AGRICULTURAL POLICIES IN DEBATE

Bio-inputs for Sustainable Agriculture in South America

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Summary

1. Introduction

Humanity has been experiencing a confluence of multidimensional crises in this first quarter of 21th century across all sectors of society. The climate crisis advances, despite the abundant scientific evidence available and governments' multilateral efforts. The COVID-19 pandemic, considered the greatest collective disruption since World War II, has caused major disruption to agri-food value chains (Barrett et al., 2021) and still poses long-term economic challenges to all countries (Kaiser et al., 2021). And, most recently, the Russia–Ukraine war has caused a decline in trade of fertilizers and grains, spiking the price of food worldwide (Ben Hassen and El Bilali, 2022). Only in 2021, international food prices were on average 53% higher than in previous years (FAO, 2022). These various crises have contributed to higher rates of poverty and food insecurity, especially in lower- and middle-income countries, and have exposed challenges in sustainability and ethics in food system (Kaiser et al., 2021).

The reduced availability and access to agricultural inputs, such as synthetic fertilizers, has been driving up food prices (FAO, 2022). Some of the major food-producing countries rely on imports to cover most of their demands for fertilizers. Brazil, for example, imports around 85% of all its fertilizer, with Russia, China, and Belarus being the most important trade partners for this kind of input (Wagner, 2022). In the context of globalized agricultural markets, the war between two major players in the global food and fertilizer industries raises widespread anxiety about global food security, since evidence shows that wars and conflicts are the most important drivers of food insecurity globally (FAO, 2017). These recent disruptions in the supply of inputs has brought renewed attention to local alternative solutions. According to experts, this represents an opportunity to re-configure the food system with emerging good practices in agriculture, in special, the adoption of bio-inputs (D'Hondt et al., 2021; Jurburg et al., 2022).

Biological agricultural inputs are alternatives to synthetic chemical inputs. While few bio-inputs use auxiliary insects and macro-organisms, most of the bio-inputs recently developed for large-scale agriculture is a result of intense biotechnological development. The biofertilizers and biopesticides are a result of laboratory work that use enzymes, bacteria, and microscopic fungi with fungicidal or insecticidal functions, or symbiosis with cultivated plants to promote their fertilization or strengthen their biological defenses (Goulet and Hubert, 2020). The demand for these products is increasing steadily worldwide as they emerge as a viable alternative for agro-industrial development (Parnell et al., 2016). The market for bio-inputs is currently valued around US$10.6 billion and it is estimated that by 2026 it will be worth around US$18.5 billion (Research and Markets, 2022). In Latin America, bio-inputs were previously promoted by alternative movements to industrial agriculture, such as organic farming and agroecology, but gained importance in recent years in policies promoting alternatives to pesticides, and in a changing agricultural input sector. This is the case in countries with a strong agro-industrial sector, with Brazil and Argentina being among the pioneers (Goulet, 2021a). These countries have a long trajectory in the development of bio-based solutions for agricultural production, in special the bio-inoculants in soybean crops. In Brazil, bio-inoculants have been in use for almost a century and are currently largely present in 30 million hectares of soybeans plantations (MAPA, 2022). Similarly, in Uruguay, the bio-inoculant industry grew strongly with the soybean boom of plantations, and paved the way to the developing further type of biofertilizers (Goulet and Hubert, 2020; López et al., 2010).

Originally developed around the world closely linked to the model of industrial agriculture, bio-inputs were later seen as a practice that could bring transformative impact in favor of sustainability (Goulet, 2021b). Biofertilizers enrich the soil with bioavailable nutrients, and biopesticides reduce the use of chemicals, with co-benefits for the environment, food quality and human health. They also maintain the productivity by improving nutrient use efficiency and increasing abiotic stress tolerance of plants (Anli et al., 2020). For that reason, bio-inputs have a large potential in the (at least partial) replacement of inorganic pesticides, fertilizers and other growth promoters. Evidence shows that problematic technologies are destined to disappear in the medium to long term, and can, thus, be described as “declining technologies” as opposed to their emerging alternatives (Goulet and Hubert, 2020). Indeed, the next decade will probably see substantial growth in novel targets for bio-inputs interventions in opposition of synthetic inputs (Jurburg et al., 2022).

In the process of technological transition, different actors influence the conditions of how this substitution occurs. In the South American cone, for example, the processes by which alternative technologies emerge as their counterparts decline can be in fact complex and non-linear (Goulet and Hubert, 2020). This appears to be the case of bio-inputs. Technological change has three major stages: invention, innovation and diffusion (del Río González, 2009). Experts argue that the main challenge for the transition towards bio-inputs lies in the last stage, i.e. in the spread of their adoption. Indeed, despite the efforts from the public sector to accelerate the transition, fewer products than expected have been successfully commercialized or widely adopted by end-user communities (Jurburg et al., 2022). The global market share for agricultural bio-inoculants is still more than ten times smaller when compared to the size of the market of agrochemicals, estimated in US$ 240 billion (Gupta, 2020).

Among the constraints for the wider adoption of bio-inputs are: i) low technical qualification of farmers and extension agents for handling and applying biological technological packages in large-scale, ii) spread of misleading information, iii) unclear steps for the registration of products, and iv) the need to consider bio-inputs as interactive and ecological entities during their development, test and validation. Therefore, the primary goal in this process of technological change should not to be to seek the complement substitution of synthetic inputs for bio-inputs. The goal should be rather to address these constraints, ensuring industrial diversification and investment in a promising sector (Goulet, 2021a). For the technological transition, policy-makers will need strategies that are better formulated, informed by theory, and guided by appropriate conceptual frameworks (Stark et al., 2022). So far, research on this area remains fragmented and focused only on specific traits of selected microorganisms and impact domains. While technological solutions are available at the basic-sciences level, interdisciplinary research around sustainability pathways remain scarce but are required to facilitate sustainable large-scale adoption. In this case, key knowledge gaps must be filled, including an interdisciplinary framework that identifies which components of economic, social, and environmental systems matter for bio-based transformation processes and their outcomes.

Therefore, the aim of this article is to discuss how countries in the South America have been fostering a technological and sustainable transition towards increased use of bio-inputs. We use Argentina, Brazil, and Uruguay as case studies and apply a conceptual framework on bioeconomic transformation to discuss the strategies that these countries have been pursuing to support the development and adoption of bio-inputs.

1.1. Technological and sustainable transitions towards a bioeconomy

In the discussions about bioeconomy, bio-inputs are receiving growing attention as one of the most promising technologies to improve on-farm sustainability. Although the definition of bioeconomy is contentious, several of these definition place a central emphasis on the use of biological resources to provide products, processes, and services

(Biber-Freudenberger et al., 2020; Siegel et al., 2022). Latin America is well-placed to contribute and benefit from the bioeconomy for several reasons. Firstly, the region is one of the world's most important regions for biodiversity conservation and the production of bio-based raw materials (Sasson and Malpica, 2018). Secondly, due to its scientific and technological capabilities, the region has substantial potential to develop high-tech solutions to improve environmental efficiency in biomass production. Thirdly, Latin America has a dynamic and booming agricultural sector, with well-established market structures, which facilitates the test of new technologies in large scale.

Therefore, strong sectors from the bioeconomy have contributed greatly to national economies in the Latin America. In Argentina, the bioeconomy contributed to 16.1% to the country's GDP in 2017 (Lachman et al., 2020). This contribution comes especially from the production of biomass and a strong private-led biotechnology sector. In Brazil, the calculated value for bioeconomic activities were 13,8% to the country's GDP in 2016 (Silva et al., 2018), with a major focus on bioenergy and biotechnology. In Uruguay, the agro-industrial sector accounted for approximately 12% of Uruguay's GDP in 2019, according to the Central Bank of Uruguay (BCU), and more than 80% of the composition of exports are related to the bioeconomy, with a steady increase in the forestry sector over the recent years (ECLAC, 2018).

To promote the principles of the bioeconomy and foster the sustainable and efficient use of natural resources, many countries in the region have sought to develop national bioeconomy strategies (Biber-Freudenberger et al., 2018). In Latin America, three countries have a formal national bioeconomy strategy: Brazil, Costa Rica and Colombia. Brazil, in particular, in response to critics that found previous strategies too market-oriented, took one-step further and included socio-biodiversity in its national bioeconomy strategy. Argentina and Uruguay are also taking steps to construct their own integrated national strategies level, with their respective regulatory frameworks, but political changes in recent years have stalled these efforts.

2. Building blocks for transformative pathways for bio-inputs

2.1 Transformation pathwaysw

Several conceptual frameworks have been proposed to describe the process of transitioning towards a bioeconomy. Dietz et al. (2018) have proposed four transformation pathways (TP) that describe this transition (Figure 1). The technological transition for bio-inputs in South America countries overlaps with three of these four archetypical bioeconomic transformation pathways, as described below.

2.1.1. TP1 – substitution of fossil- by bio-based resources

The first TP addresses the concerns related to scarcity of fossil resources, energy security and climate change. With its substitution possibilities, bio-inputs would support the world to transition away from fossil fertilizer and decrease emissions due to lower carbon emissions in their life-cycle. Synthetic nitrogen fertilizer and pesticides are fossil fuels in another form, making them an under recognized but still a driver of the climate crisis (Menegat et al., 2022). Further, the close ties between agrochemicals and fossil fuels mean that industrial food production is vulnerable to the volatility inherent in oil and gas markets, as starkly illustrated by the 2022 market shocks in food, fuel, and fertilizer prices (CIEL, 2022). Technological innovation towards bio-inputs would diminish the risk of undesired outcomes, although the challenges of a wider adoption mentioned above restrain the complete substitution of one by another.

2.1.2. TP 2 - Increases in primary sector productivity:

The second TP sustains that bio-based primary sectors have their productivity increased via technological innovations. Bio-inputs themselves are technological innovations designed as an alternative to sustain or improve the productivity in agriculture while promoting co-benefits for the environment and human health. Their final goal is not exclusively the increase of productivity, but rather promoting sustainable alternatives to synthetic products. Clearly, there is space for innovation on agricultural productivity via bio-inputs, and as any technology, those innovations will be fueled by novel insights generated from investments in data collection and analysis in the countries (Małyska et al., 2019). Trade partners engaged in the TP 1 increase their demand for products using bio-inputs supporting countries to embark on this TP 2. In the case of an increase of productivity using bio-inputs, this would result in spatially heterogeneous patterns of agricultural productivity change, which could avoid the increase in resource demand in local/regional level ('Jevons Paradox').

2.1.3 TP 4 - Bio-based value added in low-volume/ high-value industries:

The last TP related to bio-inputs represents an innovation-induced transformation pathway, which addresses the implementation of biological principles in industries to produce bioeconomic change. Bio-inputs have technical and practical application in the agro-food industries, and their use can reduce costs and increase added value in a potentially large range of applications. This type of bio-based added value is usually knowledge intensive and requires high-skilled labor, therefore this transformation is more likely to occur in economies with advanced science system. Brazil, Argentina and Uruguay are countries with bioeconomic ambitions, who have invested to unlock the use of biotechnology to boost economic productivity in agricultural systems.

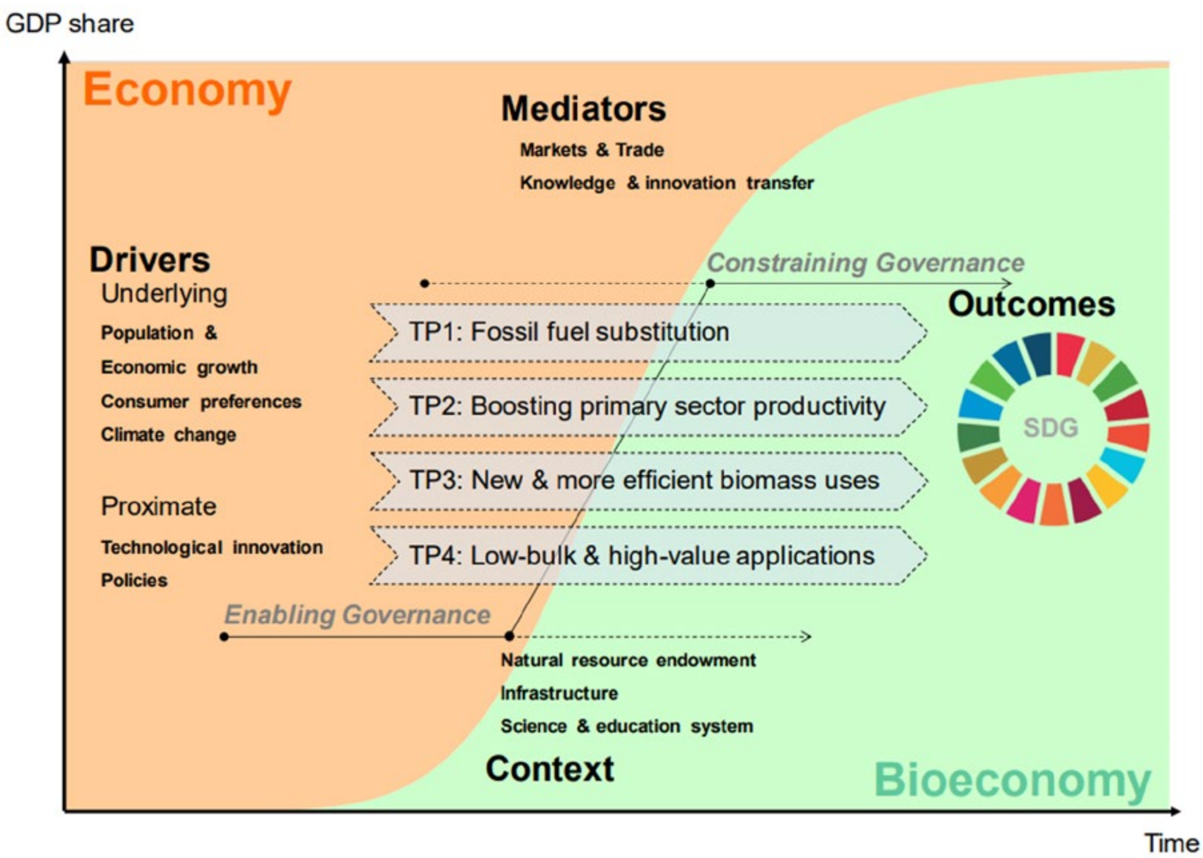
2.2 Understanding context-specific drivers, mediators, and outcomes

Dietz et al. (2018) have illustrated in a stylized s-curve the building blocks that determine the potential outcomes of each Transformation Pathway (TP). They are: context, drivers, and mediators (Figure 1). According to the authors, drivers are factors that trigger or induce changes towards bioeconomy. For any of the four TPs, technological innovation is the central driver for sustainable transformation, followed by policy programs that anticipate or respond to societal needs. Regional or national factors can act as "pre-drivers", inducing the real drivers (innovation or policy programs) to kick-off. These pre-drivers are, for example, demographic and economic development as well as climate change and consumer awareness.

The **mediators** are factors leveraging the transformation outcomes from the pathways, and these are the second building block. Examples of mediators are market mechanisms and transfers of knowledge or technologies capable of changing behavior of economic actors at different levels (Dietz et al., 2018). The level of power and susceptibility to the drivers and mediators are subject to context-specific factors, some of which can be country-specific and drive national bioeconomies into certain mixes of transformation pathways (Dietz et al., 2018).

The **context** as a third building block encompasses natural resource endowment, labor supply, legal and institutional path dependencies, infrastructure, socioeconomic conditions, and science and education systems (Dietz et al., 2018). The context-specific factors will then also co-determine the nature of the bioeconomy strategies adopted by decision-makers in that country. They will also influence how and which mediating factors have a bearing on sustainability outcomes.

Figure 1. Conceptual diagram of transformative pathways in the bioeconomy.



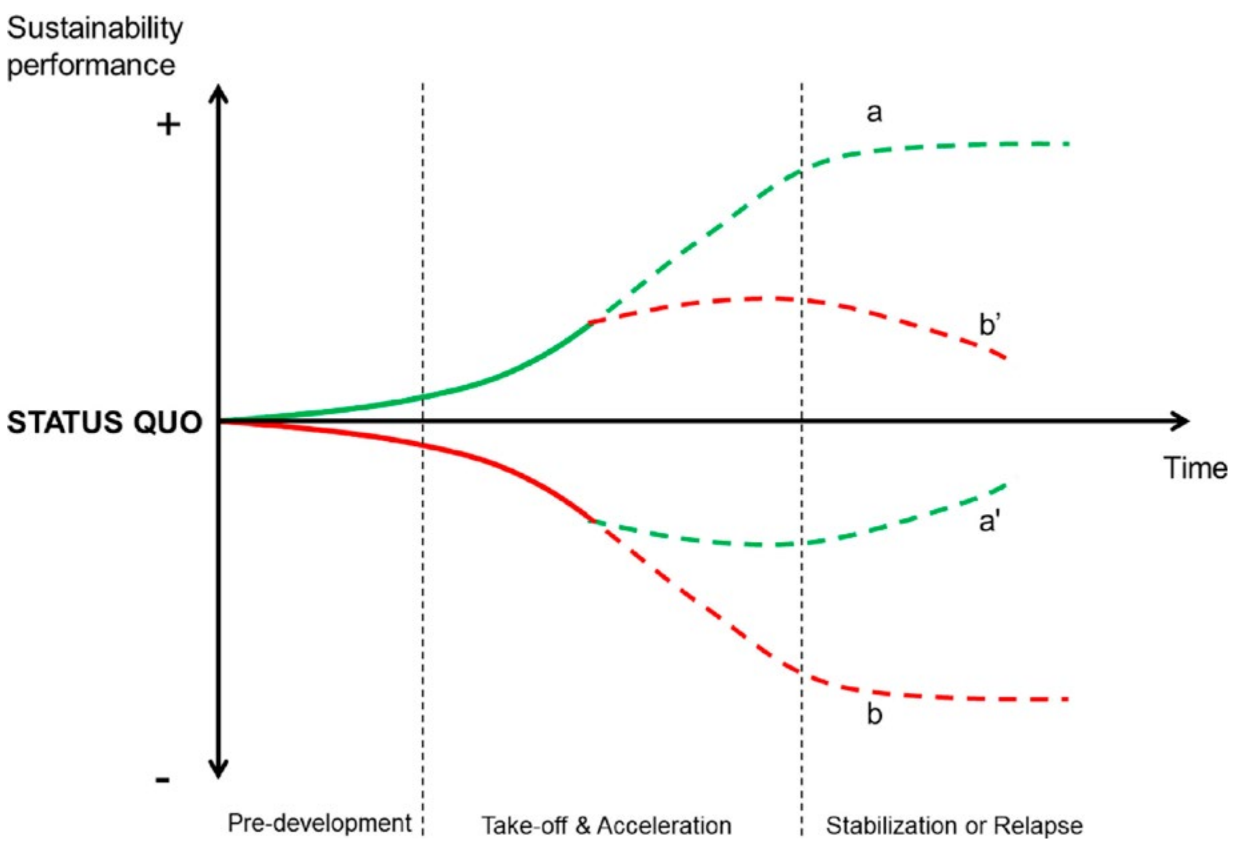
Source: Dietz et al. (2018)

Mixes of transformation pathways in a country depend on the interactions of drivers, mediators, and context. Stark et al. (2022) have illustrated the alternative trajectories of bioeconomic transformation considering those TP interactions in a temporal dimension. They divided the s-curve in four phases, adapted from the work of Rotmans et al.

(2001). These four phases are: 1) status quo, 2) pre-development, 3) take-off & acceleration, and 4) stabilization or relapse (Figure 2). The TP trajectories can either follow a sustainability enhancing path or a deteriorating path, according to the interactions with the mediators. Stark et al. (2022) explain how to visualize the TP according to its sustainability trajectory:

"(…) If an economy has embarked on the solid green transformation curve (a) in the pre-development phase, it can be thrown onto a sustainability deteriorating path (b') if economic rebound effects set in during the take-off and acceleration phase. Alternatively, societies can take corrective action once they have entered the red transformation curve (b), which may enable a gradual switch back to a more sustainability enhancing path (a')." (Stark et al., 2022)

Figure 2. Enhancing (a, a') and deteriorating (b, b') sustainability dynamics in the four phases of bioeconomic transformation.



Source: Stark et al (2022), adapted from Rotmans et al. (2001)

3. Applying the framwork toongoing bio-inputs transformations

In general, the phases and prospects of bioeconomic transformation vary in each country. However, for bio-inputs in South America, the technological development trajectories are in its major part determined by a common contextual factor: the soybean plantations. In this paper, we use the framework illustrated by the s-shaped curve to discuss interventions in Brazil, Argentina and Uruguay, and their transformation pathways towards bio-inputs. As described above, the ongoing bio-based transformations towards bio-inputs in South America relate to TP2 (by improving plant yields while considering the environment) and TP4 (by adding value in agro-industrial applications), with further contributions to the TP 1 (through material substitution) when reducing dependence on chemical inputs.

3.1. Case 1: Brazil and the National Bio-inputs Program

3.1.1. Context

Brazil is one of the biggest exporters of agricultural commodities, especially of soybean. Alongside with the increase of the soybean's harvest area[2], Brazil has been developing biological agricultural inputs since the early 90s (MAPA, 2022). After creating a new category of "bio-inputs" in the end of the decade, bringing biopesticides and biofertilizers together, the country started the scaling-up of bio-inputs to beyond the alternative agriculture niche, reaching large-scale commercial agriculture. In a country marked by development disparities between large cities and rural areas, bio-inputs have the potential to bring benefits for local economies and social development at the countryside. Besides, Brazil is the country with the greatest biodiversity in the world, and with a solid scientific and education system, a fruitful basis for transformative change (Figure 3, Phase 0). In this context, proponents of bio-inputs have demonstrated certain expectation that science and technology will be able to capture this high microbial diversity and harness its biological potential for agriculture (Goulet 2021).

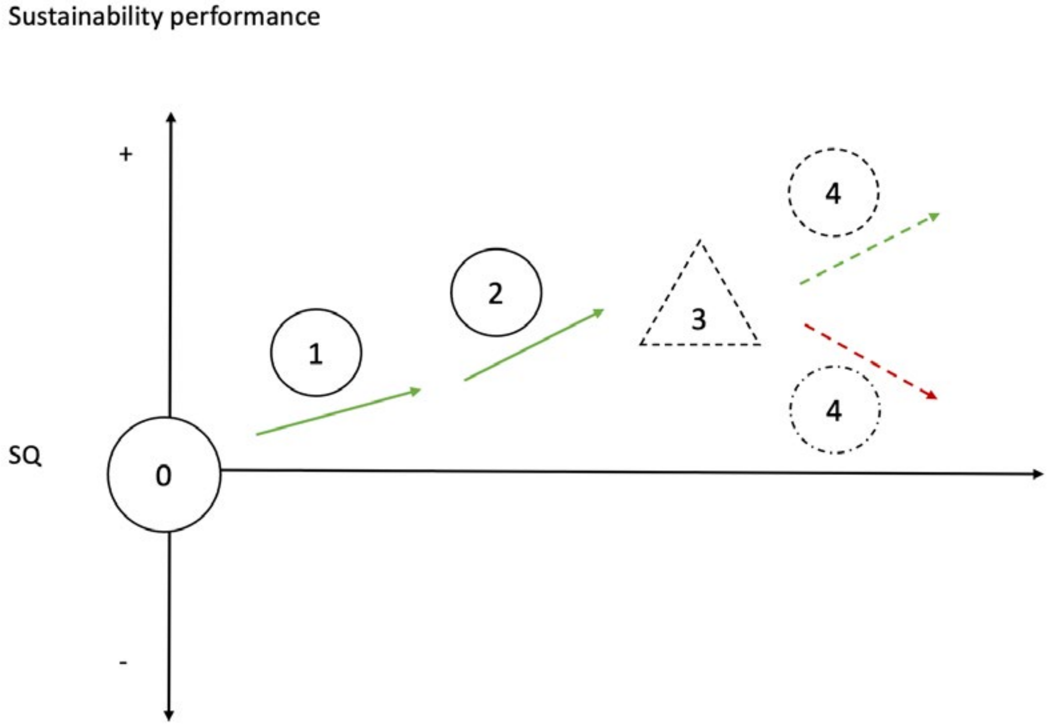
3.1.2. Drivers & Mediators

The willingness to place bio-inputs at the crossroads of a polarized system between small and large-scale farmers was the main motivations for the creation of the National Bio-input Program, Decree No. 10.375, instituted on May 26, 2020 (MAPA, 2020). Based on a logic of pairing technologies and visions, the Program is a **driver** for the use and expansion of bio-inputs in the agricultural systems in the country, and it intends to be a solution for one of the main challenges of these products: to be widely adopted by end-user communities. Besides, bio-inputs producers benefit directly from the government in the form of funds for R&D and biotechnological clusters. By implementing environmentally friendly technologies in large-scale agriculture, the driver pushes the economic and environmental dimensions initially onto the solid green transformation curve (Phase 1). Subsequent technological development of bio-inoculants and alternative biological control products supports the take-off and acceleration of the bioinputs use, working as **moderators** of the transformation (Phase 2). However, continuous research in this area (Phase 3) is key to improve success rates in product performance (Phase 4), otherwise conventional inputs could take back the place of the new bio-interventions.

3.1.3. Outcomes

The bio-based transformation driven by this political support can lead to positive outcomes in terms of social, economic and environmental dimensions. Different from other countries, the Brazilian Program promotes the development of local bio-inputs through "bio-factories", which are expected to provide innovation, economic activity and create rural jobs (SDG 2, 8, 9, Phase 1). Besides, the promotion of organic agriculture would generate co-benefits to the soil and biodiversity (SDG 15), while enabling the country to win an export position in this sector.

Figure 3. Actual (solid line) and potential (dashed line) sustainability enhancing (green) / deteriorating (red) development from the Status Quo (SQ, Phase 0) due to interactions between drivers (Phase 1), mediators, context-factors, and government responses (triangle) in the case of bio-inputs in Brazil.



Source: adapted from Stark et al. (2022).

3.2. Case 2: Argentina and the role of CABUA

3.2.1. Context

Argentina is a pioneer in the development of bio-inputs for agricultural use in the region, in special the bio-inoculants for soybeans, which are bacteria used to enhance plants' ability to capture nitrogen from the air and strengthen their growth. Already in 2001, Argentina was the only lower-income country to have more than 1% of its agricultural land under organic management (Parrott and Marsden, 2002). In fact, the notion of bio-inputs adopted in Argentina and spread by the Commission for Organic Agriculture of the Inter-American Institute for Agricultural Cooperation (IICA) inspired the Brazilian government to support bio-inputs inside its own country. Argentina introduced policy instruments that act on several levels to boost the production and use of biological inputs. In the beginning, the motivation was not environmental, but rather agronomic and economic, but later evolved to a wider discussion about the environmental problems of the current production system using chemical inputs.

3.2.2. Drivers & Mediators

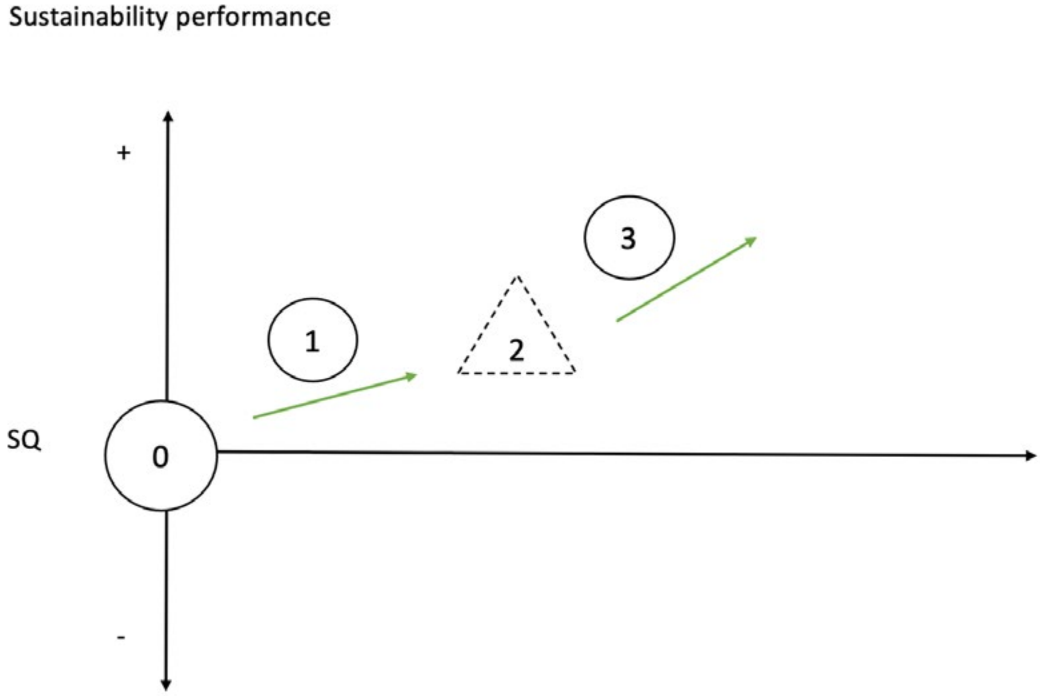
Although Argentina has supported the use of bio-inputs since the early 90s, the polarized views on biotechnologies for agriculture were a challenge for the promotion of the bio-inputs sector. Therefore, there was a need to create an intersectoral body for the management, coordination and formulation of projects for the sector of agricultural bio-inputs. In 2013, the Advisor Committee on Bio-inputs for Agriculture Use (CABUA) was created, a multistakeholder committee that made it possible to add new bio-input technologies on the agenda without threatening the dominant agricultural model and its well-established technologies and regulations (Goulet and Hubert, 2020). The CABUA provides advice on the technical requirements of quality, efficacy and biosecurity of bio-inputs, proposes new standards, and issues opinions in relation to their regulation and promotion. Here, we consider CABUA as a **driver** of bioeconomic transformation towards bio-inputs in Argentina (Phase 1). Other policy instruments and regulatory arrangements work as context-factors increasing the susceptibility to the drivers of bio-inputs development in Argentina. Those are: i) the specific line for bio-inputs within FONREBIO, the Regulatory Fund for Biotechnology Products, aimed at promoting innovation among biotechnology companies; ii) the Program to Promote the Use of Bio-inputs (PROFOBIO 2015-2016); and iii) the National Advisory Committee on Agricultural Biotechnologies (CONABIA).

CABUA is a driver that supports innovation, social cohesion and bring economic opportunities in this field, thus represented by the solid green transformation curve, similar to the Brazilian case study (Figure 4). Due to these favorable policy frameworks (Phase 2), Argentina is now better positioned to develop and commercialize bio-based technologies. The transformation outcomes brought by CABUA are leveraged by more advanced technologies than nitrogen fixation, such as towards biological fertilization (Phase 3), such as the solubilization of phosphorus and potassium and the production of bidders. Those **mediators** increase the diversity and use of bio-inputs in the formal market, and it is expected that the adoption of these technologies among farmers' groups increase.

3.2.3. Outcomes

The bio-inputs transformation in Argentina, driven by participatory arrangements, could result in several positive sustainability outcomes. It is expected that processes of research, innovation (SDG 9) and educational training (SDG 4) would be supported, in special, via biofactories distributed in the territory. For the environment, positive outcomes have been reported from the reactivation of the micro and macrobiological diversity of the soil (SDG 15) after the use of biological inputs.

Figure 4. Actual (solid line) sustainability enhancing (green) / deteriorating (red) development from the Status Quo (SQ, Phase 0) due to interactions between drivers (Phase 1), policy-frameworks (triangle), and mediators (Phase 3), in the case of bio-inputs in Argentina.



Source: adapted from Stark et al. (2022).

3.3. Case 3: Uruguay and the Rhizobia inoculants

3.3.1. Context

Bio-inputs are an innovative sector in expansion in Uruguay. The country has 14 registered biological control agents (BCA, biopesticide), and, until 2021, other 18 were being developed, according to the Ministry of Livestock Agriculture and Fisheries (MGAP). The most remarkable and popular bio-input in the country is certainly the forage legume rhizobia symbiosis. Their use has largely reduced N fertilization requirements while improving farmer profitability, since the costs are lower than the use of imported N fertilizers such as urea (Lindström et al., 2010).

Bio-inputs started to be used in the country after the implementation of a national system of bio-inoculants, created to support the use of biological nitrogen fixation in agriculture plantations. Created in 1960, this national government-supported strategy was a result of a functional relationship between public research, private industry and farmers. This system is considered a pre-driver of the bio-inputs transformation, since it provided a clear and appropriate legislation that supported regulatory authorities responsible for inoculant registration, quality control and use.

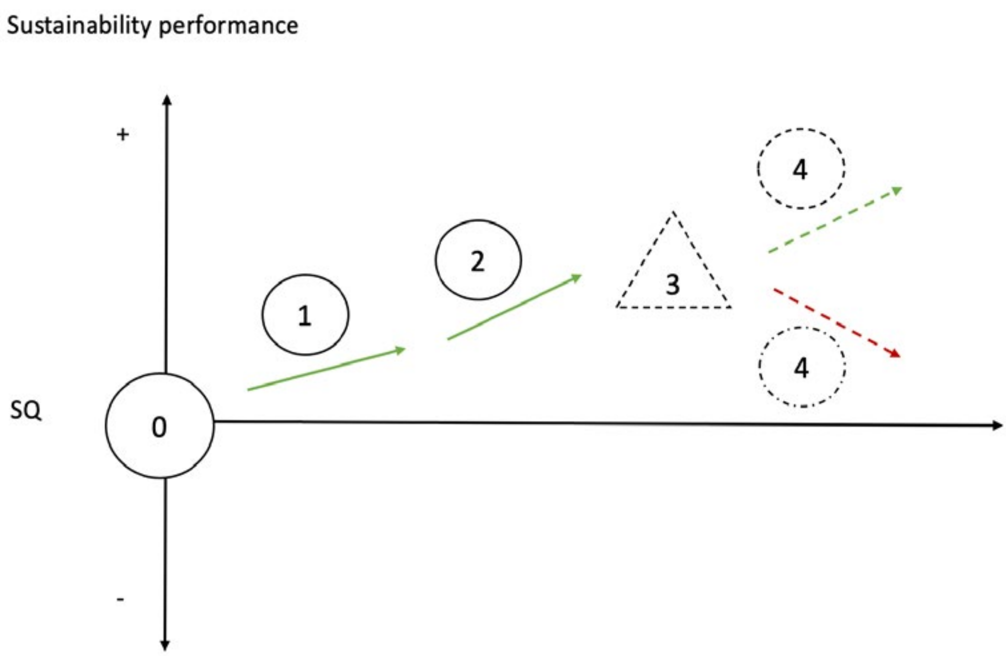
3.3.2. Drivers & Mediators

The widely adopted rhizobial inoculants for biological nitrogen fixation (BNF) is a **driver** for the biological transformation in Uruguay (Phase 1), opening doors to other more recent technologies such as inoculants for phosphorus mobilization and strains of the genera Bacillus, used as biofertilizer and biocontrol agent (Phase 2). The development of new bio-inputs increases the sustainability performance in a first moment (green line), but there are barriers that have to be overcome for these technologies to take-off (Phase 3) and thus lead to substantial sustainability gains. For Uruguay, the first barrier is related to the costs of registration of the product. In 2021, the Uruguayan ministries committed to review the requirements for registration and adapt them to the demand of other countries and markets, with the aim of future exports. Once registration costs decrease, it is important to ensure that the bio-inputs are economically viable to the farmers. Without an adequate set of incentive, farmers are unlikely to adopt bio-inputs, especially if they can access chemical pesticides at lower costs. It is also important to provide technical training for farmers, not only to improve the application of those products with less labor but also to increase the trust of the users.

3.3.3. Outcomes

The directed sustainability gains from the rhizobial inoculant technology are related to improvements of forage legume productivity, conservation of the soil and increase of soil nitrogen for the benefit of rotational non-leguminous crop. Reduced reliance on chemical inputs for agricultural production also provide benefits to the rural workers' health and safety (SDG 3, SDG 8) (Sellare et al., 2020).

Figure 5. Actual (solid line) and potential (dashed line) sustainability enhancing (green) / deteriorating (red) development from the Status Quo (SQ, Phase 0) due to interactions between drivers (Phase 1), mediators (Phase 2), and necessary conditions for sustainability (triangle) in the case of bio-inputs in Uruguay.



Source: adapted from Stark et al. (2022).

4. Conclusions

Synthetic inputs for agricultural production are responsible for around 2.1% of all greenhouse gas (GHG) emissions originating from agri-food systems and can have negative impacts on the environment and human health (Menegat et al., 2022; Sellare et al., 2020). With the war on Ukraine and the disruptions in some agri-food value chains and in the supply of synthetic fertilizers (Ben Hassen and El Bilali, 2022)the Russia–Ukraine war has various negative socioeconomic impacts that are now being felt internationally and might worsen, notably, for global food security. If the war deepens, the food crisis will worsen, posing a challenge to many countries, especially those that rely on food imports, such as those in the Middle East and North Africa (MENA, we are seeing renewed attention to bio-based inputs for agricultural production. In particular, microbiome or microorganism-based inputs (MBI) have been portrayed as a promising technology that could simultaneously increase agricultural productivity while creating synergies with environment outcomes (Jurburg et al., 2022).

Some countries in South America have been pioneers in the development of bio-based inputs, with some of these efforts dating from the early 1990s. In the past decade, Brazil, Argentina and Uruguay have enhanced their efforts to actively support the development and commercialization of bio-inputs. However, despite these efforts and a growing international market, the adoption of bio-based inputs is still rather low. Lack of sufficient knowledge on the social and economic performance of microbiome-based solutions has been identified as one of the underlying reasons for low adoption rates (Ploll et al., 2022)such as beneficial soil microbes for in-field application, may help to achieve this goal, but adoption rates have remained slow thus far. The adopter's perspective is essential to understanding why. This research investigates factors that drive the perceptions of soil microbe solutions across three groups of (potential.

The market for bio-inputs will continue to increase in the next years, but if we want them to be a key piece in the transition towards a sustainable bioeconomy, we need to pursue the three following actions points. First, regulatory frameworks have to be improved to facilitate the approval and registration of new products, thus reducing overall costs pre-commercialization stage. These new regulations should also consider issues related to intellectual property and benefit sharing, especially if large biotechnology companies make use of the biodiversity present in the lands of indigenous and other historically marginalized groups. Second, there is an urgent need to train extension agents in managing agricultural systems that rely on bio-based inputs. Some of these technologies have special needs in how they are transported, stored, and applied to be effective. Therefore, well the provision of good extension service tailored for systems that use bio-inputs can have a significant effect on how farmers perceive this technology, thus increasing adoption rates. Third, there is still a large knowledge gap about the effects of bio-inputs in "real-life" settings. Most research on bio-inputs uses experimental lab or field trials to estimate their effectiveness on agricultural productivity, soil nutrient, and other environmental outcomes. But, to the best of our knowledge, there is no evidence based on observational data that analyzes the on-farm impacts of bio-inputs. Building a solid body of scientific evidence can help push forward the agenda for bio-inputs and help identify factors that might be hindering their adoption and effectiveness.

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