diversified product range as well as a more effective and sustainable use of biomass. Similarly, based on the study of eight business cases of valorization of agro-waste in the European food sector, Donner and de Vries (2021) found that innovations in business models for a circular bioeconomy can be triggered by either economic, ecological or social reasons, or a combination thereof. This requires the interaction of different elements such as resources, skills, (bio-) technological knowledge, and the involvement of various value chain actors and stakeholders.

5.3 | Value chain features and innovations

Different value chain features (see Table 3) are supposed to be linked to specific innovation drivers (Mac Clay & Sellare, 2022). To start with governance, a comparison of the different characteristics shows that companies face strong competition (Cases 1, 2, 3, 8, 10, and 11) in both national and international markets. This means that efficient production, cost reduction, high quality, and a good sales network play an important role in economic success and innovation. Higher competition normally leads to a higher innovation tendency (Horbach, 2008). On the contrary, start-up companies are mainly active in niche markets, where they rely more on agreements and cooperation with their business partners (Cases 5, 6, 7, and 9), which can influence the direction of innovation. In line with this, it has been shown that both customer influence and market competition are crucial factors for the development of sustainable innovations by Polish bioeconomy companies (Sołtysik et al., 2019).

Market prices dominate the biomass procurement in Model 1, but some rules and standards, such as for high quality milk or deforestation-free soy, were introduced in Case 1 and 2, respectively. Case 4 of Model 2 follows an integrated approach of a closed-loop system of in-house production, processing, and marketing. In Model 3, the business model depends on the provision of waste and by-products of other industries, so collection agreements with these suppliers are important (Cases 5 and 6). In Model 4, an own supposedly sustainable biomass supply base (of the Quebracho tree) has been established by Case 7. In Model 5, vertical integration of biotechnological inputs, production of bio-blends and an own distribution network were set up by Case 8. Finally, biomass supply does not play a major role in Model 6.

The market structure in Case 1 is characterized by the coexistence of large national and multinational companies, SMEs, and the informal sector. The national company tries to assert itself against the competition from large as well as from informal players through product innovations. A special market for biofuels was created for national SMEs by Law 26093, while the companies interviewed (Cases 2 and 3) produce for and depend on the international market. However, they have also diversified their product portfolio and now sell by-products to the feed industry. In Case 4 of Model 2, the entrepreneur attempts to establish artisanal, sustainable products for the local and national niche market. In Models 3, 4, and 5, there are relatively few companies in the Argentine market, as they are mostly companies that produce very specific bioeconomy products for a niche market. However, these firms with their innovative products are in competition with large, established suppliers of standard products or have to compete on the international market. In Model 6, the companies also have to find their niche within the dominance of international big players, usually in cooperation with some of the large companies.

Collaboration with other industries is relatively low in Model 1, while Model 2 envisages horizontal cooperation between farmers, which could scale up the new production model. In Model 3, collaboration with local technical suppliers is important for optimizing industrial processes and agreements with supplier and user industries were necessary for introducing new products. Such a necessity could also be observed in Brazilian companies that introduced bio-plastics in their product portfolio, which was facilitated by the collaboration with suppliers and clients through cooperative problem-solving and market development efforts (Neutzling et al., 2018). In Model 4, the enterprise works closely with its international customers to adapt its product innovations to their needs. In contrast, no cooperation with other industries have been documented in Model 5, as the enterprise established its innovative product lines independently. In Model 6, there is close collaboration with major clients and with local technical providers.

All cases count on high human and technical capacities, and nearly all cooperate with local universities and/or R&D centers. The companies of Model 4 to 6 all have their particular laboratories and do their own R&D. The start-ups (Cases 4, 6, 7, 8, and 9) have rather limited financial resources, which seems to be less of a problem for incumbent firms (Cases 1, 2, 3, 5, 10, and 11). In general, however, it seems that all cases count on adequate internal capacities for their business to succeed. Internal influences such as management attitudes and employee initiatives are decisive factors for sustainable innovations (Sołtysik et al., 2019). A company's innovation performance is coupled to its technological, operational, managerial, and marketing capabilities, which in turn can vary in importance from sector to sector and can give companies within a certain sector a competitive advantage, as shown in a Brazilian case study (Zawislak et al., 2013). Incumbent companies have relatively high internal capacities which represents an advantage for complex eco-innovations (Cases 1, 2, 3, 5, 7, 10, and 11). SMEs often have rather limited capital, research, and technology capacities, which makes collaboration with other firms or R&D centers necessary (Cases 4, 6, 7, 8, and 9). For example, Korean food sector SMEs' cooperation with universities has been found to promote innovative performance (Jeong & Shin, 2020). However, new (and often smaller) entrants to the market might be more innovative than established (often larger) firms. All the SMEs of our case study are start-ups that took up their activities with good human and research capacities and have close links with universities and/or R&D centers, which enhances their innovation capacity. In line with this, Del Río et al. (2017) did not find a significant difference between old and new Spanish firms regarding eco-innovations. Still, they showed that internal capacities and external cooperation are more relevant for new firms to innovate.

The acceptance of innovations depends on whether the customer is a farmer, an industrial company, or a final consumer. Companies selling to farmers might need a dense distribution network to promote their products (Cases 8 and 11). This seems crucial as lack of knowledge about new, environmentally friendly technologies on the farmer's side can be a barrier to innovations, making the exchange of knowledge between all actors in the supply chain necessary (Hasler et al., 2016). For enterprises that follow a business-to-business model, as their products are invisible to final consumers, cooperation with customer industries and other value chain members are important for the success of innovations (Wilde & Hermans, 2021), as seen in Cases 7 and 9, whereas for enterprises selling to final consumers, offering innovative quality products is crucial (Cases 1 and 4).

5.4 | Innovation and value chain types

Innovation and value chain types are interlinked: In Model 1, primary innovations refer mainly to fossil fuel substitution; in Model 2, to new sustainable production processes and products with local value added;

in Model 3, to the use of waste or by-products and their transformation into higher value products; in Model 4, to new bio-products for industrial use; in Model 5, to biological agro-inputs; and in Model 6, to plant breeding, biopharmaceutics and precision farming. Given the limited number of cases, these are of course just a few examples of many possible sustainable innovations in the various bioeconomic value chain models. However, they are largely, but not exclusively, consistent with the examples provided by Mac Clay and Sellare (2022).

In Argentina, the biotech sector is strongly intertwined with the primary sector. The latter has experienced strong expansion since the 2000s with the use of genetically modified soybeans and the resulting biotechnological research and innovations such as drought-tolerant seeds and no-tillage systems, which in turn have been important for its continued growth (Sasson & Malpica, 2018). This means that, from the beginning, the Argentine bioeconomy has been largely linked to the agricultural sector, the expansion of GM crops, the development of local technologies to increase productivity, and to its potential to add value in agro-industrial chains (Deciancio & Siegel, 2022), see Cases 8, 9, and 11. This means that *ITs II* and *III* of the "advanced" Models (4, 5, and 6) of the bioeconomy can have effects on traditional value chains by making primary production more efficient. For these linkages to work, close, trustful relationships between industry and producers as well as the openness of farmers to innovate and invest seem to be important. In contrast, Model 1 is a example of the development of an agro-industrial complex based on the expansion of soybean and corn plantations, where *IT I* was driven by the opportunity to add value by the conversion of these commodities into biofuels.

Secondary innovations were observed in Models 1 to 4, in which different combinations of *ITs I-IV* take place, such as more efficient processing methods, savings of energy, and use of waste and by-products. Innovations related to more efficient use of water and energy have been proposed as one of the measures for the food industry to reduce its impact on the environment (Garnett, 2011), and at the same time, to increase its competitiveness. This is supported by a study of the Swedish agri-food sector, where one of the main sustainable business models is related to maximizing material and energy efficiency (Ulvenblad et al., 2019). Such secondary innovations were not detected in Models 5 and 6, where biomass and water and energy consumption and therefore possible improvements therein play only a limited role.

An important secondary innovation is the search for a sustainable supply of biomass. This is particularly relevant for Model 1 with its high use of biomass, for example through price incentives and advisory services (Case 1). These mechanisms were also used by an Italian pasta producer to promote eco-innovations in its durum wheat production supply chain (Blasi et al., 2015), or by a Dutch dairy company that achieved higher milk fat composition by launching a special feeding program for dairy producers (Bröring, 2008). Case 2 adopted a deforestation-free soy production sourcing as part of its sustainability supply management. As a large multinational company, this strategy seems feasible as it can influence its providers, and also necessary to secure markets in the EU or the US (Sellare et al., 2022). Case 7 depends on the sustainable biomass supply of a slow-growing tree, and therefore uses reforestation as an important strategy to secure long term supply and possibly also to enhance acceptance of its activities. The 'Quebracho Colorado' tree has been drastically reduced in the last decades due to expanding of agricultural frontiers, driven primarily by soybean and cattle production (Fehlenberg et al., 2017), as well as use in construction and tannin industries (Zarrilli, 2016). Finally, in Model 3, sustainable primary production is not directly relevant as by-products or waste from other industries are used, and in Models 5 and 6, innovations in supply chains seem irrelevant as the use of biomass is limited or zero.

6 | CONCLUSIONS

In this paper, we adopt a case-based approach to provide empirical evidence on the process of innovation by firms in the bioeconomy. The analytical framework based on the typologies of Mac Clay and Sellare (2022) and Bröring et al. (2020) enabled us to detect different sustainable innovations and link them to different value chain types. Innovations by biomass-processing and bio-tech firms often require closer vertical or horizontal cooperation with other value chain actors (e.g., providers and clients), which can lead to value chain restructuring. Although we did not focus on these up- and downstream actors, interviewing actors located midstream provided valuable information on their forward and backward linkages.

This paper made a novel conceptual distinction between "primary" and "secondary" innovations in the bioeconomy. We detected empirically that the four different innovation types described by Bröring et al. (2020) can be found at the core of the bioeconomic activity, fundamental for a certain transformation pathway (Dietz et al., 2018), as well as in various other activities, which mainly concern the processing efficiency, supply chain management and organic waste use. These secondary innovations tend to be rather incremental, but they complement the primary innovations in ways that help make the bioeconomy more sustainable overall. They can also avoid potential conflicts of interest, for example, between food and energy use, and mitigate negative environmental consequences of bioeconomic activities. Our study cannot conclusively answer whether incremental or radical innovations are necessary to achieve sustainability (Cillo et al., 2019). However, it seems that this is not necessarily a contradiction in the bioeconomy. Most of the cases presented here have made both an original, fundamental bioeconomic innovation and subsequent innovations that followed the primary one.

The fact that secondary innovations follow primary bioeconomic innovations certainly has to do with the fact that entrepreneurs in the bioeconomy often explicitly pursue sustainability goals and their commitment for sustainable innovations is crucial (Neutzling et al., 2018). Innovative companies in the bioeconomy often show great interest in solutions to implement economic and ecological improvements that can also bring about a transformation toward sustainable entrepreneurship and positively impact the environment (Sołtysik et al., 2019).

Besides this overall driver, we found that the innovation types seem to be affected differently: While *IT I* is strongly driven by market forces, R&D activities are the main influencing factors in *IT II*, the search for new, high-quality products plays a major role in *IT III*, and the explicit search for sustainable solutions becomes one of the most important drivers in *IT IV*.

The study has shown that different innovation types are linked to specific value chain characteristics, as Mac Clay and Sellare (2022) hypothesized. International market forces play a major role for bioeconomic enterprises linked to Models 1 (high volume biomass) and 6 (biomass-free), whereas companies from Models 2 to 5 rely more heavily on agreements with supplier and user industries for their innovations, and are more active in niche markets. Collaboration with other value chain actors is primarily important for firms that pursue a business-to-business model. R&D capacities are especially important for the advanced Models 4 to 6, but all cases cooperate with local universities and R&D centers. Certain value chain models are linked to specific innovation types: for Model 1, the fossil fuel substitution (*IT I*) is the main innovation type; in Models 2 and 3, *IT IV*, new behavior, is predominant; in Models 4 and 5, *IT III*, new products, are in the foreground; and Model 6 is mainly linked to *IT II*, new processes. However, our analysis also highlighted the importance of complementary secondary innovations in the business model of all enterprises linked to Models 1–4.

Therefore, promoting the bioeconomy should consider the type of value chains and specific innovation systems involved (Wilde & Hermans, 2021). And because different factors drive different types of eco-innovations, a "one size fits all" policy is not appropriate. Instead, policies should be innovation-type specific (Kiefer et al., 2019). In this direction, we develop three ideas on how policies should be adapted to different innovation models in Argentina and beyond.

First, despite several attempts to design strategic plans, the bioeconomy in Argentina has followed a bottom-up approach based on the initiative of private actors creating clusters around biomass sources or in specific knowledge areas, but still lacks an overarching strategic framework for the bioeconomy. On the contrary, in a top-down approach, the government sets the main visions and action plans, prioritizing strategic sectors and regions (Dieckhoff et al., 2015). To ensure the long-term development of a sustainable bioeconomy, it is critical to have adequate regulation that consolidates what is happening in the private sector (Overbeek et al., 2016). This entails a strategic definition of the leading technologies and the identification of hotspots for developing cascading uses around different biomass sources. Therefore, countries experiencing an early bottom-up development of the bioeconomy should proactively create a set of policy frameworks to support the private initiative in the long run.

Second, sustainable innovations in "traditional" food and other companies need appropriate frameworks and incentives to reduce the risks of investing in volatile countries such as Argentina. From an institutional perspective, these incentives should be oriented to develop markets for bio-based products (e.g., creating renewable electricity term markets for bioenergy or introducing bio-based requirements in public purchases). From a fiscal perspective, public support schemes may reduce costs or increase revenues for companies that incorporate bio-based processes (e.g., tax reduction for companies that replace chemicals with biological products or feed-in tariffs for companies that produce biogas from residues). Thus, the policy-design process in the bioeconomy should not leave aside secondary innovations of traditional sectors.

Third, Argentina offers a competitive advantage due to its natural endowment, but this advantage is unclear for ventures that are based on knowledge and biotechnology. The Argentine market is small while the economy is unstable, so many of these high-technological companies seek to scale in other countries (Deciancio & Mac Clay, 2023) by looking for international partners or opening labs abroad to secure research funding. Thus, without policies tailored for these biotech companies, countries like Argentina may lose the possibility of benefiting from the intellectual property these companies are developing. Access to international funds, clear intellectual property regulations, and public investments in R&D infrastructure will help building innovation ecosystems. Countries seeking long-term development of their biotech capacities must consider that competitive advantage in natural resources is insufficient to retain science-based startups.

The cases discussed also have different management implications: First, for biomass-intensive companies (Cases 2–7), the development of vertical and horizontal value chains is required to ensure continuous biomass inflow and biomass quality. While market-based mechanisms may work better in some cases (soybeans or corn), more specific agreements with local producers may be required for waste, rice or wood. Second, controlling costs and improving efficiency in biomass conversion are critical as the ultimate success of the primary innovation pathway depends heavily on operational efficiency. Third, fostering alliances with external research institutes is a way to develop secondary, incremental innovations that improve business sustainability. Research-intensive models (Cases 8–11) should focus on developing strategic arrangements with companies or research partners internationally to create geographic diversification that mitigates country risk while expanding market reach. At the same time, strengthening relationships with actors in their local innovation ecosystems will help better understand end-user acceptance of the adoption of these technologies (e.g., genetically modified crops by farmers or new biosimilars by patients and physicians). Technology and research risks often absorb the efforts of managers in these research-intensive companies, but focusing on adoption helps mitigate potential market risks.

Although we cannot generalize the results as a case study, they can explain how and why countries like Argentina, with its technical and scientific skills, have a good chance of using the bioeconomy to foster sustainable development. However, unforeseeable, unclear and changing regulations and policies, together with unstable macroeconomic policies negatively impact the development of the bioeconomy in the country (Sili & Dürr, 2022). The cases also demonstrated a wide range of different bioeconomic models, innovations, and pathways. Yet, the strong reliance of the Argentine bioeconomy on the agro-productivist model persists. Bioeconomic innovations are needed at different value chain levels and in different sectors. Moreover, the lack of a clear bioeconomy strategy results in the country not fully exploiting its bioeconomy potential and possible synergies between sectors and clusters (Deciancio & Mac Clay, 2023). Finally, government measures and regulations are necessary to avoid possible negative ecological and social impacts of bioeconomic developments.

At least two new questions arise from this research. First, given the characteristics of the Argentine territory, where rural areas are undergoing a process of strong restructuring, it would be interesting to better understand the territorial dynamics of innovation within the six models, in particular whether each of these models follows a defined territorial pattern. Understanding the territorial dynamics of each innovation type and value chain model will enable a clearer definition of rural development strategies. Second, given that the innovation process is linked to the provision of public goods (particularly infrastructure and R&D), and taking into account Argentina's great geographical diversity, the question arises about the regional embeddedness of bioeconomic activities and how local governments can best promote innovations in each of the identified models.

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REFERENCES

Adams, R., Jeanrenaud, S., Bessant, J., Denyer, D., & Overy, P. (2016). Sustainability oriented innovation: A systematic review. *International Journal of Management Reviews*, *18*, 180–205. https://doi.org/10.1111/ijmr.12068

Barth, H., Ulvenblad, P.-O., & Ulvenblad, P. (2017). Towards a conceptual framework of sustainable business model innovation in the agri-food sector: A systematic literature review. *Sustainability*, *9*, 1620. https://doi.org/10.3390/su9091620

Baumol, W. J. (2002). *The free-market innovation machine—Analyzing the growth miracle of capitalism*. Princeton University Press. https://doi.org/10.1515/9781400851638

Biber-Freudenberger, L., Ergeneman, C., Förster, J. J., Dietz, T., & Börner, J. (2020). Bioeconomy futures. Expectation patterns of scientists and practitioners on the sustainability of bio-based transformation. *Sustainable Development*, *28*, 1220–1235. https://doi.org/10.1002/sd.2072

Bigliardi, B., & Galati, F. (2013). Innovation trends in the food industry: The case of functional foods. *Trends in Food Science and Technology*, *31*(2), 118–129. https://doi.org/10.1016/j.tifs.2013.03.006

Blasi, E., Monotti, C., Ruini, L., Landi, C., Avolio, G., & Meriggi, P. (2015). Eco-innovation as a driver in the agri-food value chain: An empirical study on durum wheat in Italy. *Journal on Chain and Network Science*, *15*(1), 1–15. https://doi.org/10.3920/JCNS2014.x014

Bosman, R., & Rotmans, J. (2016). Transition governance towards a bioeconomy: A comparison of Finland and the Netherlands. *Sustainability*, *8*(10), 1017. https://doi.org/10.3390/su8101017

Bröring, S. (2008). How systemic innovations require alterations along the entire supply chain: The case of animal-derived functional foods. *Journal on Chain and Network Sciences*, *8*, 107–119. https://doi.org/10.3920/JCNS2008.x093

Bröring, S., Laibach, N., & Wustmans, M. (2020). Innovation types in the bioeconomy. *Journal of Cleaner Production*, *266*, 121939. https://doi.org/10.1016/j.jclepro.2020.121939

Carraresi, L., Berg, S., & Bröring, S. (2018). Emerging value chains within the bioeconomy: Structural changes in the case of phosphate recovery. *Journal of Cleaner Production*, *183*, 87–101. https://doi.org/10.1016/j.jclepro.2018.02.135

Cerca, M., Sosa, A., Gusciute, E., & Murphy, F. (2022). Strategic planning of bio-based supply chains: Unlocking bottlenecks and incorporating social sustainability into biorefinery systems. *Sustainable Production and Consumption*, *34*, 219–232. https://doi.org/10.1016/j.spc.2022.09.013

Cillo, V., Petruzzelli, A. M., Ardito, L., & Del Giudice, M. (2019). Understanding sustainable innovation: A systematic literature review. *Corporate Social Responsibility and Environmental Management*, *26*(5), 1012–1025. https://doi.org/10.1002/csr.1783

Deciancio, M., & Mac Clay, P. (2023). *The bioeconomy in Argentina: Lessons for its development and sustainability* (Vol. 43). ZEF Policy Brief. https://www.zef.de/fileadmin/user_upload/Policy_Brief_43.pdf

Deciancio, M., & Siegel, K. M. (2022). Creando condiciones para el desarrollo de la bioeconomía en la Argentina: El papel de las políticas estatales en biotecnología y biocombustibles (1990-2022) [Facilitating the development of bioeconomy in Argentina: The role of biotechnology and biofuels state policies (1990-2022)]. *Revista Estado Y Politicas Publicas*, *19*, 225–248.

Del Río, P., Romero-Jordán, D., & Peñasco, C. (2017). Analysing firm-specific and type-specific determinants of eco-innovation. *Technological and Economic Development of Economy*, *23*, 270–295. https://doi.org/10.3846/20294913.2015.1072749

Diakosavvas, D. & Frezal, C. (2019). Bio-economy and the sustainability of the agriculture and food system: Opportunities and policy challenges, OECD food, agriculture and fisheries papers, no. 136, OECD publishing, Paris. https://doi.org/10.1787/d0ad045d-en

Dieckhoff, P., El-Chichakli, B., & Patermann, C. (2015). *Bioeconomy policy: Synopsis and analysis of strategies in the G7*. German Bioeconomy Council.

Dietz, T., Börner, J., Förster, J., & von Braun, J. (2018). Governance of the bioeconomy: A global comparative study of National Bioeconomy Strategies. *Sustainability*, *10*, 3190. https://doi.org/10.3390/su10093190

Donner, M., & de Vries, H. (2021). How to innovate business models for a circular bio-economy? *Business Strategy and the Environment*, *30*(4), 1932–1947. https://doi.org/10.1002/bse.2725

Dürr, J., & Sili, M. (2022). New or traditional approaches in Argentina's bioeconomy? Biomass and biotechnology use, local embeddedness, and sustainability outcomes of bioeconomic ventures. *Sustainability*, *14*, 14491. https://doi.org/10.3390/su142114491

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1), 1–4. https://doi.org/10.11648/j.ajtas.20160501.11

Fehlenberg, V., Baumann, M., Gasparri, N. I., Piquer-Rodriguez, M., Gavier-Pizarro, G., & Kuemmerle, T. (2017). The role of soybean production as an underlying driver of deforestation in the south American Chaco. *Global Environmental Change*, *45*, 24–34. https://doi.org/10.1016/j.gloenvcha.2017.05.001

Feyaerts, H., den Broeck, G. V., & Maertens, M. (2020). Global and local food value chains in Africa: A review. *Agricultural Economics*, *51*(1), 143–157. https://doi.org/10.1111/agec.12546

Garnett, T. (2011). Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food Policy*, *36*(Suppl. S1), S23–S32. https://doi.org/10.1016/j.foodpol.2010.10.010

Gereffi, G., Humphrey, J., & Sturgeon, T. (2005). The governance of global value chains. *Review of International Political Economy*, *12*(1), 78–104. https://doi.org/10.1080/09692290500049805

Hasler, K., Olfs, H.-W., Omta, O., & Bröring, S. (2016). Drivers for the adoption of eco-innovations in the German fertilizer supply chain. *Sustainability*, *8*, 682. https://doi.org/10.3390/su8080682

Hellström, T. (2007). Dimensions of environmentally sustainable innovation: The structure of eco-innovation concepts. *Sustainable Development*, *15*(3), 148–159. https://doi.org/10.1002/sd.309

Horbach, J. (2008). Determinants of environmental innovation—New evidence from German panel data sources. *Research Policy*, *37*, 163–173. https://doi.org/10.1016/j.respol.2007.08.006

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact - The role of regulatory push/pull, technology push and market pull. *Ecological Economics*, *78*, 112–122. https://doi.org/10.1016/j.ecolecon.2012.04.005

Janssen, E., & Swinnen, J. (2019). Technology adoption and value chains in developing countries: Evidence from dairy in India. *Food Policy*, *83*, 327–336. https://doi.org/10.1016/j.foodpol.2017.08.005

Jeong, H., & Shin, K. (2020). Exploring factors affecting sustainable innovation performance of food firms. A case of Korean food industry. *Sustainability*, *12*(23), 10157. https://doi.org/10.3390/su122310157

Kemp, R. & Pearson, P. (2008). *Final report MEI project about measuring eco-innovation*, www.merit.unu.edu/MEI2008

Kiefer, C. P., Del Río González, P., & Carrillo-Hermosilla, J. (2019). Drivers and barriers of eco-innovation types for sustainable transitions: A quantitative perspective. *Business Strategy and the Environment*, *28*(1), 155–172. https://doi.org/10.1002/bse.2246

Kuijpers, R., & Swinnen, J. (2016). Value chains and technology transfer to agriculture in developing and emerging economies. *American Journal of Agricultural Economics*, *98*(5), 1403–1418. https://doi.org/10.1093/ajae/aaw069

Kuosmanen, T., Kuosmanen, N., El-Meligli, A., Ronzon, T., Gurria, P., Iost, S., & M'Barek, R. (2020). *How big is the bioeconomy? Reflections from an economic perspective*. EUR 30167 EN. Publications Office of the European Union, ISBN 978-92-76-17858-3. https://doi.org/10.2760/144526 JRC120324

Lachman, J., Bisang, R., Obschatko, E. S., & Trigo, E. (2020). *Bioeconomía: Una Estrategia de Desarrollo Para la Argentina del Siglo XXI*. Instituto Interamericano de Cooperación para la Agricultura.

Lin, J., Gupta, S., Loos, T., & Birner, R. (2019). Opportunities and challenges in the Ethiopian bamboo sector: A market analysis of the bamboo-based value web. *Sustainability*, *11*, 1644. https://doi.org/10.3390/su11061644

Mac Clay, P., & Sellare, J. (2022). Value chain transformations in the transition to a sustainable bioeconomy. ZEF–Discussion Papers on Development Policy No. 319, 34.

MINAGRO. (2016). *BioEconomía Argentina Visión desde Agroindustria*. MINAGRO.

Najib, M., Abdul Rahman, A. A., Abror, A., Rachmawati, R., Simanjuntak, M., Prasetya, P., Suhartanto, D., & Fahma, F. (2021). Leaders' support of sustainable innovation and business sustainability in developing countries: Evidence from small and medium food processing enterprises. *Sustainability*, *13*(23), 13091. https://doi.org/10.3390/su132313091

Neutzling, D. M., Land, A., Seuring, S., & Nascimento, L. F. M. (2018). Linking sustainability-oriented innovation to supply chain relationship integration. *Journal of Cleaner Production*, *172*, 3448–3458. https://doi.org/10.1016/j.jclepro.2017.11.091

Overbeek, G., de Bakker, E., Beekman, V., Kiresiewa, Z., Delbrück, S., Ribeiro, B., Stoyanov, M., & Vale, M. (2016). *Review of bioeconomy strategies at regional and national levels* (p. 78). BioSTEP Project.

Phélinas, P., & Choumert, J. (2017). Is GM soybean cultivation in Argentina sustainable? *World Development*, *99*, 452–462. https://doi.org/10.1016/j.worlddev.2017.05.033

Rabadán, A., González-Moreno, A., & Sáez-Martínez, F. J. (2019). Improving Firms' performance and sustainability: The case of eco-innovation in the Agri-food industry. *Sustainability*, *11*, 5590. https://doi.org/10.3390/su11205590

Rosário, A. T., Raimundo, R. J., & Cruz, S. P. (2022). Sustainable entrepreneurship: A literature review. *Sustainability*, *14*(9), 5556. https://doi.org/10.3390/su14095556

Rowley, J. (2002). Using case studies in research. *Management Research News*, *25*, 16–27. https://doi.org/10.1108/01409170210782990

Sasson, A., & Malpica, C. (2018). Bioeconomy in Latin America. *New Biotechnology*, *40*, 40–45. https://doi.org/10.1016/j.nbt.2017.07.007

Scheiterle, L., Ulmer, A., Birner, R., & Pyka, A. (2018). From commodity-based value chains to biomass-based value webs: The case of sugarcane in Brazil's bioeconomy. *Journal of Cleaner Production*, *172*, 3851–3863. https://doi.org/10.1016/j.jclepro.2017.05.150

Schumpeter, J. A. (1934). *The theory of economic development*. Harvard University Press. (First published in German, 1912.)

Sellare, J. (2022). New insights on the use of the Fairtrade social premium and its implications for child education. *Journal of Rural Studies*, *94*, 418–428. https://doi.org/10.1016/j.jrurstud.2022.07.015

Sellare, J., Börner, J., Brugger, F., Garrett, R., Günther, I., Meemken, E.-M., Pelli, E. M., Steinhübel, L., & Wuepper, D. (2022). Six research priorities to support corporate due-diligence policies. *Nature*, *606*(7916), 861–863. https://doi.org/10.1038/d41586-022-01718-8

Sili, M., & Dürr, J. (2022). Bioeconomic entrepreneurship and key factors of development: Lessons from Argentina. *Sustainability*, *14*, 2447. https://doi.org/10.3390/su14042447

Silvestre, B. S., & Ţîrcă, D. M. (2019). Innovations for sustainable development: Moving toward a sustainable future. *Journal of Cleaner Production*, *208*, 325–332. https://doi.org/10.1016/j.jclepro.2018.09.244

Sołtysik, M., Urbaniec, M., & Wojnarowska, M. (2019). Innovation for sustainable entrepreneurship: Empirical evidence from the bioeconomy sector in Poland. *Administrative Sciences*, *9*(3), 50. https://doi.org/10.3390/admsci9030050

Swinnen, J., & Kuijpers, R. (2019). Value chain innovations for technology transfer in developing and emerging economies: Conceptual issues, typology, and policy implications. *Food Policy*, *83*, 298–309. https://doi.org/10.1016/j.foodpol.2017.07.013

Testa, M. E., Bilbao, C. & Corti, M. A. (2021). *Inventario de políticas relacionadas a la economía verde en la Argentina*. https://www.ilo.org/buenosaires/publicaciones/WCMS_783138/lang–es/index.htm

Triguero, A., Moreno-Mondejar, L., & Davia, M. A. (2013). Drivers of different types of eco-innovation in European SMEs. *Ecological Economics*, *92*, 25–33. https://doi.org/10.1016/j.ecolecon.2013.04.009

Ulvenblad, P.-O., Ulvenblad, P., & Tell, J. (2019). An overview of sustainable business models for innovation in Swedish agri-food production. *Journal of Integrative Environmental Sciences*, *16*(1), 1–22. https://doi.org/10.1080/1943815X.2018.1554590

Urbaniec, M., Sołtysik, M., Prusak, A., Kułakowski, K., & Wojnarowska, M. (2022). Fostering sustainable entrepreneurship by business strategies: An explorative approach in the bioeconomy. *Business Strategy and the Environment*, *31*, 251–267. https://doi.org/10.1002/bse.2885

Van den Broeck, G., Swinnen, J., & Maertens, M. (2017). Global value chains, large-scale farming, and poverty: Long-term effects in Senegal. *Food Policy*, *66*, 97–107. https://doi.org/10.1016/j.foodpol.2016.12.003

Varadarajan, R. (2017). Innovating for sustainability: A framework for sustainable innovations and a model of sustainable innovations orientation. *Journal of the Academy of Marketing Science*, *45*, 14–36. https://doi.org/10.1007/s11747-015-0461-6

Vargas-Canales, J. M., Brambila-Paz, J. D. J., Pérez-Cerecedo, V., Rojas-Rojas, M. M., López-Reyna, M. D. C., & Omaña-Silvestre, J. M. (2022). Trends in science, technology, and innovation in the agri-food sector. *Tapuya: Latin American Science, Technology and Society*, *5*(1), 2115829. https://doi.org/10.1080/25729861.2022.2115829

Wierny, M., Coremberg, A., Costa, R., Trigo, E., & Regúnaga, M. (2015). *Measuring the bioeconomy: Quantifying the Argentine case*. Buenos Aires, Argentina.

Wilde, K., & Hermans, F. (2021). Innovation in the bioeconomy: Perspectives of entrepreneurs on relevant framework conditions. *Journal of Cleaner Production*, *314*, 127979. https://doi.org/10.1016/j.jclepro.2021.127979

Wydra, S. (2019). Value chains for industrial biotechnology in the bioeconomy-innovation system analysis. *Sustainability*, *11*, 2435. https://doi.org/10.3390/su11082435

Zarrilli, A. (2016). Transformaciones ambientales y producción agroforestal: El Gran Chaco Argentino en el siglo XX. *Revista História: Debates E Tendências*, *16*(1), 53–71. https://doi.org/10.5335/hdtv.16n.1.6253

Zawislak, P. A., Alves, A. C., Tello-Gamarra, J., Barbieux, D., & Reichert, F. M. (2013). Influences of the internal capabilities of firms on their innovation performance: A case study investigation in Brazil. *International Journal of Management*, *30*(1), 329.

Zilberman, D., Lu, L., & Reardon, T. (2019). Innovation-induced food supply chain design. *Food Policy*, *83*, 289–297. https://doi.org/10.1016/j.foodpol.2017.03.010

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