Matilda Baraibar Norberg/Cecilia Gelabert/Enrique Antonio Mejía

Analysing Socio-Technical Regimes

The Case of Herbicide-Tolerant Soybeans in Argentina and Uruguay

Abstract: This study investigates the dynamics of homogenization and heterogenization in soybean production in Argentina and Uruguay, focusing on the widespread adoption of herbicide-tolerant (HT) soybeans. Using an integrated theoretical framework combining systems thinking and socio-technical transitions, it examines how the dominant socio-technical regime of HT soybeans has emerged and evolved. Cross-scale analysis reveals that the current regime developed from a long-term trend of agricultural homogenization and a specific configuration of technologies, policies, and markets that preceded the spread of HT soy in the region. Various aligned stressors and feedback mechanisms, driven by agribusiness strategies and economies of scale, have stabilized the regime and reinforced homogenization over the past three decades. However, the study also uncovers countervailing forces – dynamic social and ecological feedback loops – that challenge the system's foundations. These forces may signal the onset of a new shift in the socio-technical regime.

Zusammenfassung: Diese Studie untersucht die Dynamiken von Homogenisierung und Heterogenisierung in der Sojaproduktion in Argentinien und Uruguay, mit besonderem Fokus auf die weitverbreitete Einführung herbizidtoleranter (HT) Sojabohnen. Anhand eines integrierten theoretischen Rahmens, der Systemdenken und soziotechnische Transitionen miteinander verbindet, wird untersucht, wie das vorherrschende soziotechnische Regime der HT-Sojabohnen entstanden ist und sich weiterentwickelt hat. Eine skalenübergreifende Analyse zeigt, dass sich das derzeitige Regime aus einem langfristigen Trend zur landwirtschaftlichen Homogenisierung und einer spezifischen Konfiguration von Technologien, Politik und Märkten entwickelt hat, die der Verbreitung von HT-Soja in der Region vorausgingen. Verschiedene aufeinander abgestimmte Faktoren und Rückkopplungsmechanismen, angetrieben durch Strategien der Agrarindustrie und Skaleneffekte, haben das Regime in den letzten drei Jahrzehnten stabilisiert und die Homogenisierung verstärkt. Die Studie deckt jedoch auch gegenläufige Kräfte auf – dynamische soziale und ökologische Rückkopplungsschleifen –, die die Grundlagen des Systems in Frage stellen. Diese Kräfte könnten den Beginn einer neuen Verschiebung im soziotechnischen Regime signalisieren.

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Introduction

In 2024, the global area used for genetically modified (GM) crops was approximately 190 million hectares (Mha), of which half (105 Mha) was dedicated to GM soybeans,[1] most of which are designed to be herbicide-tolerant (HT). The majority of this soy production is concentrated in a few countries including the United States, Brazil, Canada, Argentina, Paraguay, Bolivia, India, and Uruguay.[2] The first commercialized HT soy was Monsanto's (now Bayer) Roundup Ready (RR) soybean (GTS-40-3-2), which arrived on the market in 1996, first in the US and almost immediately thereafter in Argentina. RR soy was engineered to tolerate the herbicide glyphosate, which Monsanto sold under the brand name Roundup. This facilitated much cheaper, simpler and more effective weed control than required for conventional soybeans. Farmers could apply glyphosate directly to their fields without damaging the soy plants, making large-scale monoculture much easier and more profitable. Moreover, HT crops are highly compatible with no-tillage (zero-tillage, no-till) practices, which help to preserve topsoil and allow soybeans to be planted on land with less suitable soils.[3]

Modernization and standardization of agriculture are nothing new. The adoption of GM crops can be seen as merely the most recent step in a long history of homogenization of agriculture. However, the rapid pace and extensive scope of the current technological shift are unprecedented. In South America, soy employing the abovementioned technological package offered better economic margins than any other agricultural activity. Accordingly, it became the principal crop in many existing farming areas and expanded into new regions at a pioneering pace in South America, a process referred to as *sojización*. In just a few decades, the area used for soy expanded to almost 30 Mha, and at present the crop is cultivated on approximately 59.7 Mha across Argentina, Brazil, Paraguay, and Uruguay, accounting for significant portions of those countries' export revenues.[4]

The soy expansion has transformed forests, savannahs, grasslands, and diverse farming systems into simplified, often continuously cropped landscapes dominated by soy. This transformation has raised concerns about biodiversity loss and the displacement of family farms.[5]

1 AgbioInvestor 2025, Global GM Crop Area Review: AgbioInvestor GM Monitor, https://gm.agbioinvestor.com (20 May 2025).

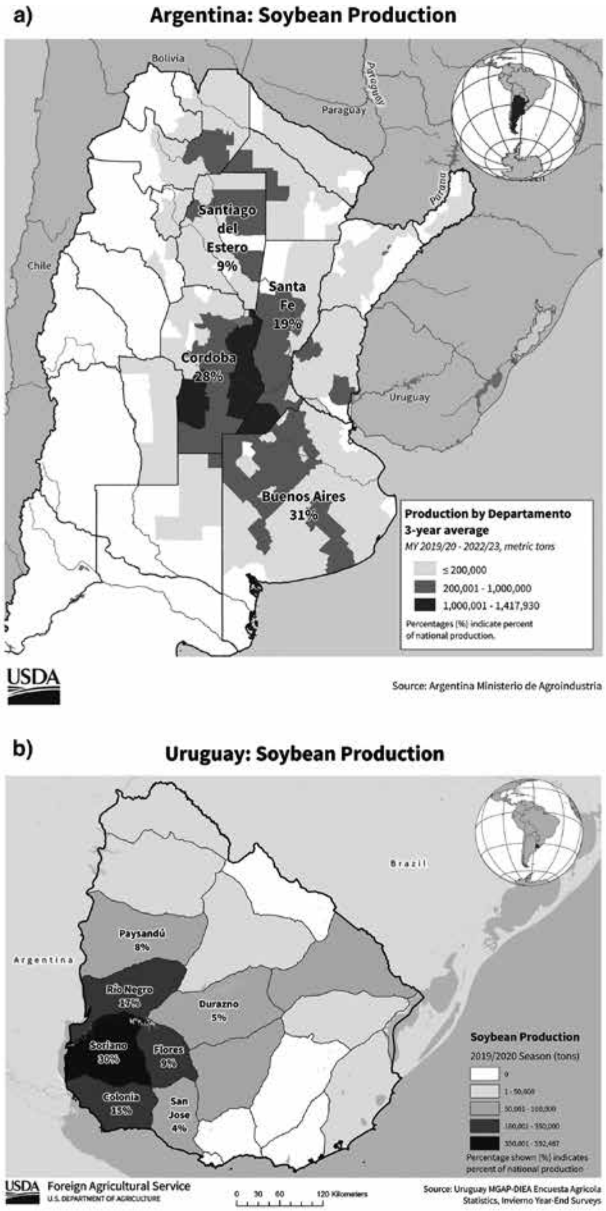
2 FAOSTAT, Crops and Livestock Products, Food and Agriculture Organization of the United Nations, https://www.fao.org/faostat/en/#data/ (25 June 2025); ISAAA, GM Approval Database, https://www.isaaa.org/gmapprovaldatabase/ (28 June 2025).

3 Matilda Baraibar Norberg, The Political Economy of Agrarian Change in Latin America: Argentina, Paraguay, and Uruguay, Cham 2020.

4 FAOSTAT, Crops.

5 Yamila Leguizamón et al., Environmental Potential for Crop Production and Tenure Regime Influence Fertilizer Application and Soil Nutrient Mining in Soybean and Maize Crops, in: Agricultural Systems 210/103690 (2023), 1–11; Sebastián Gómez Lende, El Modelo Sojero en la Argentina (1996–2014), un Caso de Acumulación por Desposesión, in: Mercator (Fortaleza) 14/3 (2015), 7–25, DOI: 10.4215/RM2015.1403.0001; Bert Vander Vennet et al., Different Farming Styles Behind the Homogeneous Soy Production in Southern Brazil, in: Gustavo de T. Olivera/Susanna Hecht (eds.), Globalization, and Environmental Politics in South America,

Figure 1: Soybean production by department, a) Argentina (3-year average for 2019/20–2022/23); b) Uruguay (2019/2020 season)



Source: a) United States Department of Agriculture (USDA) – Foreign Agricultural Service (FAS), Argentina: Crop Summary – Soybean, https://ipad.fas.usda.gov/countrysummary/default.aspx?id=AR&crop=Soybean (3 July 2025); b) USDA-FAS, Uruguay: Crop Summary – Soybean, https://ipad.fas.usda.gov/countrysummary/default.aspx?id=UY&crop=Soybean (3 July 2025). Note: percentage indicates proportion of national production.

Thus, *sojización* represents not only a change in technological application but a much wider socio-technical transition involving new production logic, social organization, and market practices.

This transition was driven and later stabilized by a combination of stressors, including a long history of agricultural homogenization, the advancement of global agribusiness, supportive policies at various scales, and the role of social organizations and networks. However, it is not an immutable process. While HT soy is the dominant socio-technical regime, there are also stressors pushing towards heterogenization. Moreover, there seems to be emerging ecosystem feedback pushing back against homogenization. This study aims to explore the dynamics of homogenization and heterogenization in soybean production with a focus on Argentina and Uruguay, where soy is the most important agricultural commodity.

Currently, the area under HT soybean cultivation in Argentina is around 17.46 Mha, which accounts for approximately 47 per cent of total crop area (38 Mha) and about 12 per cent of the total arable land (140 Mha).[6] As shown in Figure 1a, production remains concentrated in the traditional breadbasket region of the Pampa (e.g., Córdoba, Buenos Aires, Santa Fe, Entre Ríos), although cultivation has increasingly expanded northward in recent years (e.g., Chaco, Santiago del Estero). In Uruguay, the harvested area of HT soy has fluctuated between 0.9 and 1.4 Mha in recent years, reaching approximately 1.38 Mha in the 2024–25 season. This represents about 60–80 per cent of Uruguay's total crop area (2.5–3 Mha) and roughly 7–8 per cent of its total arable land (16 Mha).[7] As shown in Figure 1b, the primary production zone is located in the western littoral region (e.g., Soriano, Río Negro, Colonia), although soybean cultivation has increasingly expanded beyond traditional crop areas (e.g., Cerro Largo, Durazno, Rocha).

Drawing on the literature on systems thinking and socio-technical transitions, we explore the emergence and maintenance of the dominant socio-technical regime in Argentina from 1996 and in Uruguay from 2003 until today. We examine how soybean farming, along with the broader systems in which it is embedded, responds to stressors that either reinforce ever more uniformity or challenge and counteract homogenization. In this way, we seek to provide a more nuanced understanding of the social-ecological dynamics of soy cultivation, challenging simplistic conclusions and offering a holistic perspective on the complex relationship between agriculture and place.

New York 2017, 146–168; Facundo Zorzoli, De la Fiebre de la Soja a la Degradación de los Suelos: Economía, Ecología y Política en la Agricultura del Centro-Oeste del Chaco Seco, Argentina (1960–1990), in: Quinto Sol 25 (2021), 111–132, DOI: 10.19137/qs.v25i1.4355.

6 Eugenia Chialvo et al., Productividad y Calidad de la Soja en la Zona Núcleo Sojera: Campaña 2024/25, Laboratorio de Calidad Industrial y Valor Agregado de Cereales y Oleaginosas. EEA – INTA Marcos Juárez, Ministerio de Economía 2025; Guido Di Mauro et al., Transformations in Argentinean Soybean Systems: Recent Changes, Challenges, and Opportunities, in: Crop and Environment 4/2 (2025), 130–141; USDA-FAS, Argentina.

7 USDA-FAS, Uruguay; URUPOV, Teledetección y Caracterización del Cultivo de Soja en Uruguay 2025, https://www.urupov.org.uy/wp-content/uploads/2025/06/URUPOV-Informe-teledeteccion-_-SOJA-2025.pdf (22 October 2025).

Previous studies and gaps

Previous studies have analysed the process of *sojización* in Argentina and Uruguay in various social, economic, and ecological dimensions as well as across different spatial scales. Traditionally, agrarian social studies have employed a structuralist approach, describing agrarian subjects based on their access to production factors such as land, capital, and labour. This research has typically focused on increasing economies of scale and the substitution of labour for capital, along with their effects including land concentration, rural displacement, and rising rural conflicts.[8] The displacement of family farmers and indigenous communities as well as the expansion of agribusiness are well-documented phenomena.[9]

From an economic perspective, numerous studies have examined the benefits of HT soy such as lower costs for weed management and increased export revenues, mainly through dependence on China as a critical market.[10] However, other research within the political economy highlights how rising land and leasing prices have increased pressure towards land-use intensification, ousting smaller farmers and fuelling competition.[11] Several studies have also addressed how these changes intersect with national governance structures, international regulations, and markets.[12]

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8 Irma Acosta Reveles, El Enfoque de la Nueva Ruralidad como Eje de las Políticas Públicas: ¿Qué Podemos Esperar?, in: Revista Electrónica Zacatecana sobre Población y Sociedad 8/32 (2008), 1–20; Susana Aparicio/Carla Gras, Las Tipologías Como Construcciones Metodológicas, in: Norma Giarraca (ed.), Estudios Rurales: Teorías, Problemas y Estrategias Metodológicas, Buenos Aires 1999, 151–172; Javier Balsa, La Conceptualización de los Productores Rurales y su Transformación a lo Largo del Siglo XX: Reflexiones a Partir de la Confrontación con los Estudios sobre el Agro Norteamericano, in: Fernando Jumar (ed.), Empresas y Empresarios Rurales en la Argentina del Siglo XVIII al XX, Buenos Aires 2002, 29–58, 51–55; Pablo Lapegna, Soybeans and Power: Genetically Modified Crops, Environmental Politics, and Social Movements in Argentina, Oxford 2016; Matilda Baraibar Norberg, Sojización as a New First Movement. A Polanyian Analysis of the South American Soybean "Boom," in: Claiton Da Silva/Claudio De Majo (eds.), The Age of the Soybean: An Environmental History of Soy During the Great Acceleration, Winwick 2022, 91–114.

9 Diego Domínguez/Pablo Sabatino, La Conflictividad en los Espacios Rurales de Argentina, in: Lavboratorio: Revista de Estudios Sobre Cambio Estructural y Desigualdad Social 22 (2008), 38–44, 39; Gustavo García-López/Nancy Arizpe, Participatory Processes in the Soy Conflicts in Paraguay and Argentina, in: Ecological Economics 70/2 (2010), 196–206; Leguizamón et al., Environmental Potential; Gabriel Oyhantçabal Benelli et al., Who Rents Out the Land? Agrarian Capital Accumulation and Lessor Landowners in South America. The Case of Uruguay, in: Journal of Agrarian Change (2024), 1–20, DOI: 10.1111/joac.12603.

10 Roberto Bisang et al., Una Revolución (No Tan) Silenciosa: Claves para Repensar el Agro en Argentina, in: Desarrollo Económico (2008), 165–207; Eduardo Trigo/Eugenio Cap, The Impact of the Introduction of Transgenic Crops in Argentinean Agriculture, in: AgBioForum 6/3 (2003), 87–94; Rebecca Ray, The Panda's Pawprint: The Environmental Impact of the China-Led Re-Primarization in Latin America and the Caribbean, in: Ecological Economics 134 (2017), 150–159.

11 Gastón Caligaris, Los Países Productores de Materias Primas en la Unidad Mundial de la Acumulación de Capital: Un Enfoque Alternativo, in: Cuadernos de Economía Crítica 3/6 (2017), 15–43; Clara Craviotti, Which Territorial Embeddedness? Territorial Relationships of Recently Internationalized Firms of the Soybean Chain, in: The Journal of Peasant Studies 43/2 (2016), 331–347; José Muzlera/Rocío Pérez-Gañán, The Legacy of Megapools and Chacareras in the Pampa Húmeda of Argentina (2010–2015), in: Perfiles Latinoamericanos 30/60 (2022), 1–26; Leguizamón et al., Environmental Potential.

12 Baraibar Norberg, Political Economy; Matilda Baraibar Norberg/Lisa Deutsch, The Soybean through World History: Lessons for Sustainable Agrofood Systems, New York 2023, DOI: 10.4324/9780367822866; Mariano Turzi, The Political Economy of Agricultural Booms: Managing Soybean Production in Argentina, Brazil, and Paraguay, Cham 2017.

Ecological and agronomic research has extensively analysed the impacts of agricultural intensification on ecosystems in Argentina and Uruguay. Studies have examined how the shift from mixed farming systems for continuous cropping (primarily soybeans) has led to increased agrochemical use, soil degradation, and biodiversity loss.[13] In Uruguay, soil erosion and declining productivity have emerged as prominent concerns.[14] The simplification of crop rotations has also reduced resilience against environmental and economic variability.[15] In Argentina, the expansion of soy production beyond the Pampas has driven deforestation and carbon emissions, with far-reaching impacts on regional ecosystems.[16]

Technological adoption studies, particularly in Argentina, have analyzed levels of mechanization, input use, and process technologies across production regions.[17] In Uruguay, research has often assumed uniform input use, though recent studies have begun to differentiate practices by soil type and crop rotation.[18] Some new modeling approaches integrate multiple decision-making variables such as farmer preferences, technology levels, yields, and natural resources, aiming to optimize both economic and environmental outcomes.[19]

Despite the breadth of research on *sojización*, significant gaps remain. The different strands of literature – whether social, economic, or ecological – are largely disconnected and lack a cohesive framework that examines the systemic dynamics at play. Most studies focus on individual components without exploring the interdependencies between technological transformations, social structures, and ecological impacts.

This research seeks to bridge these gaps by adopting a holistic, interdisciplinary approach based on an integrated theoretical framework to examine how the dominant socio-technical

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13 Fernando Andrade et al., Los Desafíos de la Agricultura Argentina: Satisfacer las Futuras Demandas y Reducir el Impacto Ambiental, Buenos Aires 2017, 25; Alfredo Bruno, Plaguicidas Usados en el Cultivo de Soja: Evolución de su Uso y Estimación de su Impacto Ambiental, Río Negro 2007; Enrique Antonio Mejía, Five Decades of Soybean Agriculture: Soil Nitrogen Exports and Social Costs in the Argentine Pampas, 1970–2021, in: Da Silva/De Majo (eds.), The Age of the Soybean, 185–203; Pablo M. Demetrio et al., Effects of Pesticide Formulations and Active Ingredients on the Coelenterate Hydra Attenuata (Pallas, 1766), in: Bulletin of Environmental Contamination and Toxicology 88 (2012), 15–19.

14 Oswaldo Ernst et al., Depressed Attainable Wheat Yields Under Continuous Annual No-Till Agriculture Suggest Declining Soil Productivity, in: Field Crops Research 186 (2016), 107–116; Mario Pérez Bidegain et al., La Erosión de Suelos en Sistemas Agrícolas, in: Fernando García Préchac et al. (eds.), Intensificación Agrícola: Oportunidades y Amenazas para un País Productivo y Natural, Montevideo 2010, 67–89.

15 García Préchac et al., Intensificación.

16 Mitchell Aide et al., Deforestation and Reforestation of Latin America and the Caribbean (2001–2010), in: Biotropica 45/2 (2013), 262–271; Matthias Baumann et al., Land-Use Competition in the South American Chaco, in: Jörg Niewöhner et al. (eds.), Land Use Competition: Ecological, Economic, and Social Perspectives, Cham 2016, 215–229; Esteban Jobbágy et al., Impronta Ambiental de la Agricultura de Granos en Argentina: Revisando Desafíos Propios y Ajenos, in: Ciencia Hoy 29/173 (2021), 35–44.

17 Eugenio Cap/Paz González, La Adopción de Tecnología y la Optimización de su Gestión como Fuente de Crecimiento de la Economía Argentina, Buenos Aires 2004; Eugenio Cap et al., Perfil Tecnológico de la Producción Agropecuaria Argentina: Análisis Descriptivos y Prospectivos, Buenos Aires 1993.

18 Gonzalo de Rizzo/Oswaldo Ernst, Mapeando la Brecha de Rendimiento en Soja para Diferentes Zonas Climáticas y Grupos de Suelos, in: Cangué 41 (2018), 10–14.

19 Diego Ferraro/Rodrigo de Paula, A Fuzzy Knowledge-Based Model for Assessing Risk of Pesticides into the Air in Cropping Systems, in: Science of the Total Environment 820 (2022), 153–158; Felipe Ghersa et al., AgrOptim: A Novel Multi-Objective Simulation Optimization Framework for Extensive Cropping Systems, in: Computers and Electronics in Agriculture 224 (2024), 109–119; Sebastián Pessah et al., An Integrated Ecological-Social Simulation Model of Farmer Decisions and Cropping System Performance in the Rolling Pampa, in: Journal of Artificial Societies and Social Simulation 25/1 (2022), 1–34.

regime of HT soybeans has emerged and evolved in Argentina and Uruguay using a cross-cutting (global to local) analysis. By combining insights from the natural and social sciences, we explore the dual forces of homogenization and heterogenization in these agricultural systems in detail.

Research design, theoretical frameworks and methods

This study examines soybean farming in Argentina and Uruguay through the lens of processes of homogenization/heterogenization. It investigates whether the widespread adoption of HT soy (since 1996 in Argentina and 2003 in Uruguay) has merely reinforced uniformity or whether countervailing forces have also emerged over time.

Drawing on systems thinking and socio-technical transitions theory, the study conceptualizes HT soy not as a discrete technological breakthrough but instead as being embedded within a broader socio-technical regime. This regime is shaped and stabilized through the alignment of multiple factors including global market demand, institutional and technological infrastructures, actor coalitions, and historical legacies.

Systems thinking offers a conceptual approach for analysing agriculture as a dynamic, non-linear, and interconnected system. Central concepts in this tradition such as feedback loops, system boundaries, and leverage points guide the study's analysis of how interventions and pressures reverberate across coupled social and ecological structures.[20] Systems thinking also draws attention to emergent properties, thresholds, and delayed effects, which are critical for assessing the resilience and potential fragility of agro-industrial regimes.

In this study, feedback loops refer to the recurring interactions among social, ecological, and technological components that either reinforce or counteract the dominant HT soy regime. Some feedbacks are stabilizing (e.g., the co-evolution of glyphosate-tolerant varieties and mechanized equipment), while others introduce friction or resistance (e.g., herbicide resistance, soil degradation or sociopolitical contestation). Although we do not model these loops visually, the terminology of reinforcing and balancing dynamics is used descriptively to trace how system behaviour evolves over time. Particular attention is paid to ecological thresholds and feedbacks that may signal or precipitate systemic shifts, especially when accumulated pressures challenge the regime's internal coherence and external legitimacy.[21]

This study also builds on socio-technical transitions theory, with particular focus on the multi-level perspective developed by Frank Geels.[22] This framework conceptualizes systemic change as emerging from interactions across three analytical levels:

- Landscape (macro-level): Broad, external forces and long-term trends such as climate change, global trade dynamics, or geopolitical realignments;
- Regime (meso-level): Stabilized configurations of technology, practice, institutions, and actor networks that reproduce dominant systems;

20 Diana Wright/Donella H. Meadows, Thinking in Systems: A Primer, London 2012.

21 Carl Folke et al., Building Resilience and Adaptive Capacity in Social-Ecological Systems, in: Fikret Berkes et al. (eds.), Navigating Social-Ecological Systems, Cambridge 2003, 352–387.

22 Frank W. Geels, Technological Transitions as Evolutionary Reconfiguration Processes. A Multi-Level Perspective and a Case Study, in: Research Policy 31/9 (2002), 1257–1274.

- Niches (micro-level): Spaces in which alternative practices and innovations can be tested, nurtured, and potentially upscaled.

This provides a structured lens through which to examine both the emergence, rise, and consolidation of HT soy as a dominant regime and its subsequent contestation. In the context of Argentina and Uruguay, the study maps landscape-level pressures (e.g., international regulations, market shifts, and climate variability), regime-level dynamics (e.g., technological lock-ins, agronomic limits, and institutional support), and emerging niches (e.g., agroecological or low-input farming initiatives). These are interpreted not as isolated developments but as interacting processes across scales that jointly shape the trajectory of soybean agriculture.[23]

By combining systems thinking with socio-technical transitions theory, this research enables an integrated, cross-scalar analysis of how homogenizing forces such as monoculture expansion, input standardization, and market integration can become challenged by heterogenizing dynamics including ecological feedbacks that demand innovation and differentiation. This dual perspective also highlights that transitions in agricultural systems are often non-linear, contested, and reversible, shaped by both material and discursive power.

Methods and empirical material

This study is based on a multi-method qualitative research design combining two complementary sets of interviews with secondary sources, thus enabling a cross-scale, multi-actor analysis of soybean production systems in Argentina and Uruguay.

The core empirical material consists of 15 semi-structured expert interviews conducted between January and October 2024, complemented by a second set of 33 face-to-face interviews carried out between 2008 and 2020, which provide historical and contextual depth. The interviews targeted a broad range of stakeholders involved in monitoring, managing, and researching soybean systems. Many respondents held multiple roles related to soybean production in Argentina and Uruguay, but they were selected to represent three broad domains of expertise:

1. Academic researchers: This group includes scholars in agrarian ecology, soil science, crop physiology, and environmental governance, affiliated with leading research institutions such as the Faculty of Agronomy at the University of Buenos Aires (FAUBA), the Institute for Physiological and Ecological Research Related to Agriculture (IFEVA), the National Scientific and Technical Research Council (CONICET), the National Institute of Agricultural Technology (INTA), the Faculty of Agronomy of the University of the Republic (FAGRO-UDELAR), and the National Institute of Agricultural Research (INIA). In addition to their research on agronomic processes, ecological dynamics, and sustainability challenges in soybean systems, several have also served as consultants or advisors to producers, bridging academic and practical domains.
2. Technical field experts and agribusiness practitioners: This category comprises private consultants, extensionists, production managers, and technical directors working in commercial agriculture across Argentina and Uruguay. Their expertise lies in the daily manage-

23 Geels, Technological Transitions.

ment of soybean cultivation, pest control, and soil conservation, as well as in implementing precision and input-intensive technologies. Through their practical engagement with producers and firms, they provide grounded perspectives on technological adoption and production strategies.
3. Public sector and policy specialists: This group includes officials and advisors from key governmental institutions such as Uruguay's Ministry of Livestock, Agriculture and Fisheries (MGAP), the Ministry of Housing, Territorial Planning and Environment (MVOTMA), and Argentina's Secretariat of Agriculture, Livestock, Fisheries and Food (SAGPyA), as well as international organizations such as the Inter-American Institute for Cooperation on Agriculture (IICA) and the Food and Agriculture Organization of the United Nations (FAO). These experts design, implement and monitor policies related to land use, soil and water conservation, and territorial planning.

The interviews focused on recent transitions in HT soy systems, emerging challenges (e.g., resistance, soil degradation), and potential pathways for transformation. Interviewees were contacted through professional networks, provided with detailed information about the study, and gave informed consent. All interviews were recorded, transcribed, and thematically coded, focusing on actors' perspectives on technological change, ecological pressures, institutional dynamics, and governance. Together, these materials provide a rich understanding of the emergence and stabilization of the HT soy regime, as well as its tensions and challenges. Full details on the interviewees and dates are provided in the appendix.

The interview data are complemented by a diverse set of written materials, including official agricultural and environmental statistics, policy and regulatory documents, agricultural press and corporate communications, and reports from multilateral and national institutions, as well as international market studies on soy and agrochemical inputs. The triangulation of interview data with documentary and statistical sources enables a multi-layered and cross-scalar analysis of soybean production dynamics. It allows for the integration of both structural and institutional trends with grounded, actor-specific experiences and interpretations. This approach supports the study's overarching aim of understanding how agro-industrial systems are stabilized, challenged, and potentially transformed over time through the interaction of ecological, technological, and political-economic forces.

Forging *sojización*: Historical precedents, emergence and stabilization

The rise of HT soy has played a pivotal role in transforming agricultural landscapes across South America. Its rapid adoption brought about a profound simplification of farming systems, standardizing and homogenizing agriculture. This section examines the broader socio-technical regime of HT soy within a longer historical trend of technology-driven agricultural homogenization. It also explores the global-to-national policy and market changes that facilitated *sojización*, as well as how these shifts in production practices and social relations further accelerated the uniformity of agriculture. By linking historical trajectories, policy environments, and the reconfiguration of social relations, we will trace how HT soy emerged and became stabilized as a dominant regime.

HT soy situated in the long historical trend of technology-driven homogenization

Agriculture inherently involves a degree of ecological simplification, and the expansion of farming significantly affects biodiversity as well as carbon, nitrogen, and hydrological cycles.[24] However, considerable variation exists between small-scale, diverse farming systems and large-scale, uniform ones.[25] In South America, colonialism marked a major shift from the diverse agricultural practices of indigenous communities to more standardized systems. This transition reduced agricultural biodiversity and made the region's economy heavily dependent on a narrow range of commodities.[26]

Agricultural homogenization accelerated during the first wave of globalization (1860–1914), as technological innovations and infrastructure investments lowered transportation costs and facilitated the specialization and globalization of agricultural production and trade.[27] South America became a key agro-food supplier to industrial centres, particularly Great Britain.[28] The construction of railways and ports enabled the export of cash crops and deepened the region's integration into global markets, reinforcing uniformity. Argentina and Uruguay exported vast quantities of meat and wool, while Argentina also shipped wheat, corn, and other grains from its breadbasket region, La Pampa Húmeda.[29]

Technological innovations including chemical fertilizers, pesticides, and mechanization spread gradually – albeit unevenly – across the region, enabling large-scale, standardized farming. The Green Revolution of the mid-twentieth century intensified these trends by promoting high-yield crop varieties tailored for industrial agriculture, further reducing crop diversity. Monoculture, the large-scale cultivation of a single crop over consecutive seasons, became more widespread, maximizing machinery efficiency and economies of scale while reducing biodiversity and local crop varieties. Though Argentina and Uruguay adopted Green

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24 Morufu Olalekan Raimi et al., Exploring How Human Activities Disturb the Balance of Biogeochemical Cycles: Evidence from the Carbon, Nitrogen and Hydrologic Cycles (30 July 2021), available at SSRN, DOI: 10.2139/ssrn.3896054.

25 Natalia Estrada-Carmona et al., Complex Agricultural Landscapes Host More Biodiversity than Simple Ones: A Global Meta-Analysis, in: Proceedings of the National Academy of Sciences 119/38 (2022), e2203385119, https://pubmed.ncbi.nlm.nih.gov/36095174/ (31 July 2025).

26 Carlos Assadourian et al., Agriculture and Land Tenure, in: Victor Bulmer-Thomas et al. (eds.), The Cambridge Economic History of Latin America, Cambridge 2005, 75–314; Victor Bulmer-Thomas, The Economic History of Latin America Since Independence, New York 2014, 87–125.

27 Federico Givoanni, Feeding the World: An Economic History of Agriculture, 1800–2000, Princeton 2010, 85.

28 Luis Bértola/José Antonio Ocampo, The Economic Development of Latin America since Independence, Oxford 2012; Luis Bértola/José Antonio Ocampo, Latin American Economic History in the Light of the Recent Economic Cycles, in: Felipe Valencia Caicedo (ed.), Roots of Underdevelopment: A New Economic and Political History of Latin America and the Caribbean, Cham 2023, 33–67.

29 Vicente Pinilla/Agustina Rayes, How Argentina Became a Super-Exporter of Agricultural and Food Products During the First Globalisation (1880–1929), in: Cliometrica 13/3 (2019), 443–469; Bulmer-Thomas, Economic History, 87–125. La Pampa Húmeda is a vast, fertile plain covering central-eastern Argentina, including parts of Buenos Aires, Santa Fe, Córdoba, and Entre Ríos provinces.

Revolution technologies more slowly than some other regions, in part due to capital constraints and conservative producer attitudes, those who invested in these inputs transitioned toward more uniform, large-scale farming.[30] This transformation concentrated land ownership, marginalized small-scale farmers, and eroded traditional practices and crop diversity.

During the Green Revolution era, soybeans began to gain ground in Argentina, initially being used in mixed systems as a rotational crop to improve soil fertility and diversify production. Soy cultivation was modest in 1970 at only 25,000 hectares (ha) but grew rapidly to over 2 Mha in 1980. This expansion was driven by local seed adaptation efforts alongside rising global demand for vegetable oils and animal feed. Yet the dominance of soy was still limited by high input costs and scarce herbicide options, which made weed control labour-intensive and expensive.

Uruguay likewise saw growth in soybean cultivation after the 1970s, peaking in 1987–89 due to a bilateral trade agreement with Taiwan. However, low yields meant soy was mainly used as a rotational crop to enhance pastures within mixed farming systems.[31] By the 1990s, soybean growing had nearly vanished in Uruguay, and the leading public research organization dedicated to innovation and development in agriculture, INIA, discontinued its soybean research program due to minimal national production.[32]

While soybean cultivation in Argentina was already expanding, the major transformation known as *sojización* did not occur until the 'gene revolution', when Argentina became one of the first countries to approve Monsanto's RR soybeans. Within a few years, this HT variety almost completely replaced conventional soybeans, and Argentina emerged as a global leader in no-till farming, with these technologies adopted in 95 per cent of its grain and oilseed production.[33]

As this section has shown, the homogenization of agriculture in Latin America is a long-term process that began with colonialism. Yet the technological package of HT soy, glyphosate, and no-tillage farming represented a significant acceleration of this trend. New technologies do not emerge in a vacuum, however, nor do they arrive in isolation. Historical legacies such as highly concentrated land ownership, powerful domestic agricultural lobbies, and export-oriented infrastructure aligned seamlessly with large-scale HT soy production.[34] In addition, the neoliberal reforms of the late twentieth century, both globally and nationally, created favourable conditions for the expansion of *sojización*, as we will now explore.

Changes in markets and policies paving the way for sojización

The policy and market shifts that enabled the expansion of soy farming in Argentina and Uruguay from the 1970s to the late 1990s were rooted in broader global transformations. After

30 Baraibar Norberg, Political Economy.

31 Matilda Baraibar, Green Deserts or New Opportunities? Competing and Complementary Views on the Soybean Expansion in Uruguay, 2002–2013, doctoral thesis, Stockholm University 2014.

32 Interview no. 6 (Research Director; specialist in crop ecophysiology, soil management, and simulation models, INIA, Uruguay; adjunct professor, FAGRO-UDELAR), 12 August 2024.

33 Baraibar Norberg, Political Economy; OECD, Agricultural Policies in Argentina, in: OECD Food and Agricultural Reviews, Paris 2019, DOI: 10.1787/9789264311695-en.

34 Baraibar Norberg, Political Economy.

the collapse of the Bretton Woods system in 1973, the global governance of food production began moving away from the nationally oriented, state-led developmentalist model that had defined the post-war era of embedded liberalism. In its place emerged a more corporate-driven, globally integrated market system. During this period, South America underwent a profound transformation. Import substitution industrialization strategies were increasingly seen as unsuccessful, and the debt crisis of the 1980s prompted international financial institutions to demand austerity, liberalization, privatization, and deregulation as conditions for debt relief. In response to these pressures and their own economic crises, Argentina and Uruguay adopted neoliberal reforms, promoting export-oriented agriculture in line with the logic of comparative advantage.[35]

Under President Carlos Menem (1989–1999), Argentina fully embraced Washington Consensus reforms including the liberalization and privatization of state-owned enterprises, the Convertibility Plan that pegged the peso to the US dollar, and measures to attract foreign investment. Key agricultural reforms included dismantling the Junta Nacional de Granos, which had controlled grain and oilseed exports, and eliminating export taxes on most grains – though a reduced rate of 3.5 per cent was retained for soybeans and sunflowers. Uruguay likewise adopted neoliberal reforms, though more cautiously, with popular referendums blocking several privatization efforts. Both countries reduced tariffs on imported agricultural machinery and inputs, cut back on farmer support programs, and liberalized land markets, indirectly promoting the growth of large-scale, industrialized farming.[36]

At the same time, multinational agribusiness corporations (including Cargill, Archer Daniels Midland [ADM], Bunge, and Louis Dreyfus Commodities [LDC]) became increasingly vertically integrated through mergers and acquisitions, consolidating control over global commodity supply chains.[37] These firms invested heavily in infrastructure such as grain storage and port facilities, reinforcing South America's role as a key supplier in the global grain trade. International markets favour consistency and high volumes, incentivizing farmers and agribusinesses to produce standardized crops tailored to buyers' specifications. Moreover, the high cost of idle shipping time in ports pushes traders to cooperate by sourcing and blending grain from multiple suppliers to load ships quickly.[38] This highly efficient system leads to the grain losing traceability to its place of origin, eliminating any reward for superior quality and further reducing varietal and geographical differentiation.

Another key development was the rise of agrochemical giants like Monsanto, BASF, Bayer and DuPont, which moved into biotechnology during the 1980s and 1990s. These firms acquired or partnered with seed companies to develop proprietary technologies bundled into complete input packages (standardized seeds, fertilizers, and pesticides) that facilitated homogenization. This expansion was supported by the growing strength of global intellectual property regimes. Reforms to the International Union for the Protection of New Varieties of Plants (UPOV) in 1991 enhanced breeders' rights and curtailed farmers' ability to save seeds.

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35 Interview no. 20 (Director of Social Studies, Institute of Social Studies, INTA; former coordinator, 2013 National Census of Agricultural Producers; former researcher, Ministry of Economy, Argentina), 2 March 2017.

36 Baraibar Norberg, Political Economy, 170–177.

37 Jennifer Clapp, Titans of Industrial Agriculture: How a Few Giant Corporations Came to Dominate the Farm Sector and Why It Matters, Cambridge 2025.

38 Interview no. 30 (Traders; commercial agents from major trading companies involved in soy and grain trade, Port of Nueva Palmira, Uruguay), 11 March 2017.

These changes informed the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization, which requires signatory countries to protect plant varieties through patents, sui generis systems, or both.[39]

The dominant role of a few giant agribusiness firms in the 'gene revolution' marked a clear departure from the earlier Green Revolution, where the public sector played a central role. It promotes even more large-scale, standardized production systems aimed at maximizing yields and protein content while minimizing labour costs.

The convergence of these technological innovations, corporate strategies, and liberalization policies laid the foundation for the rapid spread of soy cultivation in South America. The result was a highly efficient but increasingly homogenized socio-technical regime centred on HT soy. The dynamics of this model will now be examined in the cases of Argentina and, subsequently, Uruguay.

Effects of sojización *on production practices and social relations*

Argentina experienced one of the fastest and most extensive adoptions of HT soy in the world. Within just a few years of its introduction in 1996, over 90 per cent of soybeans planted in the country were of the glyphosate-tolerant variety known as RR soy. Several factors facilitated this rapid spread. One key driver was the coordinated effort of actors promoting its integration with no-till farming and glyphosate use.[40] This alliance drew strength from Argentina's well-developed network of public and private agricultural institutions as well as influential producer organizations, most notably the Argentine Association of Zero-Tillage Farmers (AAPRESID), the Argentine Association of Regional Agricultural Experimentation Consortia (AACREA), and Argentina's main public agricultural research body INTA.

AAPRESID, founded in 1989 by farmers and agronomists concerned about soil degradation from conventional tillage, became a leading advocate of no-till farming. With the arrival of HT soy and glyphosate in the mid-1990s, the organization embraced the new package as a way to boost productivity while preserving soil health. It facilitated field trials, training, farmer networks, and partnerships with seed companies and agronomists, serving as a key link between research and practice.[41] AACREA, established in the 1960s, supported the model through its regional producer-consultant groups. Known for on-farm experimentation, AACREA tested and refined RR soy varieties across diverse environments, monitored input use and yields, and produced practical, site-specific data to guide adoption. This helped to legitimize and tailor the model to local conditions.[42] INTA further advanced the diffusion of HT soy and no-till systems through applied research and technical support. INTA worked

39 Clapp, Titans, 211–218.

40 Rocío Ceverio et al., Obtentores de Semillas, Agricultores y Estado: El Conflicto por los Derechos de Propiedad Intelectual en Argentina, in: Cadernos de Ciência & Tecnologia 1/3 (2008), 9–35.

41 Interview no. 3 (Researcher; extensionist and consultant; professor of ecology of agrarian systems, IFEVA, FAUBA, CONICET, Argentina; FAGRO-UDELAR, Uruguay), 20 May 2024.

42 Eduardo Trigo et al., The Case of Zero-Tillage Technology in Argentina, IFPRI Discussion Papers 915, International Food Policy Research Institute, 2009, https://cgspace.cgiar.org/server/api/core/bitstreams/ee9f9cc6-11cf-49b3-8ae9-b51074e42f0f/content (31 July 2025); María Soledad Córdoba et al., Agronegocios y Hegemonía: Estrategias para la Producción de Consenso Social Ampliado, in: Población y Sociedad 30/2 (2023), 121–149.

closely with machinery manufacturers to adapt no-till equipment, assessed varietal performance, and framed the technological package as both agronomically sound and environmentally beneficial.[43] Together, these organizations aligned technical, institutional, and discursive support behind the HT soy model.[44] By promoting soil conservation, efficiency, and competitiveness, they helped to normalize a profound transformation of Argentine agriculture, establishing a new socio-technical regime centred on HT soy, glyphosate, and no-till farming.

A further crucial factor was the absence of a valid Monsanto patent on the RR gene in Argentina. This allowed local seed companies licensed by Monsanto to sell RR seeds without enforcing royalty payments. Farmers were able to save and replant seeds, a legally protected practice under Argentina's 1973 seed law. As a result, Argentine producers faced significantly lower seed costs than their counterparts in countries with stricter intellectual property regimes, accelerating adoption. Monsanto initially tolerated this arrangement, pursuing a "seed now, pay later" strategy to encourage diffusion and build future market dominance.[45] However, once adoption was widespread, Monsanto shifted strategy and began seeking royalty payments. These efforts were met with strong resistance from farmers and the Argentine government. Although Argentina was a signatory to UPOV and TRIPS, its national legislation explicitly upheld the farmers' privilege, i.e. the right to save and reuse seed.[46]

Beyond business strategies and institutional arrangements, the core driver of the rapid adoption of HT soy was its practical effectiveness. The combination of RR soy and glyphosate offered farmers a simple, reliable, and inexpensive solution for weed control, eliminating the need for labour-intensive tilling and repeated herbicide applications. A single glyphosate spray could replace complex weed management routines, significantly reducing costs especially in large-scale monoculture systems.[47] Moreover, the effectiveness of glyphosate made tilling unnecessary and spurred the adoption of no-till farming, lowering fuel and machinery expenses while minimizing soil disturbance. This helped prevent erosion, retain soil moisture, and preserve organic matter and microbial life. Together, these factors enabled soybean cultivation to expand into areas previously considered marginal or unsuitable for mechanized farming, including forests and shrublands. In this way, soy farming expanded from central Argentina into natural or semi-natural ecosystems in the north of the country.[48] Between 1990 and 2015, Argentina lost 22 per cent of its forests, largely due to agricultural expansion driven by soy.[49] At the same time, crop production in Argentina's breadbasket region, la

43 Trigo et al., Case.

44 Interview no. 18 (Director of Agricultural Affairs, CARI; advisor to the Director-General of FAO on strategic planning; former Vice Minister of Agricultural Economy; former Director General, IICA; former President of the Board, IFPRI), 1 March 2017; interview no. 20.

45 Trigo et al., Case.

46 Eduardo J. Trigo, Veinte Años de Cultivos Genéticamente Modificados en la Agricultura Argentina, [Buenos Aires] 2016, 1–43, https://www.fiba.org.ar/wp-content/uploads/2016/12/informe20gm.pdf (14 July 2025); interview no. 19 (Former Secretary of Agriculture, Livestock and Fisheries, MAGyP; director, CICPES, INTA; former president, INTeA S.A.), 2 March 2017.

47 Interview no. 1 (Researcher, specialist in agrarian ecology, FAUBA, CONICET, Argentina), 3 May 2024; interview no. 2 (Researcher, specialist in management practices in agro-food systems, FAUBA, Argentina), 21 February 2024.

48 Di Mauro et al., Transformations; Trigo, Veinte, 12.

49 Néstor Gasparri/Yann Le Polain de Waroux, The Coupling of South American Soybean and Cattle Production Frontiers: New Challenges for Conservation Policy and Land Change Science, in: Conservation Letters 8/4

Pampa Húmeda, intensified. Traditional rotation systems that included pastures were displaced by simplified schemes such as double cropping (typically soy and wheat) or even continuous soybean cultivation.[50]

Counterintuitively, Argentina's devastating 2001–2002 crisis ultimately benefited its soybean sector as well. In January 2002, the government converted dollar-denominated debts into pesos at a 1:1 rate. Soon after, the peso sharply depreciated, losing about two-thirds of its value by mid-year and stabilizing around 3 pesos per dollar.[51] Many soy producers held significant debts incurred during the era of peso–dollar parity. Once converted to pesos, these debts were drastically reduced in real terms. At the same time, soybean exports (priced in dollars) generated far greater revenues in local currency. This combination of reduced liabilities and soaring income resulted in a substantial windfall for producers. The peso devaluation also enhanced Argentina's overall export competitiveness, positioning soy as a critical source of foreign exchange in the country's economic recovery. Together, these factors intensified the expansion of the soybean sector during the early 2000s.

Around 2002–2003, HT soy began to expand rapidly in Uruguay as well, largely driven by Argentine producers and firms who brought with them technologies, capital, and production practices.[52] A key push factor was the reintroduction of export taxes (*retenciones*) on agricultural products by the Argentine government to address fiscal deficits following the 2001–2002 crisis. Combined with the pull factor of lower land prices and the absence of export taxes in Uruguay, this encouraged Argentine farmers and agribusinesses to spread both their geographical and political risk by expanding across the border.[53] The previously mentioned deregulation of land markets played a crucial role in enabling these firms to rapidly scale and replicate their model elsewhere. While yields in Uruguay were typically lower due to more erosive soils, the adoption of the new technological package centred on HT soy helped reduce the yield gap.[54]

Following this initial, largely foreign-led and 'spontaneous' phase of expansion, domestic actors also began to play an important role in the rapid growth of soybean cultivation in Uruguay. INIA reactivated its soybean breeding program (which had been suspended between 1999 and 2003 due to limited farmer interest) to adapt herbicide-tolerant varieties

(2015), 290–298; Néstor Gasparri et al., Linkages Between Soybean and Neotropical Deforestation: Coupling and Transient Decoupling Dynamics in a Multi-Decadal Analysis, in: Global Environmental Change 23/6 (2013), 1605–1614; Ricardo Grau et al., Agriculture Expansion and Deforestation in Seasonally Dry Forests of North-West Argentina, in: Environmental Conservation 32/2 (2005), 140–148; OECD, Agricultural Policies, 144.

50 Roberto Álvarez et al., Cambios en los Niveles de Fósforo Extraíble de los Suelos Pampeanos por el Uso, in: Carmen Cholaky/José Cisneros (eds.), Actas XXV Congreso Argentino de la Ciencia del Suelo, Río Cuarto 2016, 175–189.

51 Sumit Agarwal et al., The Impact of the 2001 Financial Crisis and the Economic Policy Responses on the Argentine Mortgage Market, in: Journal of Housing Economics 14/3 (2005), 242–270.

52 Baraibar, Green Deserts; Baraibar Norberg, Political Economy.

53 Interview no. 24 (Chief Executive Officer, El Tejar Uruguay; President, MTO; agronomist and consultant), 23 February 2008; interview no. 25 (Chief of Sales, Agronegocios del Plata, Uruguay), 13 February 2008.

54 Interview no. 41 (Director, OPYPA, MGAP; former tax specialist; agronomist, Uruguay), 8 March 2017; interview no. 31 (President, National Institute of Seeds; agronomist; politician, Socialist Party, Frente Amplio, Uruguay), 6 March 2010.

to local conditions and support technological packages such as no-till and crop rotations.[55] These efforts were complemented by new public–private initiatives, such as the Oilseeds Technological Board (MTO), which strengthened the institutional framework for soybean production. As a result, soybean area expanded from 27,600 ha in 2000/01 to 1.33 Mha in 2014/15. Although average yields (2.1 t/ha in 2001–2016) remained lower than in Argentina or Brazil, total production surged due to the vast increase in cultivated area.[56]

This growth was part of broader land-use changes. Over 3.5 Mha of native grasslands were converted to cropping systems, and Uruguay's annually cultivated area grew from 0.4 to 2 Mha within a decade, with soy and wheat accounting for approximately 50 and 25 per cent respectively.[57] The expansion was accompanied by rapid agricultural intensification: Double cropping became widespread, crop rotations were shortened, and agrochemical use surged. Between 2000 and 2023, Uruguay's total pesticide imports more than quadrupled, rising from 10,540 tons to 46,100 tons. During the same period, pesticide use per hectare of cropland increased from 2.58 kg in 2000 to 7.35 kg in 2023.[58] Herbicides accounted for about 89 per cent of this increase, largely due to rising glyphosate use.[59]

A key organizational innovation on the cultivation side was the emergence of a new type of agricultural firm: the *pools de siembra* (sowing pools). These entities aggregated capital from new financial actors such as pension funds and institutional investors and operated primarily on leased land. Originating in the Argentine Pampas, they soon expanded into frontier areas like the Chaco and across borders into Uruguay, Paraguay, and Bolivia. Geographic diversification became a central strategy for managing climatic, market, and political risks.[60] As a result, HT soy in both Argentina and Uruguay came to be predominantly cultivated by large firms operating on leased land.

This marked a sharp departure from traditional arrangements, where large landowners (often cattle ranchers) leased plots to tenant farmers.[61] As land values rose, many traditional tenants and sharecroppers were priced out, with farmland increasingly leased by corporate operators under short-term contracts requiring upfront payment.[62] Not only land but also core production inputs, i.e. machinery, seeds, and labour, were increasingly leased or out-

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55 Interview no. 35 (Director, Programme for Production and Environmental Sustainability, INIA; researcher and lecturer, FAGRO-UDELAR; board member, ISTRO, Uruguay), 3 March 2017.

56 Bruno Lanfranco et al., En la Búsqueda de los Límites de la Intensificación Sostenible de la Agricultura, in: Revista INIA 77 (2024), 32–36.

57 Ingrid Tejada, Soy in Uruguay from 1961–2016: How the Adoption of Soy Has Influenced Agricultural Production Systems and Land-Use, doctoral dissertation, Flinders University, Adelaide 2019.

58 FAO Annual Analytical Brief: FAO. 2025. Pesticides Use and Trade, 1990–2023. FAOSTAT Analytical Briefs, No. 109. Rome, DOI: 10.4060/cd5968en; FAOSTAT, Pesticides Trade, https://www.fao.org/faostat/en/#data/RT (23 October 2025); FAOSTAT, Pesticides Use, https://www.fao.org/faostat/en/#data/RP (23 October 2025).

59 Cintia Palladino et al., Pesticide Dependence and Associated Risks in Uruguayan Agriculture: Limitations in Its Approach, in: Agrociencia Uruguay 27/1156 (2023), 3–4, DOI: /10.31285/AGRO.27.1156.

60 Interview no. 26 (President, Rural Federation; veterinarian, rancher and landowner; lecturer, FAGRO-UDELAR, Uruguay), 3 March 2009; interview no. 24; interview no. 25.

61 José Barrán/Benjamín Nahum, Uruguayan Rural History, in: Hispanic American Historical Review 64/4 (1984), 655–673; James Scobie, Revolution on the Pampas: A Social History of Argentine Wheat, 1860–1910, Austin 1964.

62 Clara Craviotti/Carla Gras, De Desafiliaciones y Desligamientos: Trayectorias de Productores Familiares Expulsados de la Agricultura Pampeana, in: Desarrollo Económico (2006), 117–134; José Manuel Deninotti, Caracterización de los Cededores de Tierra "Rentistas" en los Partidos de Pergamino y Junín, y sus Relaciones

sourced, giving rise to a model of asset-light farming.[63] In this way, *pools de siembra* and other agribusiness actors operated with minimal in-house labour or fixed capital, outsourcing core tasks like planting, spraying, harvesting, and hauling to *contratistas* (contractors). Many of these contractors were former farmers who had lost access to land due to the rising lease prices.[64] By investing in machinery, they began offering services to larger operators, reinforcing a model of highly mechanized and subcontracted farming.[65] This system shifted decision-making power away from farmers and toward input suppliers, agronomists, technical advisors, contractors, and grain traders. Input providers played a central role by offering integrated service packages that included seeds, agrochemicals, technical advice, and financing.[66] Networks of innovation and information linking producers, input suppliers, research institutes, and firms facilitated knowledge transfer and institutionalized the new regime. These networks, often overlapping across the Argentina–Uruguay border, were consistently cited by interviewed actors as a key driver of homogenization. This shift consolidated a production model in both countries based on economies of scale, standardized inputs, and uniform agronomic practices.[67]

Even as new intermediaries emerged, small and medium-sized farmers continued to disappear. In Uruguay, this was exacerbated by high debt levels among traditional farmers during 2002–2005, followed by a sharp rise in lease prices driven by the influx of Argentine producers (from an average of $28/ha in 2000 to $133/ha between 2011 and 2020).[68] Only soy could justify such high rents, creating a reinforcing feedback loop that further concentrated land and capital.[69] Some of the largest firms came to manage up to 100,000 ha, while many smaller producers either exited farming or leased their land to larger operations.[70]

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con la Agricultura Familiar, diploma thesis, Universidad Nacional del Noroeste de la Provincia de Buenos Aires, Pergamino 2020; Oyhantçabal Benelli et al., Who Rents Out the Land.

63 Christian Berndt et al., Postneoliberalism as Institutional Recalibration: Reading Polanyi Through Argentina's Soy Boom, in: Environment and Planning A: Economy and Space 52/1 (2020), 216–236, DOI: 10.1177/0308518X19825657; Pedro Arbeletche, El Agronegocio en Uruguay: Su Evolución y Estrategias Cambiantes en el Siglo XXI, in: Rivar 7/19 (2020), 109–129, DOI: 10.35588/rivar.v7i19.4355; Martine Guibert et al., De Argentina a Uruguay: Espacios y Actores en una Nueva Lógica de Producción Agrícola, in: Pampa: Revista Interuniversitaria de Estudios Territoriales 7 (2011), 13–38.

64 Baraibar, Green Deserts.

65 Valeria Hernández/José Muzlera, El Contratismo y su Integración al Modelo de Agronegocios: Producción y Servicios en la Región Pampeana, in: Mundo Agrario 17/34 (2016), 1–22; José Muzlera, Análisis de los Vínculos Familia-Empresa en los Contratistas de Maquinaria Agrícola Pampeanos, in: La Rivada 6 (2018), 152–166.

66 CASAFE, Industria de Fitosanitarios en Argentina, https://www.casafe.org/informe-industria-de-fitosanitarios-en-argentina/ (15 September 2024); interview no. 4 (Researcher; assistant professor, IFEVA, FAUBA; CONICET, Argentina), 3 September 2024; interview no. 12 (Production Manager, agribusiness firm, various provinces, Argentina), 2 August 2024.

67 Carla Gras/Valeria Hernández, Agribusiness and Large-Scale Farming: Capitalist Globalisation in Argentine Agriculture, in: Canadian Journal of Development Studies 35/3 (2014), 339–357; Carla Gras/Valeria Hernández, El Agro como Negocio, Buenos Aires 2023; interview no. 14 (Advisor; specialist in agricultural public policy, DINOT, MVOTMA, Uruguay), 17 June 2024.

68 DIEA, Anuario de Estadísticas Agropecuarias (2024), Oficina de Estadísticas Agropecuarias, Ministerio de Ganadería, Agricultura y Pesca, https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/diea/anuario2024 (18 September 2024).

69 Gastón Caligaris, Los Países; Clara Craviotti, Embeddedness; Muzlera/Pérez-Gañán, Legacy; Leguizamón et al., Environmental Potential.

70 Baraibar, Green Deserts.

The decline of traditional sharecroppers and the rise of dense, transnational networks of information and services contributed to a striking convergence in production methods. As one Uruguayan agronomist explained:

> "There really aren't any differences in practices or management among soybean farmers anymore. Everyone is well-informed and uses the same technological package centred around herbicide-tolerant seeds. Margins are tight, and competition is fierce – those who didn't get it right have been outcompeted and are no longer in the game. The farmers still in business are managing rather large extensions; they are highly professional, deeply connected to knowledge networks. The same agronomists work across the country, so the only real differences between places are those tied strictly to agroecological conditions."[71]

The homogenization of agricultural practices was further reinforced by downstream market demands. Soybeans from Argentina and Uruguay were (and still are) primarily exported by multinational grain traders – most notably ADM, Bunge, Cargill, LDC, and, since the 2010s, China's state-owned China National Cereals, Oils and Foodstuffs Corporation (COFCO) – who require standardized products for global feed and processing markets. Unlike food products with geographic branding (e.g., wine or coffee), soy for animal feed lacks place-based differentiation. This absence of consumer-facing quality distinctions favours uniformity, prioritizing consistency, protein content, and bulk efficiency over agroecological or varietal diversity.

China's growing demand played a decisive role in reinforcing these dynamics as well. As China liberalized its agricultural trade regime by lowering import tariffs, phasing out export subsidies, and opening key sectors in the wake of its accession to the World Trade Organization in 2001, it rapidly transitioned from a largely self-sufficient soybean producer into the world's largest importer.[72] By 2022, China imported 97 million metric tons of soybeans (around nine times the volume in 2000) and accounted for approximately 60 per cent of global soybean trade. Around 95 per cent of these imports were crushed into soymeal for animal feed, while domestic production remained focused on soy for direct human consumption (e.g., tofu, soy sauce, sprouts). This bifurcated demand structure reinforced the need for a highly standardized, high-protein feed crop with little market incentive for differentiation in taste, texture, or environmental origin, thus further entrenching homogeneity in the global soy supply chain.[73] Together, the mentioned overlapping market, technical, and institutional pressures drove farmers to reduce variability and adopt standardized production systems geared toward efficiency. Uniform inputs, agronomic practices, and managerial models generated economies of scale, favouring large-scale operations and further accelerating the spread of *sojización*.

71 Interview no. 15 (Public Official; technician in Soil Management and Conservation, RENARE, MGAP, Uruguay), 14 August 2024.

72 Baraibar Norberg/Deutsch, Soybean, 126–128.

73 Interview no. 3; interview no. 6.

Understanding HT soy as a socio-technical regime

The expansion and consolidation of HT soy in Argentina (from the late 1990s) and Uruguay (from the early 2000s) marked the emergence of a new socio-technical regime; a dominant configuration of technologies, practices, institutions, and actors that became increasingly stabilized and self-reinforcing. As illustrated in Figure 2, this regime came to revolve around three interlocking elements: HT soy, glyphosate use, and no-till farming.

At the *landscape level* (characterized by broad, exogenous trends), global shifts such as trade liberalization, strengthened intellectual property rights, and the rise of China as the world's dominant soybean importer created structural conditions that favoured this transformation. These trends were reinforced by strategies pursued by global agribusiness actors, including mergers and acquisitions, vertical integration, and the growing financialization of agriculture, all of which shaped the opportunity space for HT soy adoption across the Southern Cone.

The regional boom was further facilitated by preceding neoliberal reforms at both the international and national levels. These included the deregulation and flexibilization of land markets, the weakening of state support systems for smallholders, and the consolidation of agribusiness networks. Together, these developments helped create an institutional and political context highly conducive to the rise and stabilization of this new socio-technical system.

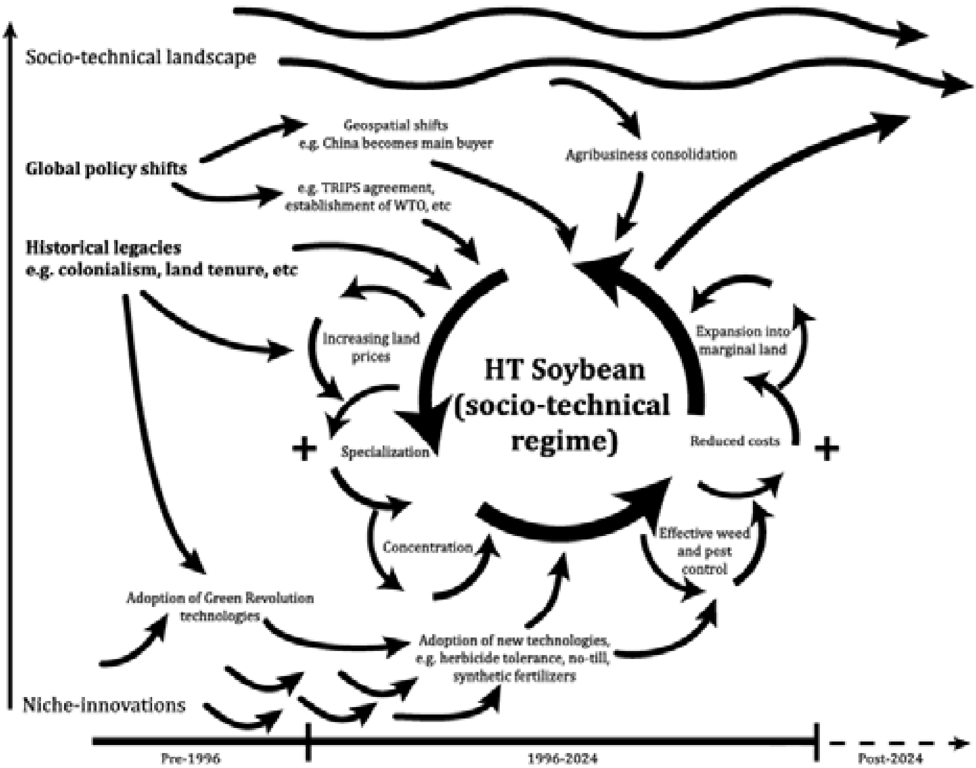
At the *regime level,* the HT soy system entrenched itself by offering farmers a simple and highly effective technological package. Glyphosate-based weed control drastically reduced labour and input costs, while the adoption of no-till farming enabled expansion into less fertile or marginal lands. The technical advantages of the system were low complexity, adaptability, and cost-effectiveness, making it particularly attractive for large-scale mechanized farming.

Thanks to strong global demand and high international prices (as shaped by *landscape level* forces), HT soy consistently offered higher profit margins than any alternative land use. These economic incentives contributed to rapidly rising land and lease prices, creating a powerful feedback loop: To remain competitive in an increasingly costly environment, many farmers and firms intensified their reliance on soy. This dynamic further accelerated the expansion of cultivation and promoted the homogenization of agricultural landscapes. Economies of scale favoured large operators, while growing demand for standardized soymeal from multinational grain traders and China's feed industry locked producers into uniform production systems with limited scope for diversification.

Historical legacies also played a significant role. Earlier processes of agricultural homogenization such as colonial frontier expansion, the Green Revolution, and the industrialization of agriculture had already produced highly concentrated land structures and powerful rural lobby groups. HT soy did not break with these trajectories but rather intensified them: Small and medium-sized producers were increasingly displaced, while larger actors cemented their dominance.

The consolidation of the regime was facilitated by multiple self-reinforcing mechanisms: standardized production practices encouraged by downstream actors (e.g., multinational traders and Chinese buyers), rising land prices, dense knowledge networks, and major investments in logistics and infrastructure. As shown in Figure 2, these feedback loops contributed to stabilizing the dominance of HT soy across diverse agroecological zones in both Argentina and Uruguay.

Figure 2: Representation of the HT soybean socio-technical regime and feedback mechanisms driving homogenization



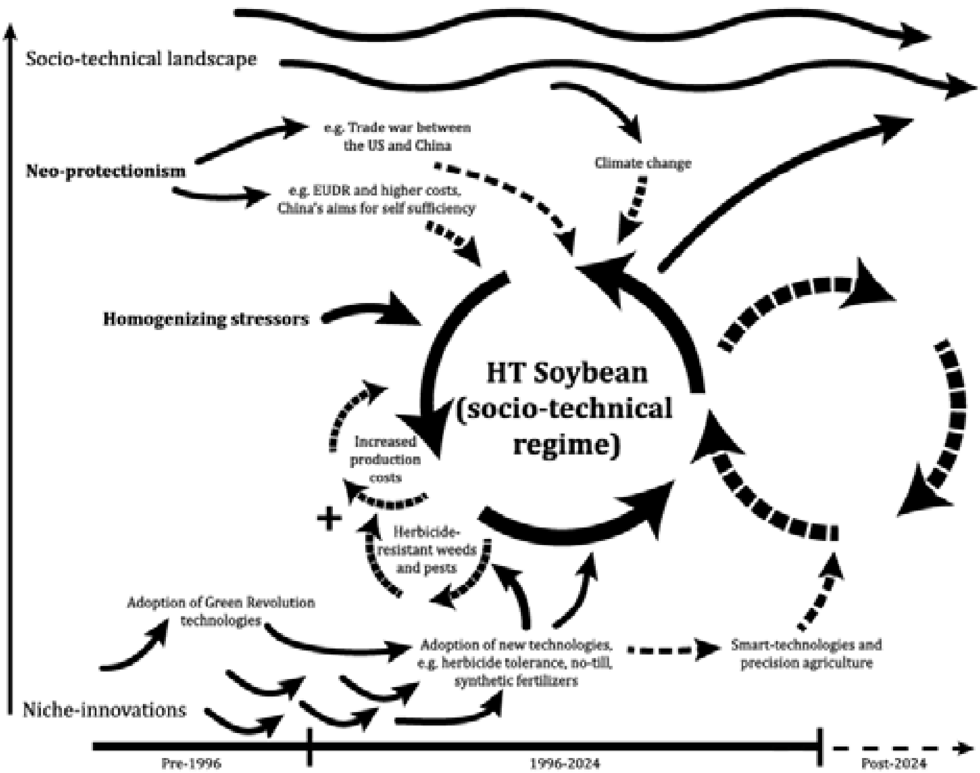
Source: Authors' illustration, following Geels, Technological Transitions.

Are social-ecological pressures pushing toward greater complexity?

Socio-technical regimes, however, are not immutable, for social-ecological systems are inherently dynamic. While the HT soy regime in Argentina and Uruguay achieved an extraordinary rate of expansion, transforming diverse agroecosystems into highly specialized monocultures managed through uniform practices, it now faces pressures from both above and below.

This section analyses the dynamic ecological and social feedback mechanisms and other pressures that emerged after *sojización*. By the time these countervailing dynamics became visible, the simplified production systems centred on HT soy seeds, glyphosate, and no-till practices had already been applied on vast areas for several years. Opposing pressures emerged across multiple scales including national and subnational policies, local ecosystems, international markets, and shifting regulatory frameworks. While some feedback mechanisms continued to align with and reinforce the HT soy regime, others began to contest its dominance and impel the system toward greater heterogeneity and complexity.

Figure 3: Representation of the HT soybean socio-technical regime and feedback mechanisms countervailing it



Source: Authors' illustration, following Geels, Technological Transitions.

Despite the enduring legacy of *sojización,* owed in particular to entrenched infrastructural and logistical systems favouring large-scale operations, countervailing dynamics are gaining ground. As Figure 3 illustrates, environmental degradation, herbicide-resistant weeds, social contestation, and shifting political and trade environments are increasingly challenging the regime's stability. These pressures originating at both the landscape and niche levels remain largely peripheral for now but could eventually become destabilizing forces.

Figure 3 thus complements and contrasts Figure 2. While Figure 2 visualizes the feedback mechanisms reinforcing the homogenization of the HT soy regime, Figure 3 indicates a system at a crossroads. Drawing on developments from the bio-environmental, socio-political, and economic domains, the following sections explore potentially destabilizing elements and ask whether the system may be moving away from homogenization.

Socio-political responses to sojización

As noted in the literature review, much of the research on the social effects of soy expansion in Argentina and Uruguay has emphasized the growing power of agribusiness actors, increasing land concentration, and the displacement of family farmers and indigenous communities. These issues were widely debated by the newly elected left-leaning governments across South America (often referred to as the 'pink tide'), including *Kirchnerismo* (2003–2015)[74] in Argentina and Frente Amplio (2005–2020 and again from 2025 onward)[75] in Uruguay. Emerging from the wave of social mobilization against neoliberalism in the early 2000s, both governments embraced state intervention and heterodox economic strategies.[76] While they frequently denounced the socially polarizing and environmentally damaging consequences of the expanding soy sector and emphasized the need for active industrial policies to reduce dependence on natural resource–intensive and low-wage exports, most scholars agree that their policies did little to meaningfully constrain its prevalence.[77] Nonetheless, several policy measures shaped the trajectory of *sojización* in distinct ways.

In Argentina, export taxes became a central pillar of fiscal policy under Kirchnerismo, especially during the commodity boom of the 2000s. By 2008, *retenciones* accounted for nearly 3 per cent of the Gross Domestic Product, with soybeans subject to the highest duties at 35 per cent.[78] These fiscal choices reinforced the HT soy regime by sustaining profitability at scale and by incentivizing asset-light, financialized land control. In addition, these taxes were framed as redistributive tools to capture windfall profits and finance social spending. However, they triggered fierce opposition from farmers' organizations and agribusiness groups. The introduction of a variable export tax tied to global prices in March 2008 provoked the *conflicto del campo*, the largest rural protest in decades. A broad coalition of actors rallied under the banner of *el campo*, portraying the measure as an assault on private property and market freedoms. The resulting political crisis forced the government to retract the reform, revealing the limits of state extractive capacity when confronted with powerful agrarian actors.[79]

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74 *Kirchnerismo* refers to the political project associated with Néstor Kirchner (President of Argentina from 2003 to 2007) and Cristina Fernández de Kirchner (President from 2007 to 2015).

75 The *Frente Amplio* (Broad Front) is a left-wing political coalition that governed Uruguay from 2005 to 2020 under presidents Tabaré Vázquez (2005–2010, 2015–2020) and José Mujica (2010–2015) and returned to power in 2025 under Yamandú Orsi.

76 Berndt et al., Postneoliberalism; Baraibar Norberg, Sojización.

77 Fabio dos Santos/Joana Vasconcelos, The Glyphosate Consensus: Rural Poverty Management and Agribusiness in South America during the Pink Tide (1998–2016), in: Pablo Vommaro/Pablo Baisotti (eds.), Persistence and Emergencies of Inequalities in Latin America: A Multidimensional Approach, Cham 2022, 247–266; Leandro Vergara-Camus/Cristóbal Kay, New Agrarian Democracies: The Pink Tide's Lost Opportunity, in: Socialist Register 54/54 (2017), 211–230.

78 These taxes helped finance federal programs and captured a portion of the global agricultural export boom.

79 Interview no. 22 (Director of Research Promotion; researcher in pedagogy, CLACSO, Argentina), 3 March 2017.

Despite these high duties, soy cultivation continued to expand, driven by strong global demand and lower capital and labour requirements relative to other land uses. Export taxes did, however, influence production and investment patterns. They encouraged the rise of financialized farming models such as the previously mentioned *pools de siembra*, which spread risk and sustained profitability at scale.[80] Meanwhile, differential export tax rates (lower on processed soymeal and oil than on unprocessed beans) supported the development of domestic crushing industries, especially around the Rosario export hub. This strategy reinforced Argentina's position as the world's top soymeal exporter and strengthened vertically integrated agribusiness firms.

Additional fiscal and quasi-fiscal policies also affected soy's trajectory. Currency controls and multiple exchange rates, particularly from 2011 onward, represented a de facto tax on exports. Soy exporters were often required to sell foreign currency earnings at artificially low official rates, reducing their real revenues. To mitigate the resulting export slowdown and boost foreign reserves, the state intermittently introduced preferential exchange rates, for example via the *dólar soja* programs in 2022–2023. While intended to accelerate exports, such interventions added volatility and encouraged strategic stockpiling.[81]

Under the centre-right administration of Mauricio Macri (2015–2019), fiscal policy shifted toward liberalization. Macri reduced export taxes on soybeans from 35 to 30 per cent, eliminated them for most other agricultural goods, and promised a more predictable investment climate.[82] Yet his administration soon faced macroeconomic instability: Amid a currency crisis in 2018, it reintroduced broad-based export taxes via a fixed peso-per-dollar mechanism that effectively raised the burden as the currency depreciated.

Alberto Fernández (2019–2023) restored a more interventionist stance. Soy export duties were raised to 33 per cent by 2021 to address fiscal deficits linked to recession, inflation, and the COVID-19 crisis.[83] The government argued this was essential for macroeconomic stability, but tensions with the agricultural sector resurfaced.

During the 2024 presidential campaign, Javier Milei promised to eliminate export taxes on soy, corn, and wheat.[84] In early 2025, his government temporarily reduced duties on soybeans from 33 to 26 per cent and on soymeal and oil from 31 to 24.5 per cent, citing drought conditions and low prices.[85] However, by July 2025, these rates reverted to their previous values despite protests from rural groups, many of whom had backed Milei politically.[86] The

80 Interview no. 20.

81 Interview no. 3.

82 OECD, Agricultural Policies, 144; OECD, Agricultural Policy Monitoring and Evaluation 2023: Adapting Agriculture to Climate Change, Paris 2023, DOI: 10.1787/b14de474-en.

83 OECD, Agricultural Policy Monitoring.

84 Javier Milei ante Productores Agropecuarios en La Rural: "Vamos a Eliminar el Impuesto PAIS y Después las Retenciones," in: El Economista online (24 May 2024), https://eleconomista.com.ar/politica/javier-milei-productores-agropecuarios-rural-vamos-eliminar-impuesto-pais-despues-retenciones-n73989 (28 June 2025).

85 Argentina Slashes Export Taxes to Rescue Drought-Hit Farmers, in: Buenos Aires Times online (23 January 2025), https://www.batimes.com.ar/news/economy/argentina-slashes-export-taxes-to-rescue-drought-hit-farmers.phtml (16 July 2025). The tax on corn was reduced from 12 per cent to 9.5 per cent. There were also cuts for other major crops including wheat, barley, and sunflowers.

86 El Campo Volvió a Reclamarle a Milei una Baja de Retenciones: "Esperábamos...," in: El Cronista online (6 July 2025), https://www.cronista.com/economia-politica/el-campo-volvio-a-reclamarle-a-milei-una-baja-de-retenciones-esperabamos/ (16 July 2025); Fernando Bertello, A Solas: La Contundente Frase de Nicolás Pino

enduring reliance on *retenciones* reflects Argentina's structural dependence on soy-derived revenue, regardless of political ideology.

More broadly, Argentina's unstable fiscal and exchange rate regimes incentivized spatial and financial diversification among agribusiness actors. Firms increasingly sought to manage risk by expanding into neighbouring countries such as Uruguay, where the tax environment was more predictable. Cross-border leasing, contract farming, and vertical integration enabled companies to operate regionally while hedging against domestic policy shocks. This asset and production flexibility supported continuity of the regime despite domestic policy shocks. Although soybean cultivation continued to expand within Argentina, interviews with producers and company representatives consistently identified tax and currency volatility as key drivers of outward expansion.[87]

By contrast, Uruguay pursued a more stable and transparent fiscal approach. There were no export taxes on agricultural products, and while the 2007 tax reform introduced a progressive personal income tax and a flat 25 per cent corporate tax (IRAE), the system also offered a wide range of favourable tax incentives and exemptions.[88] For instance, the government provided substantial investment incentives through the Investment Promotion Act (Act 16,906) of 1998 and its subsequent decrees (particularly Decree No. 455/07 of 2007), under which agribusiness firms could qualify for corporate tax exemptions of up to 90 per cent on approved investments, lasting between 4 and 25 years, with the highest benefits granted to the largest projects (Art.16).[89] Additional advantages included exemptions from Value Added Tax and import duties on machinery and inputs. Eligible projects covered irrigation systems, soil improvements such as liming, clean technologies, certifications, and agricultural research and development.[90] These incentives effectively reduced the average corporate tax rate for participating firms to around 13.4 per cent, well below the statutory 25 per cent.[91]

Overall, the effective fiscal burden on agriculture in Uruguay remained relatively low. In 2015, however, rural property taxes were slightly increased, placing greater fiscal pressure on large landowners.[92] This was partly framed as a response to public debate on land concentration and the "foreignization" of farmland in the wake of *sojización*.

While progressive income and property taxes have generated some revenue for public spending, including targeted support for family farmers, the investment-promotion regime

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a Javier Milei en un Desayuno donde se Habló Mucho de un Lastre del Campo, in: La Nación online (10 July 2025), https://www.lanacion.com.ar/economia/campo/a-solas-la-contundente-frase-de-nicolas-pino-a-javier-milei-en-un-desayuno-donde-se-hablo-mucho-de-nid10072025/ (16 July 2025).

87 Interview no. 17 (Senior expert; producer and consultant for agribusiness firms and international organisations; former president, INTA, Argentina), 28 February 2017; interview no. 33 (Director, COUSA, soybean oil supplier, Uruguay), 10 March 2010.

88 Interview no. 26; interview no. 41.

89 Act No. 16,906 of 7 January 1998, Ley de Inversiones: Promoción indústrial, in: Diario Oficial online (IMPO), https://www.impo.com.uy/bases/leyes/16906-1998 (28 October 2025); Decree No. 455/07 of 6 December 2007, in: Diario Oficial online (IMPO), www.impo.com.uy/bases/decretos-originales/455-2007 (28 October 2025); and all subsequent decrees and resolutions in: Diario Oficial online (IMPO), https://www.impo.com.uy/bases/leyes/16906-1998?verreferencias=norma (28 October 2025).

90 Fiscal Incentives for Farms in Uruguay, in: Farmland Urugay, https://farmlanduruguay.com/investments/investment-promotion-for-farms-in-uruguay/ (16 July 2025).

91 Comisión de Aplicación de la Ley de Inversiones, Ministerio de Economía y Finanzas, Uruguay, https://www.gub.uy/ministerio-economia-finanzas/Comap (16 July 2025).

92 Interview no. 41.

(together with rising land prices and rents and the economies of scale in agriculture) has allowed high land concentration and *sojización* to persist.

Soil and forest protection responses

Uruguay's primary public policy response to soy expansion has been the Soil Use and Management Plan (PUMS), a system designed to combat erosion and soil degradation. Although not fully implemented until 2013, PUMS built on long-standing legislation, and was later reinforced by decrees that specified responsibilities, acceptable erosion levels, and penalties for non-compliance.[93] Since 2013, the plans have been mandatory for all crop farms over 100 ha, with the threshold lowered to 50 ha in 2018.

PUMS requires farmers to submit soil use and management plans to the state, demonstrating that they adopt practices that sustain long-term soil health and keep erosion within tolerable limits. The tolerated level is estimated through a local adaptation of a widely used universal soil loss equation (USLE/RUSLE).[94] Farmers need to adopt practices such as crop diversification, rotation, and the use of winter cover crop in order to meet the requirements.[95] In this way, continuous soybean cultivation is discouraged and complexity is added to expansion dynamics.[96] By 2018, protective cover crops were already used on 85 per cent of soybean stubble land, and total annual soy acreage had decreased significantly, from 1.33 Mha in 2014 to 0.91 Mha in 2021.[97]

While land use decisions are influenced by multiple factors, this contraction was likely due in part to PUMS restrictions, which made continuous soy planting impossible in many

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93 Act No. 15.239 of 23 December 1981, Declaración de Interés Nacional. Uso y Conservación de los Suelos y de las Aguas Superficiales Destinados a fines Agropecuarios, in: Diario Oficial online (IMPO), https://www.impo.com.uy/bases/decretos-ley/15239-1981 (28 October 2025). Two key regulatory decrees were later added: No. 333/04 of 16 September 2004, in: Diario Oficial online (IMPO), https://www.impo.com.uy/bases/decretos/333-2004 (28 October 2025), and No. 405/08 of 21 August 2008, in: IMPO, https://www.impo.com.uy/bases/decretos/405-2008 (28 October 2025). Both decrees are titled Regulación de Usos y Conservación de Suelos y Aguas Superficiales. Sanctions under this system are governed by Act No. 18.564 of 11 September 2009, Regulación de Uso y Manejo de las Aguas y el Suelo, Sanciones por Incumplimiento, in: Diario Oficial online (IMPO), https://www.impo.com.uy/bases/leyes/18564-2009/2 (28 October 2025).

94 Significant local adaptations have been made to the model's parameters, including terrain models, soil mapping, and rainfall erosivity data based on experimental studies. Interview no. 43 (Advisor and Independent Consultant; former researcher, CONEAT and Texas A&M University, Uruguay), 11 March 2017; interview no. 7 (Coordinator; specialist in soil and water systems, DGRN, MGAP, Uruguay), 9 August 2024.

95 Mariana Hill/Juan Andrés Quincke, Erosión Hídrica y Buenas Prácticas: Las Dos Caras que Definen la Realidad de los Suelos Uruguayos, in: INIA Informa 5 (2019), 2–7, https://ainfo.inia.uy/digital/bitstream/item/13875/1/INIA-Informa-Especial-Suelos-Diciembre-2019.pdf; Martín Dell'Acqua/Andrés Beretta, Estimación del Impacto de la Implementación de la Política de Planes de Uso y Manejo Responsable del Suelo, in: Anuario Opypa 2020, https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/comunicacion/publicaciones/anuario-opypa-2020/estudios/estimacion-del-impacto-implementacion (31 July 2025).

96 Cristina Zurbriggen et al., Experimentation in the Design of Public Policies: The Uruguayan Soils Conservation Plans, in: Ibero-Americana: Nordic Journal of Latin American Studies 49/1 (2020), 52–62; interview no. 5 (Researcher; professor of environmental governance, Faculty of Social Sciences, UDELAR; SARAS, Uruguay), 6 June 2024; interview no. 43; interview no. 7.

97 DIEA, Anuario; URUPOV, Teledetección.

areas that would otherwise have remained under soy.[98] At the same time, PUMS encouraged the inclusion of soy within broader crop rotations.[99] As a result, and somewhat counterintuitively, the total cumulative area of land incorporating soy within rotations increased even as the annual harvested area declined. Between 2017 and 2022, the cumulative soybean area in Uruguay reached approximately 2.75 Mha, nearly three times the annual harvested area.[100] In socio-technical terms, PUMS shifts the regime from a single 'HT soy + glyphosate + no-till' operating logic toward locally differentiated management packages.

In Argentina, although its Pampas soils are less prone to erosion, concerns about land degradation (structure, nutrient depletion, water quality) from *sojización* remain significant. However, replicating Uruguay's PUMS model in Argentina is considered infeasible due to political and cultural factors. Many stakeholders perceive such measures as excessive state intervention and a violation of private property rights.[101] Instead, Argentina's flagship environmental response has been the 2007 Forest Protection Act (Act 26,331) aimed at curbing deforestation. The Argentine portion of the Gran Chaco Forest[102] produces less than 10 per cent of the country's soy, but it accounts for 95 per cent of soy-related deforestation. Enforcement of the law has been inconsistent, however, with provinces with the highest deforestation rates often adopting the least rigorous implementation strategies.[103] Between 2015 and 2019, annual deforestation rates in the Gran Chaco rose from 116,000 ha to 211,000 ha, while soy cultivation in the region rose from 2.6 Mha to 2.8 Mha.[104]

Policy responses to pesticides

The dramatic rise in pesticide use associated with the HT soy model has had profound environmental and health implications in both Argentina and Uruguay. Residues have been detected in water, soil, air, and agricultural products, raising concerns over biodiversity loss and human health risks.[105] In many soybean-producing regions, residents have reported a wide range of serious health impacts (e.g., chronic respiratory diseases, diarrhoea, dizziness, cephalalgia, nausea, vision problems, dermal rashes) resulting from aerial and ground spraying of agrochemicals, as well as due to pollution from grain storage and pesticide facilities.[106] Although scientific research and residents have increasingly documented these impacts (see previous research), policy responses have been limited and inconsistent.

98 Interview no. 14; interview no. 7

99 Interview no. 15.

100 URUPOV, Teledetección; FAOSTAT, https://www.fao.org/faostat/en/#data/QCL (25 October 2025).

101 Interview no. 19; interview no. 3; interview no. 20.

102 The Gran Chaco is the second-largest forest in South America (behind only the Amazon), known for its dry, semi-arid climate and high biodiversity.

103 Gasparri et al., Linkages.

104 Michael Lathuillière, Argentina: The Overlooked Hub of South American Soy, in: Trase online (11 August 2022), DOI: 10.48650/CJZ1-8M45.

105 Palladino et al., Pesticide Dependence.

106 Sebastián Gómez Lende/Guillermo Velázquez, Soybean Agribusiness in Argentina (1990–2015): Socio-Economic, Territorial, Environmental, and Political Implications, in: Gokhan Egilmez (ed.), Agricultural Value Chain, London 2018, 117–136.

Both countries have prohibited some highly toxic pesticides; however, numerous substances banned in the European Union (EU) remain widely used.[107] Buffer zones have been established to restrict pesticide application near water bodies and inhabited areas, yet enforcement remains erratic. In Argentina, the corresponding regulatory framework is decentralized, with each province setting its own standards, resulting in significant variation.

In this context, legal action has emerged as a relevant, albeit limited, avenue for contesting harmful pesticide practices.[108] One of the earliest and most influential rulings occurred in San Jorge, Santa Fe, in 2009, where a court granted an injunction prohibiting land and aerial spraying within 800 and 1,500 meters of a residential area, respectively. This decision invoked the precautionary principle and has since served as a reference point for subsequent cases. Another landmark ruling was issued in Entre Ríos in 2018 following a lawsuit filed by a regional teachers' union and environmental organizations. The court prohibited spraying within 1,000 meters (ground) and 3,000 meters (aerial) of rural schools and mandated the establishment of vegetative barriers and epidemiological monitoring programs. However, in response to agribusiness pressure, the provincial government later reduced these buffer zones to 100 and 500 meters, respectively, provoking widespread protest.[109]

In Uruguay, comparatively stricter regulations have been adopted in ecologically sensitive areas, particularly near water sources. Nevertheless, contamination remains a serious issue. In the Laguna del Cisne watershed (a drinking water source for over 100,000 people), precautionary regulations were introduced in 2016 to promote an agroecological transition. Despite this, a 2019 study found residues from 25 pesticides in both water and fish samples, including glyphosate, chlorantraniliprole, and banned substances such as Dichloro-Diphenyl-Trichloroethane (DDT).[110] These findings illustrate the inadequacy of existing safeguards and the persistent gap between chemical innovation and comprehensive environmental risk assessment.[111]

Mounting concern about pesticide-related effects has also galvanized localized forms of resistance. Civil society organizations, such as RAP-AL and *La Soja Mata* have played a key role in contesting the dominant agrarian model, linking the expansion of HT soy to environmental degradation, rural depopulation, and the displacement of traditional farming systems. These groups often collaborate with local actors such as environmental organizations,

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107 For Uruguay, see DGSA, Dirección General de Servicios Agrícolas, Ministerio de Ganadería, Agricultura y Pesca, https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/dgsa (16 July 2025); for Argentina, see SENASA, Servicio Nacional de Sanidad y Calidad Agroalimentaria, https://www.argentina.gob.ar/senasa (16 July 2025).

108 María Berros, Stop Experimenting on Us! Judicial Stories of Pesticide Resistance in Argentina, in: Global Environment 17/2 (2024), 378–395, DOI: 10.3828/whpge.63837646622495.

109 Ibid.

110 César Rodríguez-Bolaña et al., Multicompartmental Monitoring of Legacy and Currently Used Pesticides in a Subtropical Lake Used as a Drinking Water Source (Laguna del Cisne, Uruguay), in: Science of the Total Environment 874/162310 (2023), DOI: 10.1016/j.scitotenv.2023.162310. Surprisingly, glyphosate and its metabolite AMPA were detected in fish muscle tissue despite their high solubility in water.

111 Rodríguez-Bolaña et al., Multicompartmental Monitoring; Luciana Griffero et al., Basin-Scale Monitoring and Risk Assessment of Emerging Contaminants in South American Atlantic Coastal Lagoons, in: Science of the Total Environment 697/134058 (2019), DOI: 10.1016/j.scitotenv.2019.134058. For instance, researchers found that some newer pesticides marketed as safer alternatives to glyphosate and certain insecticides were even more harmful to pollinators.

teachers, smallholders, and municipal leaders to campaign for tighter regulations. Similar efforts have taken place in other Argentine provinces such as Córdoba, where the *Madres de Barrio Ituzaingó* have denounced pesticide exposure and mobilized public opinion. In Santa Fe, the *Paren de Fumigarnos* (Stop Fumigating Us) campaign has sustained pressure for nearly two decades.

Despite these efforts, the broader influence of objecting endeavours remains limited. Producer organizations in both countries continue to defend HT soy cultivation, emphasizing private property rights and the autonomy of landowners to lease their land under short-term arrangements to maximize returns. As one agronomist affiliated with a crop firm explained, companies coordinate with rural teachers to ensure that schoolchildren are not present during fumigation, but this does not alter the underlying model. In one such instance, a rural teacher – described by the respondent as a vocal critic – was said to stand and watch the spraying while "looking mad," illustrating how the agricultural sector perceives dissenting voices.[112]

In summary, although legal action and civil society mobilizations have challenged certain practices, they have not yet translated into transformative change. National policy frameworks remain permissive, and dominant production practices continue largely unchecked.[113] Still, together with increasing biophysical stresses, which are explored further in the following section, these counteracting pressures may foreshadow deeper tensions within the current agro-industrial regime.

Bio-environmental responses: Weed and pest resistance

The initial success of HT soy in Argentina and Uruguay stemmed largely from its promise of simplified weed management. However, the repeated large-scale use of glyphosate across millions of hectares, combined with simplified agronomic practices and landscape homogenization, has led to significant weed resistance. The absence of winter crops in many areas also left fallow periods rich in resources, further exacerbating the problem. Over time, glyphosate lost its effectiveness; resistant weeds became a major constraint on soybean yields and are now considered the primary biotic limitation to productivity in the region.[114]

In response, farmers and firms began increasing herbicide doses and application frequencies, raising concerns over environmental toxicity, human health, and rising production costs.[115] Biotech companies reacted by releasing new soybean varieties tolerant to other herbicides, such as dicamba and glufosinate. The once-standardized glyphosate regime has thus evolved into a far more complex system requiring diverse herbicide mixtures and locally adapted management strategies. There are also emerging signs of 'stacked resistance', where weed species exhibit resistance to several different herbicide modes of action.

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112 Interview no. 13 (Phytosanitary Specialist, agribusiness firms in Argentina and Uruguay), 28 February 2024.

113 Victoria Evia, Between Denouncing and Enduring: Soybean Expansion, Pesticides, and Environmental Health Participation in Uruguay, in: Saúde em Debate 46 (2022), 62–74.

114 Di Mauro et al., Transformations.

115 Interview no. 11 (Private Consultant and Extensionist; working for private crop firms in Argentina and Uruguay), 31 May 2024.

Farmers and agronomists must now constantly monitor fields, select appropriate chemical combinations, and understand interactions between formulations.[116] Some production managers report attending specialized courses on herbicide mixtures to keep up with the escalating complexity.[117] Several researchers argue that temporary tillage would be the most effective way to reduce weed pressure in soybean fields.[118] This increasing demand for expertise and time-consuming practices undermines one of the foundational promises of HT soy: simplified, low-cost production.

Resistance challenges are not confined to weeds. Since the introduction of Bacillus thuringiensis (Bt) soybeans, which are resistant to certain caterpillar pests, in 2012, pest resistance has also become a growing concern. The widespread use of Bt crops exerts strong selection pressure on insect populations, prompting the development of resistances and complicating pest management. To mitigate this, producers must rotate insecticides with different mechanisms of action and tailor practices to evolving local pest ecologies. As one agronomist noted, "going out to the field, monitoring, and making decisions is now a constant requirement."[119]

Necrotrophic fungi responsible for end-of-cycle diseases, which thrive in monocultural systems, are also becoming more problematic. The lack of crop rotation in the dominant forms of HT soy has thus likely led to increased need for fungicide use, further accelerating the development of chemical resistance. New disease challenges such as root and stem rots are also anticipated to expand. Researchers and firms are now experimenting with alternatives like biostimulants, defence inducers, and bio-fungicides to complement or replace traditional fungicides.[120]

These evolving biophysical constraints form a counteracting feedback loop: The ecological resistance created by prolonged homogenization has begun to erode the functional efficiency of the system. The very features that made HT soy attractive – landscape uniformity, chemical standardization, and low labour intensity – have, over time, fostered biological responses that make the standard practices less efficient, pushing the system toward greater complexity and heterogeneity. Climate change adds yet another layer of complexity: Shifting weather patterns and temperature regimes require adaptation in all types of management practices, and hence further shifts away from standardized solutions.

In this context, non-chemical strategies are gaining traction. Integrated pest management (IPM), which combines chemical, biological, and cultural approaches, is increasingly promoted. However, evidence of overall pesticide reduction remains limited.[121] Agronomic diversification through crop rotation, intercropping, and cover crops is being reintroduced, often under the label of 'service crops' that provide ecological functions rather than direct yields.[122]

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116 Interview no. 13.

117 Interview no. 12.

118 Fernando Oreja et al., Weed Seedbank Changes Associated with Temporary Tillage After Long Periods of No-Till, in: Agronomy 15/6, 1410 (2025), 1–15.

119 Interview no. 10 (Technical Director, agribusiness firm, Province of Buenos Aires, Argentina), 14 April 2024.

120 Interview no. 13; interview no. 2; interview no. 4; interview no. 8 (Senior Data Analyst; leader of data analysis on grain production using business intelligence tools, ReTAA, Buenos Aires Grain Exchange, Argentina), 2 August 2024; interview no. 9 (Researcher; specialist in applied economics for the agricultural sector, INIA, Uruguay), 11 July 2024.

121 Palladino et al., Pesticide Dependence.

122 Marcos Petrasek et al., Are Service Crops an Alternative for Mitigating N_2O Emissions in Soybean Crops in the Argentinian Pampas?, in: Journal of Environmental Quality 52/2 (2023), 258–269; Priscila Pinto et al.,

Crops like vetch and rye, sown in the off-season, help to suppress glyphosate-resistant weeds and improve soil structure. Biological controls are also used to manage pest populations.[123]

Despite these innovations, trends remain ambiguous. Interviews with producers and agronomists suggest both adaptation and entrenchment. While management systems have undeniably grown more complex and knowledge-intensive, imports of herbicides and pesticides continue to rise in both countries (see DGSA for Uruguay and SENASA for Argentina). The use of mixed chemical formulations, commonly referred to as 'cocktails', raises concerns over so-called synergistic toxicity, with ecological impacts poorly understood and rarely evaluated at the community level.[124] This underscores a key spatial mismatch: Despite the broad ecological reach of intensive agrochemical use, risk assessments focus on individual organisms rather than entire ecosystems.

Rather than disrupting the dominant regime, many adaptations seem to reinforce it. Industry groups like CropLife Latin America, active in both countries, promote "Good Agricultural Practices."[125] Meanwhile, firms and farmers rely on increasingly sophisticated technologies such as drones, field sensors, and geo-referenced data systems to fine-tune input application.[126] Producer organizations like CREA and AAPRESID in Argentina, or FUCREA and MTO in Uruguay, serve as key information nodes facilitating knowledge exchange and collective experimentation. Several interviewees described the importance of continuous meetings with other producers to discuss new production strategies and share trial results of new varieties in this rapidly changing context.[127]

These changes reflect a shift from standardized to customized management, but without necessarily challenging the underlying logic of HT soy. Technological tools are streamlining field monitoring and enhancing coordination within large-scale farming operations. For example, some companies use software platforms like SIMA to manage field teams and make real-time decisions. In this sense, the system is becoming more complex and differentiated, but not less dependent on capital-intensive inputs.[128]

Nevertheless, there are signs that the long-standing model is under strain. As mentioned, continuous soy planting has largely displaced the traditional mixed system of crop and livestock rotation in the Pampas and the Uruguayan Littoral, which supported soil health and

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Including Cover Crops During Fallow Periods for Increasing Ecosystem Services. Is It Possible in Croplands of Southern South America?, in: Agriculture, Ecosystems & Environment 248 (2017), 48–57; Priscila Pinto et al., Variable RootShoot Ratios and Plant Nitrogen Concentrations Discourage Using Just Aboveground Biomass to Select Legume Service Crops, in: Plant and Soil 463 (2021), 347–358.

123 Candelario Palma-Bautista et al., Multiple Resistance to Glyphosate and 2,4-D in Carduus acanthoides L. from Argentina and Alternative Control Solutions, in: Agronomy 10/11, 1735 (2020), 1–14, DOI: 10.3390/agronomy10111735.

124 Palladino et al., Pesticide Dependence.

125 Crop Life Latin America, https://croplifela.org/es/nosotros/quienes-somos (26 June 2025).

126 Interview no. 11.

127 Interview no. 12.

128 Ibid.; SIMA monitors fields, geolocates data, analyses information, and generates spray application orders, see SIMA – Integrated Agricultural Monitoring System, https://sima.ag/en (31 July 2025). There are also some public initiatives. For example, INIA Uruguay has developed the CultiDOCTOR app, launched in 2023, which provides free assistance to technicians and farmers for identifying early signs of crop diseases in wheat, barley, soybeans, canola and other crops, see INIA Uruguay, CultiDOCTOR_Uy: Una Nueva Herramienta para Identificación de Enfermedades en Cultivos, https://www.inia.uy/cultidoctoruy-una-nueva-herramienta-para-identificacion-de-enfermedades-en-cultivos (17 July 2025).

long-term productivity. However, some producers are now reintroducing pastures into rotation, especially where grain alternatives are limited.[129] As one researcher noted, these shifts may represent early indicators of a broader systemic transition.[130]

Economic structures are also evolving unevenly. In Uruguay, data from the 2016/17 to 2022/23 seasons show a decline in the number and area of farms larger than 500 ha, alongside growth in mid-sized farms.[131] This contrasts with Argentina, where the 2002 and 2018 agricultural censuses show continued consolidation in provinces like Buenos Aires, Córdoba, and Santa Fe. Here, farms exceeding 1,000 ha have proliferated while smaller units have declined.[132]

These contrasting trajectories suggest that more complex, localized management strategies may be compatible with large-scale operations – but their diffusion is shaped by differing institutional, political, and ecological dynamics. For example, Uruguay's implementation of mandatory soil use and management plans may have reduced profit margins, slowing large-scale expansion. Despite certain variations, however, economies of scale still underpin the extensive agricultural systems in both countries.

Climate change represents another emerging feedback. Nearly all soy production in the region is rainfed, making it highly vulnerable to precipitation variability. The 2022/23 drought in Uruguay led to record losses: 23 per cent of the sown area was abandoned and yields dropped by 73 per cent.[133] The financial losses were exacerbated as input prices rose while output prices fell. In Argentina, a study found that rainfall and temperature explain over 90 per cent of yield variation between 2001 and 2021, with projections indicating a growing frequency of extreme weather events and rising average losses.[134]

Finally, global market shifts – particularly changes in demand from China or regulatory shifts in Europe – may further destabilize the model of *sojización*. These exogenous pressures, together with internal ecological feedback loops, suggest that the future trajectory of HT soy will depend not only on technological innovation but also on the interplay between agrarian social relations, environmental constraints, and international political economy. This dynamic landscape will be further examined in the following section.

129 Interview no. 12.

130 Interview no. 4.

131 DIEA, Anuario.

132 Carlos Rossi, El Censo Nacional Agropecuario 2018: Resultados Insatisfactorios y Profundización de los Cambios Estructurales en el Agro Bonaerense, in: Susana Soberna (ed.), La Argentina Agropecuaria Vista Desde las Provincias: Un Análisis de los Resultados Preliminares del CNA 2018, Buenos Aires 2021, 239–269; Gustavo Soto et al., Análisis Intercensal 2002–2018 Provincia de Córdoba, in: Soberna (ed.), La Argentina Agropecuaria, 270–278; Roxana Albanesi/Patricia Propersi, Transformaciones Fundiarias y en el Uso del Suelo en la Provincia de Santa Fe entre el CNA 2002 y el CNA 2018, in: ibid., 309–321; see also, Censo Nacional Agropecuario 2002, INDEC, https://sitioanterior.indec.gob.ar/index_agropecuario.asp (18 September 2024); Censo Nacional Agropecuario 2018, INDEC, https://www.indec.gob.ar/indec/web/Nivel4-Tema-3-8-87 (18 September 2024).

133 Catalina Rava et al., El Complejo Oleaginoso en Uruguay en la Zafra 2022/2023 y sus Perspectivas, in: Revista INIA 75 (2023), 45–50.

134 Esteban Otto Thomasz et al., Assessing the Impact of Climate Change on Soybean Production in Argentina, in: Climate Services 34, (2024), 1–20, DOI: 10.1016/j.cliser.2024.100458

The market economy: Key buyers changing the rules?

China's increasing emphasis on soybean self-sufficiency poses a potential challenge for global soy exporters. Historically self-reliant with regard to soy, China's demand for imports surged after the 1990s as it opened up its markets and became a major buyer. Nearly 100 million metric tons of soybeans were imported in 2021, primarily for animal feed and cooking oil.[135] However, concerns over food security, trade tensions, and fluctuating global markets have prompted the Chinese government to push for greater domestic production. In response, China has implemented soybean revitalization plans, offering subsidies and technical support to farmers to boost yields. Additionally, the government is promoting alternative feed crops such as rapeseed, sorghum, and peas to reduce reliance on soy imports. These policies align with China's broader strategy of food sovereignty aimed at reducing vulnerabilities in key agricultural commodities.[136]

While domestic production is still limited by competition with more profitable crops like corn, the government's efforts signal a shift toward less dependence on imported soy.[137] If these initiatives succeed, China's reduced demand for foreign soybeans could significantly impact countries like Uruguay and Argentina (as well as the United States of America and Brazil) which have long been key suppliers.

While China's efforts for self-sufficiency could reshape its role as a major importer, the EU, which is the second most important buyer of Argentine and Uruguayan soy, is also driving market change, but through a different route. The EU is introducing stricter sustainability requirements that could complicate market access for soy from both countries. A central instrument is the EU's new Anti-Deforestation Regulation (EUDR).

Under the EUDR, companies exporting soy to the EU must demonstrate that their products are not linked to deforestation. This requires detailed supply chain documentation, including traceability, geolocation of production plots, and comprehensive due diligence systems. Exporters must also comply with strict standards related to biodiversity, indigenous peoples' rights, and anti-corruption measures. Non-compliance may result in exclusion from the EU market, fines, and confiscation of goods.[138]

As a key supplier of soymeal to the EU, Argentina has raised concerns about these requirements.[139] The main challenge lies in ensuring physical segregation of compliant soy, as most silos, crushing plants and port facilities lack the infrastructure for separate storage and traceability systems. Building such infrastructure would significantly raise operational costs.[140] Originally scheduled to apply for large enterprises from 31 December 2024, the

135 OEC, Soybeans in China, https://oec.world/en/profile/bilateral-product/soybeans/reporter/chn (19 September 2024).

136 USDA, Oilseeds and Products Update – China, Report Number: CH2024-0077, prepared by FAS China Staff, approved by Adam Branson, 2024.

137 GAIN – Global Agricultural Information Network, Oilseeds and Products Annual, Report Number: AR2024-0005, prepared by Chase McGrath, 2024.

138 European Commission, Deforestation Regulation implementation, https://green-forum.ec.europa.eu/nature-and-biodiversity/deforestation-regulation-implementation_en (14 August 2024).

139 Lathuillière, Argentina.

140 Can the EU's Deforestation Law Save Argentina's Gran Chaco from Soy?, in: Mongabay online (6 June 2023), https://news.mongabay.com/2023/06/can-the-eus-deforestation-law-save-argentinas-gran-chaco-from-soy/ (3 September 2024).

EUDR's implementation was postponed following opposition from suppliers and European livestock producers. The regulation now applies from 30 December 2025 for large and medium-sized companies, and from 30 June 2026 for smaller firms.[141] Despite this delay, industry stakeholders continue to call for further postponement, warning that reduced throughput and higher costs could drive up food prices and inflation across the EU.[142]

In parallel, the EU's Carbon Border Adjustment Mechanism (CBAM), which imposes a carbon-based levy on imports, entered into force on 1 January 2026. Initially limited to industrial materials and energy products, it is under discussion for expansion to include agricultural commodities.[143] If adopted, this could impose additional carbon-related costs on South American exporters, further eroding their competitiveness in the European market.

Combined with the EU's efforts to strengthen domestic agricultural production, these regulatory changes pose a long-term challenge to the current articulation of the South American soy industry. In addition, the EU has expressed its intention to include Ukraine as a member state. If accession proceeds, Ukraine would likely become the largest recipient of Common Agricultural Policy (CAP) funding due to its vast agricultural area and production capacity.[144] This could further reduce the competitiveness of overseas soy in the European market. At the same time, the EU's increasing demands for traceability under EUDR may lead to differentiated, location-specific pricing. Soy sourced from regions with robust compliance infrastructure may command a premium, while products from areas with weaker traceability systems could face discounts or be excluded from the market. This could drive more heterogeneous dynamics in soy production, challenging the notion of soy as a uniform commodity.

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141 European Commission, On EUDR Regulation on Deforestation-free Products, https://environment.ec.europa.eu/topics/forests/deforestation/regulation-deforestation-free-products_en (14 December 2024).

142 COCERAL Urges EU to Postpone EUDR Implementation by One More Year, in: Miller Magazine 191 (November 2025), 61, https://millermagazine.com/magazine/issue-191/; EUDR Concerns Slow EU Soymeal Trade, Raise Alarms in South America, in: S&P Global, Commodity Insights (5 November 2025), https://www.spglobal.com/energy/en/news-research/latest-news/agriculture/110525-eudr-concerns-slow-eu-soymeal-trade-raise-alarms-in-south-america?utm_source (8 November 2025).

143 European Parliament, Opinion of the Committee on Agriculture and Rural Development for the Committee on the Environment, Public Health and Food Safety on the Proposal for a Regulation of the European Parliament and of the Council Establishing a Carbon Border Adjustment Mechanism, COM(2021)0564, C9-0328/2021, 2021/0214 COD, https://www.europarl.europa.eu/doceo/document/AGRI-AD-699239_EN.pdf (8 November 2025).

144 EU-Ukraine Accession Offers Important Opportunity for Common Agricultural Policy Reform, in: EU NEIGHBOURS East online (13 June 2024), https://euneighbourseast.eu/young-european-ambassadors/blog/eu-ukraine-accession-offers-important-opportunity-for-common-agricultural-policy-reform/ (14 December 2024).

Sojización at a crossroads: Destabilization and emerging alternatives

This study has examined the interplay between homogenizing and heterogenizing dynamics within the socio-technical regimes that structure soybean production in Argentina and Uruguay. Drawing on systems thinking and socio-technical transitions theory, we have shown how the HT soy regime emerged as a dominant configuration by aligning technological innovation with broader political, economic, and institutional trends. At the same time, it offered farmers a standardized and profitable package that restructured farm systems, reshaped landscapes, and reinforced global commodity chains.

Yet after decades of expansion, the foundations of this regime (management simplification, chemical dependency, and economies of scale) are showing signs of strain. Ecological consequences such as herbicide and pest resistance coupled with other environmental costs are undermining the agroeconomic efficiencies that once stabilized the system. Climate change further exacerbates these pressures, intensifying soil-borne diseases and the vulnerabilities of monoculture systems.

At the same time, new technologies and shifting market and policy signals are enabling more adaptive, site-specific, and diversified management practices. Tools such as drones, georeferenced monitoring, and precision agriculture offer potential for more nuanced responses, while regenerative techniques like cover cropping, IPM, and biological controls are gaining ground. However, many of these innovations remain embedded in the logic of input-intensive production, limiting their transformative potential.

The adoption and implications of these changes are shaped by divergent socio-economic and institutional contexts. In Argentina, consolidation continues, with digital tools supporting adaptation without disrupting large-scale economies. By contrast, Uruguay shows signs of structural divergence, with mid-sized farms gaining ground under regulatory frameworks such as mandatory environmental management plans. These differences highlight how policy and institutional design mediate both adaptation and the prospects for deeper transformation.

Climate change introduces yet another layer of complexity. As extreme weather events become more frequent, one possible response is the expansion of irrigation infrastructure. However, such investments entail significant costs that could jeopardize Argentina's and Uruguay's role as low-cost soy exporters in the global market.

Global market dynamics also influence the future trajectory of HT soy. China's efforts for agricultural self-sufficiency, although partial, suggest a potential decline in external demand. Meanwhile, Europe's evolving sustainability requirements may impose stricter production standards. For countries whose economies remain closely tied to soy exports, these global developments may both constrain and open new opportunities for transitioning away from monoculture systems.

Thus, while the HT soy regime remains dominant, its internal coherence is weakening. It is no longer sustained by uniformity and simplification alone, but increasingly by adaptive complexity. Whether current adaptations can resolve the deep-seated environmental and socio-economic contradictions of *sojización* or merely defer a more fundamental regime shift remains uncertain.

At any rate, cracks are visible. As the system is faced with growing ecological, technological, and socio-political complexity, a tipping point may be approaching. The future of soybean production in the Southern Cone will not be determined by technological innovation or market signals alone, but by contested decisions over what kind of agriculture is desirable – and for whom. The evolution of the HT soy regime thus offers a revealing window into the broader tensions, limits, and possibilities of agricultural modernization in the twenty-first century.

Appendix

The core empirical material comprises 15 semi-structured interviews conducted between January and October 2024, and a set of 33 longitudinal in-depth interviews conducted between 2008 and 2020. Eight of the 2024 interviews were carried out jointly by *Matilda Baraibar Norberg* and *Cecilia Gelabert* via Zoom, four were conducted in person in Argentina by *Gelabert*, and three were conducted independently by *Baraibar Norberg* via Zoom. The longitudinal interviews were all conducted by *Baraibar Norberg* and provide historical and contextual depth.

Many respondents have held multiple positions relevant to soybean production in Argentina and Uruguay; the most pertinent affiliations are listed below. All names are anonymised in accordance with ethical research guidelines.

Principal interviews (2024)

1. Researcher, specialist in agrarian ecology, Faculty of Agronomy, University of Buenos Aires (FAUBA); National Scientific and Technical Research Council (CONICET), Argentina. Lecturer at FAUBA and researcher at CONICET. Buenos Aires, 3 May 2024.
2. Researcher, specialist in management practices in agro-food systems, FAUBA, Argentina. Zoom, 21 February 2024.
3. Researcher, extensionist and consultant, professor of ecology of agrarian systems, Institute for Physiological and Ecological Research Related to Agriculture (IFEVA), FAUBA; CONICET, Argentina; Faculty of Agronomy (FAGRO) - University of the Republic (UDELAR), Uruguay. Independent consultant for grain producers in Argentina and Uruguay. Zoom, 20 May 2024.
4. Researcher, assistant professor, specialist in pesticide dynamics and sustainability indicators in agroecosystems, IFEVA, FAUBA, Argentina. Buenos Aires, 3 September 2024.
5. Researcher, professor of environmental governance, Faculty of Social Sciences, UDELAR; South American Institute for Resilience and Sustainability Studies (SARAS), Uruguay. Zoom, 6 June 2024.
6. Research Director, specialist in crop ecophysiology, soil management, and simulation models, National Institute of Agricultural Research (INIA); adjunct professor, FAGRO-UDELAR, Uruguay. Zoom, 12 August 2024.
7. Coordinator, specialist in soil and water systems; contributor to national soil conservation models (RUSLE), General Directorate of Natural Resources (DGRN), Ministry of

Livestock, Agriculture and Fisheries (MGAP), Uruguay. Zoom, 10 July and 9 August 2024, additional email correspondence.

8. Senior Data Analyst, leader of data analysis on grain production using business intelligence tools (e.g. Power BI, matplotlib), Survey of Applied Agricultural Technology (ReTAA), Buenos Aires Grain Exchange, Argentina. Zoom, 2 August 2024.
9. Researcher, specialist in applied economics for the agricultural sector, INIA, Uruguay. Zoom, 11 July 2024.
10. Technical Director, agribusiness firm, Province of Buenos Aires, Argentina. Buenos Aires, 14 April 2024.
11. Private consultant and extensionist, working for private crop firms in both Argentina and Uruguay. Buenos Aires, 31 May 2024.
12. Production Manager, agribusiness firm, various provinces, Argentina. Zoom, 2 August 2024.
13. Phytosanitary Specialist, agribusiness firms in Argentina and Uruguay. Zoom, 28 February 2024.
14. Advisor, specialist in agricultural public policy, National Directorate of Territorial Planning (DINOT), Ministry of Housing, Territorial Planning and Environment (MVOTMA), Uruguay. Zoom, 17 June 2024.
15. Public Official, technician in Soil Management and Conservation, National Directorate of Renewable Natural Resources (RENARE), MGAP, Uruguay. Zoom, 5 July and 14 August 2024.

Longitudinal interviews (2008–2020)

Argentina

16. Researcher, associate professor of ecology, FAUBA; CONICET, Argentina. Agricultural extensionist; consultant to grain producers in Argentina and Uruguay. Buenos Aires, 11 February 2017.
17. Senior expert, producer and consultant, agribusiness firms (e.g. El Tejar) and international organisations (World Bank, Inter-American Development Bank [IADB], Inter-American Institute for Cooperation on Agriculture [IICA], Food and Agriculture Organization of the United Nations [FAO]); former President, National Institute of Agricultural Technology (INTA); former national director of agricultural production, Secretariat of Agriculture, Livestock, Fisheries and Food (SAGPyA); author of works on agro-industrial chains and competitiveness. Buenos Aires, 28 February 2017.
18. Director of Agricultural Affairs, Argentine Council for International Relations (CARI); adviser to the FAO Director-General on strategic planning; former vice minister of agricultural economy; former director general, IICA; former president of the board, International Food Policy Research Institute (IFPRI); agricultural producer; author of works on agricultural policy and development. Buenos Aires, 1 March 2017.
19. Former Secretary of Agriculture, Livestock and Fisheries, Ministry of Agriculture, Livestock and Fisheries (MAGyP); director, Centre for Research in Political, Economic and Social Sciences (CICPES), INTA; former national director of agricultural information

and quality systems, INTA; former President, Agricultural Technological Innovations Inc. (INTeA S.A.). Buenos Aires, 2 March 2017.

20. Director of Social Studies, Institute of Social Studies, INTA; former coordinator, 2013 National Census of Agricultural Producers; former researcher, Ministry of Economy (MECON), Argentina. Buenos Aires, 2 March 2017.
21. Rural Development Specialist, specialist in territorial management, agriculture, and rural wellbeing, IICA, Argentina office. Buenos Aires, 3 March 2017.
22. Director of Research Promotion, researcher in pedagogy, Latin American Council of Social Sciences (CLACSO), Argentina. Buenos Aires, 3 March 2017.
23. Researcher and Former Public Official. Department of Rural Development, University of Misiones; Department of Economy and Crop Planning; former advisor, Secretariat of Family Agriculture, Ministry of Agroindustry, Argentina. Stockholm, 10 September 2018.

Uruguay

24. Chief Executive Officer, El Tejar Uruguay; president, Oilseeds Technological Board (MTO); agronomist and consultant. Young, 23 February 2008.
25. Chief of Sales, Agronegocios del Plata (ADP). Dolores, 13 February 2008.
26. President, Rural Federation of Uruguay (FRU); veterinarian, rancher and landowner; lecturer, FAGRO-UDELAR. Montevideo, 3 March 2009.
27. Director, Schandy Shipping and Logistics. Montevideo, 19 February 2009.
28. President, National Commission for Rural Development (CNFR); agricultural producer. Montevideo, 5 March 2009.
29. Agronomist and Family Farmer, grain cooperative of Dolores (CADOL). Dolores, 5 March 2010.
30. Traders, commercial agents from major trading companies involved in buying and selling soy and grains in the Port of Nueva Palmira. Nueva Palmira, 11 March 2017.
31. President, National Institute of Seeds (INASE); agronomist; politician, Socialist Party, Frente Amplio. Montevideo, 6 March 2010.
32. Director, Alcoholes del Uruguay (ALUR). Montevideo, 9 March 2010.
33. Director, Compañía Oleaginosa Uruguay S.A. (COUSA). Montevideo, 10 March 2010.
34. Chief Executive Officer, regional head of Marfrig Beef Southern Cone. Montevideo, 7 March 2010.
35. Director, Programme for production and environmental sustainability, INIA; Researcher and lecturer FAGRO-UDELAR; Board member of the International Soil Tillage Research Organisation (ISTRO). Skype, 3 March 2017.
36. Researcher, professor in Political Science, Faculty of Social Sciences, UDELAR.; Former Director at the Latin American Faculty of Social Sciences (FLACSO), Uruguay office. Montevideo, 6 March 2017.
37. Former Minister, MGAP, Uruguay; member, Movement of Popular Participation (MPP), Frente Amplio; former president, National Institute of Colonisation (INC); lecturer FAGRO-UDELAR. Montevideo, 6 March 2017.
38. Advisory Director, National Office of the Environment (DINAMA), MVOTMA; political advisor, Frente Amplio; author of works on the impacts of soybean expansion. Montevideo, 6 March 2017.

39. Director, National Agency for Research and Innovation (ANII); professor in farming systems and production ecology, Department of Plant Production, FAGRO-UDELAR. Montevideo, 7 March 2017.
40. Senior Researcher, Department of Nutrition in Intensive Dairy and Livestock Systems, INIA La Estanzuela. Skype, 8 March 2017.
41. Director, Office of Planning and Agrarian Policy (OPYPA), MGAP; former tax specialist, OPYPA, MGAP; agronomist. Montevideo, 8 March 2017.
42. Director, SARAS; professor in limnology, Eastern Regional University Centre (CURE), UDELAR; member, Santa Lucía water basin group. Punta del Este, 10 March 2017.
43. Advisor and independent consultant, former researcher, National Commission for Agronomic Land Assessment (CONEAT) and Texas A&M University; former executive director, International Network on Migration and Development; long-standing advisor on soils and land planning for MGAP. Punta del Este, 11 March 2017.
44. Coordinator, Uruguayan Centre for Applied Technologies (CEUTA). Montevideo, 12 March 2017.
45. Dean, Faculty of Social Sciences, UDELAR; professor of sociology; author of works on land concentration, agrarian history, and rural relations. Montevideo, 13 March 2017.
46. Researcher, specialist in erosion, FAGRO-UDELAR; course leader at CEUTA. Stockholm, 23 June 2018.