Resilience of small-scale farming to the emergence of bioenergy as a climate policy: lessons from Brazil's social biodiesel programme

Master's thesis - European Master in System Dynamics

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Abstract

This master thesis describes effects of the Brazilian social biodiesel policies on smallholder farmers. Through interviews, documental analysis and a simulation model, it rejects a dynamic hypothesis about market manipulation by biodiesel refineries indirectly financed by these biodiesel policies. It examines some of the threats posed by these policies to conclude that their risks are more relevant when associated with pull migration factors. It analyses decisions smallholders make and reveals which of them are more important to their own resilience. It demonstrates that land sales timing is key to determine smallholder farmer resilience and that the emergence of industrial agriculture phenomena such as regional biodiesel supply chains might be an opportunity for them to leave rural areas with more assets, which can help them adapt to urban life. It recommends an array of policy instruments to mitigate the researched risks when it comes to future bioenergy policy design.

Introduction

Background

The latest IPCC reports (2007, 2014) point to bioenergy (BE) as a key climate solution and recommend an increase in BE production supported by public policy, especially in Latin America and Africa, continents with highest BE potential (IPCC, 2012: 226). However, Robledo-Abad et al. (2017) show that BE policies in these regions are not informed by science when it comes to the planning and assessment of their impacts. This is consistent to Rasmussen et al. (2018) demonstration that policy trade-offs between social and environmental (in this case, climate) aspects are stronger when it comes to non-food crops.

BE policies might expose smallholder farmers in these continents to risks. Creutzig et al. (2015) built a compendium of potential implications of BE policies mentioned in specific literature. The negative ones are summarized in Table 1 below:

Table 1

Negative implications of BE policies from Creutzig et al. (2015)

Type	**Negative implications**
Institutional	Threats to land tenure and use rights loss for local stakeholders; Conflicts between forestry, agriculture, energy and/or mining; Impacts on labor rights among the value chain;
Social	Competition with food security including food availability, food access, land use and food stability; Discouraging local knowledge and practices; Displacement of small-scale farmers; Gender impacts;
Environmental	Deforestation and/or forest degradation; Impacts on soil quality, water pollution and biodiversity; Displacement of existing land uses; Trade-offs between different land uses, reducing land availability for local stakeholders;
Economic	Market opportunities decrease; Changes in prices of feedstock; Concentration of income and/or increased poverty; Uncertainty about mid- and long-term revenues; Technology might reduce labor demand; High dependence of technology transfer and/or acceptance.

Hunsberger, Bolwig, Corbera, and Creutzig (2014) alert about access to land issues, related to income: land ownership concentration, rural displacement, among others. German, Schoneveld and Pacheco (2011), as well as Lima, Skutsch, and De Medeiros Costa (2011) demonstrate that, even when land ownership rights are respected, the emergence of biofuel crops in specific regions leads to land concentration in the hands of agri-business conglomerates. Clancy and Narayanaswamy (2014) describe power asymmetries in agricultural supply-chains and suggest increased levels of transparency and partnerships to mitigate them.

Mainstream climate models utilized for climate-related BE policy recommendations incorporate farmer decisions mostly in a top-down way (Creutzig, Popp, Plevin, Luderer, Minx, & Edenhofer, 2012) by assuming cost-optimal decisions, as opposed to the System Dynamics (SD) tradition, in which decisions rules are described from decision makers' realities and treated as parts of models that explain structural problems (Richardson, 2011; Sterman, 2018). This is the reason why the Grantham Institute, a climate research leader, became interested in this SD master thesis.

Alexandre Koberle (personal communication, May 25, 2018), a researcher at Grantham Institute and IPCC author, suggested a case study of a Brazilian public policy to understand how farmers involved in BE schemes make decisions that affect their own resilience and what could be learnt from the Brazilian experience, in line with the recommendations by Slade, Bauen and Gross (2014), who recommend the use of bottom-up approaches to inform the bioenergy policy debate, as well as Dooley, Christoff and Nicholas (2018), who demonstrate that current climate models, when applied to land use policy, may result in less consideration of social trade-offs. Daw et al. (2015) suggested the use of illustrative models to elicit taboo trade-offs in social-ecological systems and incorporate views of less-privileged actors.

Biodiesel policy in Brazil

Brazil is the second most important BE producer in the world and the first in the southern hemisphere (World Energy Council, 2016), with a longstanding tradition as an ethanol producer and a relatively recent role in the biodiesel (BD) arena. A landmark in the history of BD in Brazil was the establishment of the National Program of Production and Use of Biodiesel (PNPB: *Programa Nacional de Produção e uso de Biodiesel*) in December 2004 (Brazil, 2004). The policy has three declared objectives (MDA, 2019, translated by the author):

- *To implement a sustainable programme, promoting social inclusion;*
- *To ensure competitive prices, quality and biodiesel supply;*
- *To produce biodiesel from different oilseeds, strengthening the regional potentialities for the production of biodiesel supply.*

As shown in Figure 1, most of this BD is currently produced from soybeans (ANP, 2019b – April 2019), which means that it is a by-product of the soybean meal, considered the main product extracted from the beans. In the south region of the country, where this research was conducted, the prevalence of soy is slightly higher, amounting to 74.79% of the total crops utilized in BD (ANP, 2019b – April 2019).

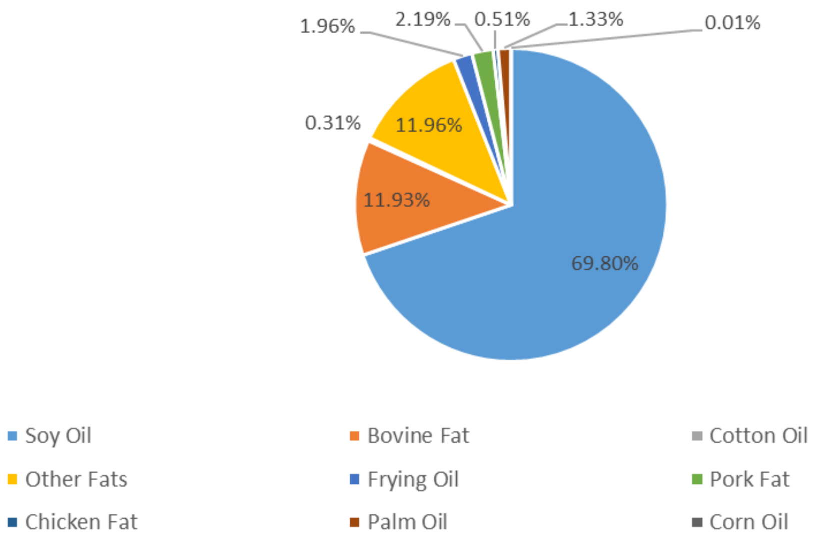

Figure 1. Breakdown of sources of biodiesel in Brazil in April 2019 (ANP, 2019b)

One of the key policy instruments utilized in the PNPB is a mandatory blend enforced by the National Oil Agency (ANP). Diesel importers and producers within the Brazilian territory are obliged to mix a percentage of pure BD (known as B100) into the diesel they sell in the country. This percentage has been increased over time by the country's authorities, as shown in Table 2 (ANP, 2019):

Table 2

Evolution of mandatory B100 blends on diesel (ANP, 2019)

Year	**Blend**
2006	2% (optional)
2007	2% (optional)
2008	2%-3%
2009	3%-4%
2010	5%
2011	5%
2012	5%
2013	5%

2014	5%-7%
2015	7%
2016	7%
2017	7%-8%
2018	8%-10%
2019	10%-11%

Another important component of PNPB is the Social Fuel Stamp (SCS: *Selo Combustível Social*), a social programme to include smallholder farmers in the BD supply-chain (Brazil, 2004; Brazil, 2005; SEAD, 2018). As a social criterium, BD refineries must buy a minimum fraction of their crops from smallholder farmers in order to have the right to participate in the B100 auctions. This fraction varies according to the region where the farmers are located: 15% in the North and Midwest, 30% in the Southeast and Northeast and 40% in the South of Brazil. This percentage can be discounted if the refinery buys from underprivileged crops, underprivileged regions or from cooperatives, especially if more than 80% of cooperative members are smallholders (SEAD, 2018).

In exchange to complying with this social criterium, refineries have access to the government-organized auctions where at least 80% of the acquisitions must obey the social criterium. In these auctions, diesel importers and diesel refineries that are obliged to add B100 to their products buy B100 from certified BD refineries. The acquisitions that obey the social criteria also pay lower taxes that end up adding an extra profit margin ranging between 4% and 12% of the commercial price of diesel to the BD refineries (Hall, Matos, Severino & Beltrão, 2009; La Rovere, Pereira & Somoes, 2011; IPEA, 2011).

SCS created an entire market structure for smallholders to be able to participate in the dynamic BD market, but also posed a risk of unbalance between small and large-scale actors (Abramoway & Magalhães, 2013). Da Silva César, Conejero, Ribeiro and Batalha (2018) characterize a “social soybean” production chain generated by PNPB and SCS, where sometimes BD refineries pay premium prices to smallholder farmers in order to ensure their supply and compliance with the SCS requisites. The concept of smallholder farmer is also defined by law in Brazil, varying across regions. In the researched region, they have to be under 80 hectares to be considered smallholders.

However, this set of policies seem to have created a concentrated market, with a small number of BD refineries which has stabilized in the latest years despite a growth in revenues (Antoniosi & Maintinguer, 2016), possibly generating a concentration of bargain power and profit margins in the hands of these players, expressed in both crop and land prices, the basis of the preliminary dynamic hypothesis on this paper. Figure 2 shows the evolution of the mandatory blend and the number of refineries in Brazil (ANP, 2019).

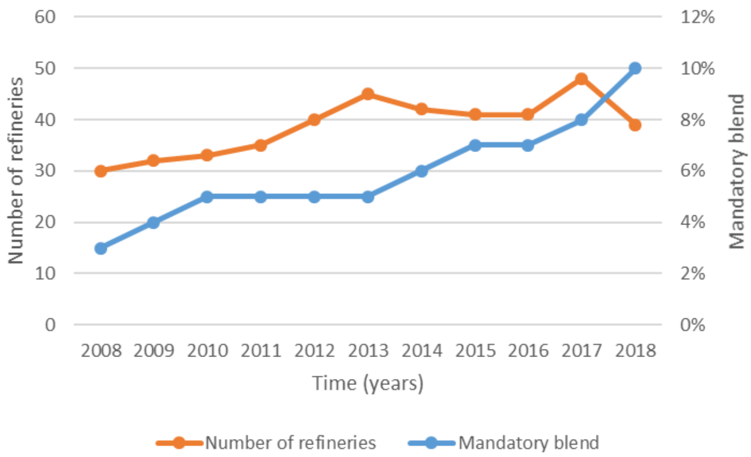

Figure 2. Evolution of number of refineries and the % mandatory B100 blend (ANP, 2019).

Da Silva César, Conejero, Ribeiro and Batalha (2018) interviewed several actors and analyzed the institutional structure of the social biofuel programme to conclude that producers tend to buy from small farmers only because of the benefits from the programme; the south of Brazil benefits more from these institutional pressures, as the local farmers are more organized. Martinelli and Filoso (2008) had already argued the same point about the ethanol policies.

This is also in line with Machado (2018), who found that recent policies have not contributed to the climate resilience of small farmers in the Northeast, the poorest region in the country, despite positive short-term impacts on life quality and drought management. In fact, the south of Brazil and, especially, Rio Grande do Sul state (RS) prevailed in the adherence to SCS at least until 2017, as shown in Figure 3 below (SEAD, 2018b), which also portrays a recent decline in the number of smallholder families involved in the SCS scheme.

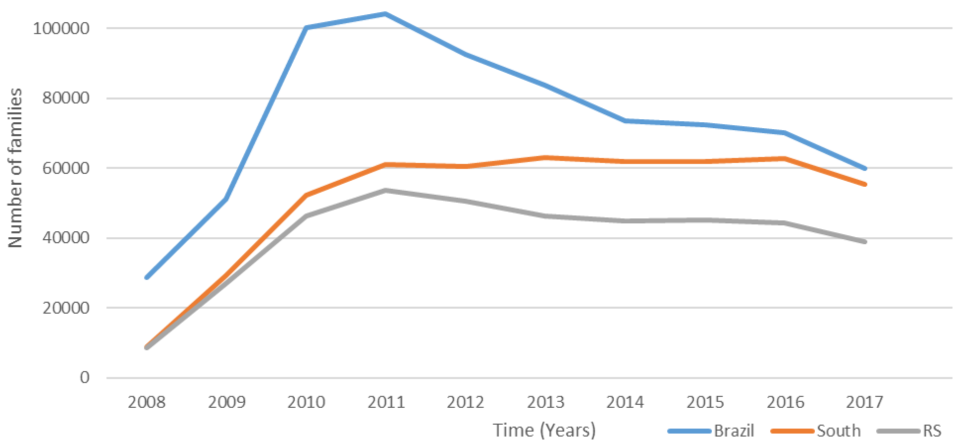

Figure 3. Number of families in SCS in the country, south region and RS state (SEAD, 2018b).

Lima, Skutsch, and De Medeiros Costa (2011) found evidence of land concentration generated by the PNPB program, despite acknowledging existence of evidence of social inclusion of smallholders in some cases. These paradoxes in policy-design level are discussed by Fernandes, Welch, and Gonçalves (2010), who argued that BE crops have "changed the processes of land acquisition and use by both agribusiness and the peasantry", making conflicts between them more explicit. Weinhold, Killick and Reis (2011) had already empirically related the advancement of soybean crops to economic inequalities in Brazil. Rathmann, Szklo, and Schaeffer (2012) demonstrate that the BD policies in Brazil fail to generate jobs and fail to tackle the regional inequalities in the country.

As a matter of fact, in 2009, Hall et al. had already alerted that the Brazilian BD programmes could be evolving in the wrong direction, because of their tendency to favour large-scale production schemes. The contracts between farmers and refineries, involving price negotiations, were treated as a key arena that defines the outcomes, as also pointed by Garcez and Souza Vianna (2009).

Although they still have an advantage in terms of profitability when compared to the average of soybean farmers, participating smallholders' margins are being gradually squeezed, as shown in Figure 4.

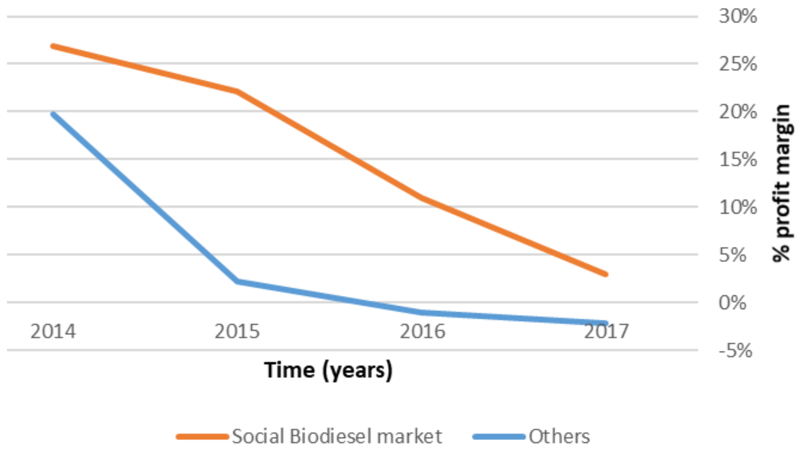

Figure 4. Farmer profit margin from soybeans within and without SCS (elaborated by the author with data from SEAD, 2018b and Secretaria da Agricultura, 2018).

Meanwhile, the BD refineries' profit margins seem to be on the rise. Although few refineries have their financial data disclosed, one of the refineries cited by farmers in this study has had an impressive growth in assets in the last years (Figure 5):

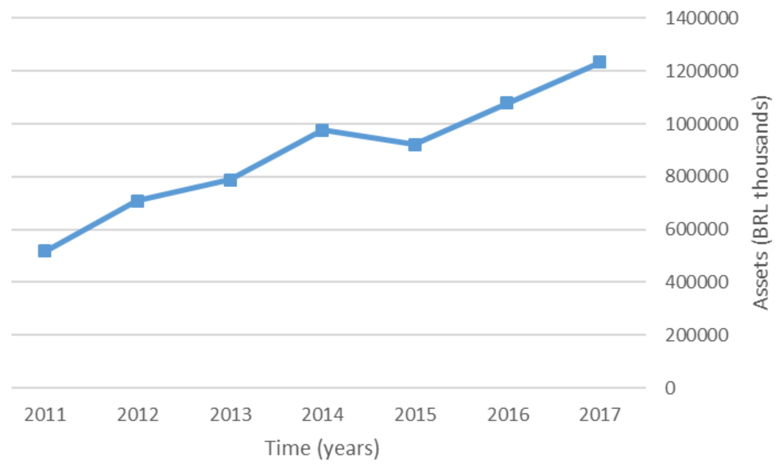

Figure 5. Assets of BD refining company in thousands of Brazilian Reais (BRL), elaborated by the author with data from Diário Oficial, 2019 and Corag, 2019.

Part of the decline in farmer profit margins is explained by the soaring land prices, which increase costs (in the case of rented land) and opportunity costs (in the case of land owned by the farmers themselves), as shown in Figure 6 below.

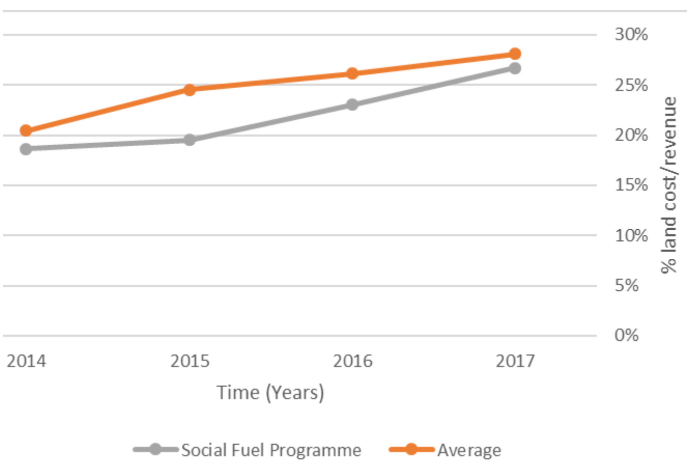

Figure 6. Land cost over revenue ratio in Rio Grande do Sul state in and out of SCS (Secretaria da Agricultura, 2018 and SEAD, 2018b).

Egeskog et al. (2016) interviewed Brazilian farmers in the ethanol supply-chain about decisions regarding land use to conclude that they see BE crops as a diversification strategy from other crops and are willing to buy more land if land prices decline. Martinelli and Filoso (2008) had pointed that the ethanol policies in Brazil did not generate the intended benefits for small farmers.

Therefore, it is possible to observe that land prices and crop prices are consistently mentioned in a specialized body of literature as sources of power and control by large-scale agents over smallholder farmers in the context of BE (including BD) schemes. The risks of these schemes playing a destructive role and, ultimately, compromising smallholders' livelihood is explained in qualitative and/or static terms, but no quantitative dynamic demonstration of the plausibility of this hypothesis has been conducted.

Initial hypothesis and objectives

Based on this context, an initial hypothesis (Figure 7) was established. It is characterized by a hypothetical "success to the successful" situation (Senge, 1990, p. 113) where the social biodiesel policy is supposedly fostering the bargain power of refineries (also known as producers, as seen in the R2 feedback loop) as opposed to bargain power of smallholder farmers (R1 feedback loop). Such increased bargaining power means that refineries could be controlling the land and crop markets, looking for a hegemonic position within the production chain and gradually constraining the farmers profit margins, which then makes farmers more prone to selling their land to the refineries themselves.

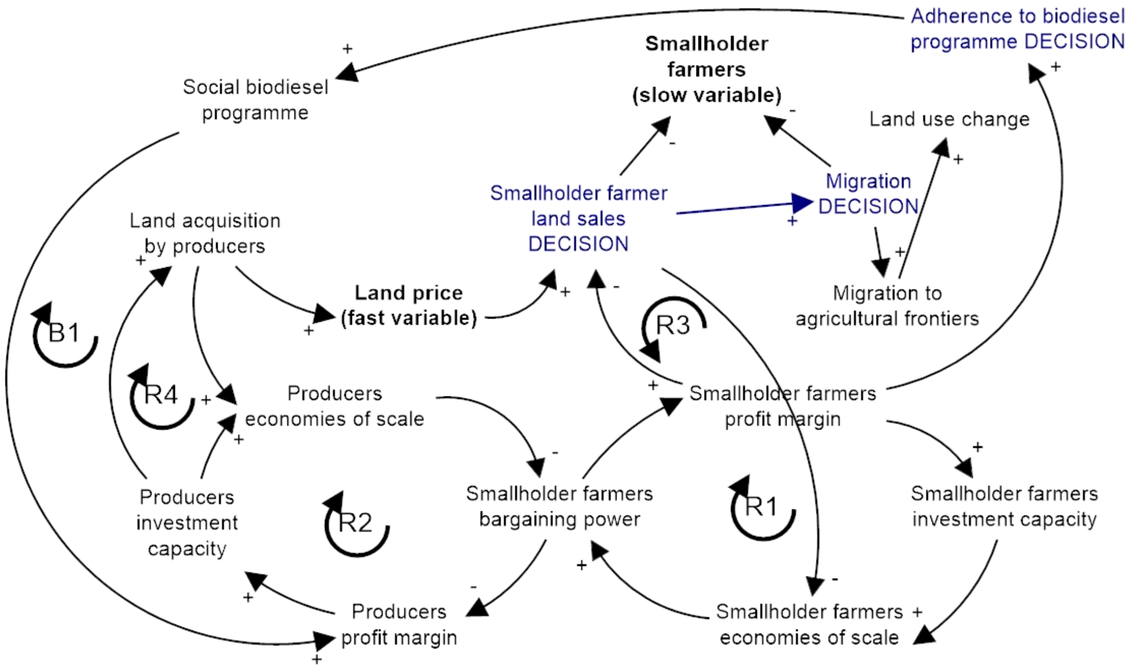

Figure 7. Initial dynamic hypothesis, elaborated by the author

In this causal loop diagram, if any reinforcing loop except R1 dominates, there is a depletion of the 'smallholder farmers' variable, which is potentially a variable determining resilience. R1 domination indicates the opposite: an increasing resilience of small farmers, helped by their adherence to BE crops and the social biodiesel programme. In case B1 dominates, the situation might be tragic for both farmers and producers. Table 3 describes the feedback mechanisms in this initial dynamic hypothesis.

Table 3

Feedback loops of the initial hypothesis, elaborated by the author

Feedback loop	**Description**
R1: Rampant farmer domination	Smallholders' production scale and investment capacity are continuously fed by the profit margins they obtain from producers, which is a result of bargaining process.

R2: Rampant refinery domination	Refineries have more bargaining power if their economies of scale grow disproportionally more than the farmers. The social biodiesel programme increases their profit margins via subsidies.
R3: Vicious farmer scale loss	The more land farmers decide to sell the lower their economies of scale become, which makes them sell even more land.
R4: Rampant refinery domination by increasing land scale	Land acquisition and the consequent gains of scale might help refineries increase their bargaining power.
B1: Programme stagnation by lack of attractiveness for farmers	The social biodiesel policy depends on producers maintaining a minimum amount of their supply coming from smallholder farmers. In case this does not happen, the entire programme might fail, removing the subsidy to refineries.

By testing the dynamic plausibility of this hypothesis, **this research aimed to build a dynamic understanding of the effects of recent Brazilian BE policies (PNPB and SCS) in Brazilian small farmers' resilience.** The objective is further underpinned by the research questions and their consequent research strategy (see Methods).

Research Question 1: What are the threats for the resilience of smallholder farmers involved in the social biodiesel programme, especially those generated by the existence of the programme itself?

Research Question 2: Which heuristics, decision rules and thresholds guide smallholder farmers' decisions that relate to their own resilience?

Research Question 3: What happens to smallholder farmers involved in SCS when severe resilience loss (or regime shift, in the resilience jargon) occurs?

Methods

This thesis utilizes a multimethod process suggested by Herrera (2017) to analyze resilience using a system dynamics modelling approach. The concept of resilience here builds on a tradition initiated by Holling (1973), who characterizes resilience as the ability of a *system* to absorb *changes* of different variables.

The first step of Herrera's (2017) approach is conceptualization, the definition of resilience of what to what. Specialized literature claims that resilience research must be defined in terms of "resilience of whom to what" (Carpenter, Walker, Anderies & Abel, 2001: 1). The *system* of interest in this research is small-scale farming in Brazil. To be able to further characterize it, a territorial focus in the south of Brazil was adopted, more specifically on the Rio Grande do Sul state, the most important BD state in the country. It is understood that, if a farmer abandons the farming activity in a given region of Brazil where BE crops are relevant, this means her resilience is compromised. If this becomes the case for a relevant fraction of the farmers in that region, then the resilience of the small-scale farming *system* in the region is compromised. The researched *changes* are the above-mentioned public policies (PNPB and especially SCS). Resilience is therefore not treated as a single variable, but analysed as a state or a feature of the *system*. Differently from other applications of system dynamics, resilience studies using system dynamics do not necessarily aim to explain all the observed behaviours from structure, but rather to interrogate to what extent system structure resists to shocks or *changes*.

Another key principle in resilience literature is the slow versus fast variable approach (Carpenter & Gunderson, 2001; Gunderson, Holling, Pritchard & Peterson, 2002; Walker, Carpenter, Rockstrom, Crépin & Peterson, 2012). Resilience of socio-ecological systems is considered compromised when the relationship between a key slow and a key fast variable in a *system* moves away from a long-standing state, usually called an attraction basin, depicted in a phase diagram. When this happens, the *system* ceases to exist as previously observed, generating a regime shift.

It is hypothesized that 'number of soy smallholder farmers' (number of small farmers in a region) and 'land prices', depicted in Figure 7 above, are the slow and fast variables, respectively.

This initial dynamic hypothesis (Figure 7), step 2 of Herrera (2017) approach, was based in the above-mentioned literature as well as in a preliminary documental analysis of public data to identify reference behaviours of the *system* (Figures 2 to 6).

The third step (Herrera, 2017) is the construction of a simulation model (see Model Documentation at Annex 1). For this research, a state-level, soybean-only system dynamics model was built using the modelling software Stella, based on documental analysis of interview transcripts and mostly official sources (ANP, 2019; SEAD, 2018, 2018b; Cavalcante, de Sousa & Hawamaki, 2011; Conab, 2018, 2018b, Secretaria de Agricultura, 2018; IBGE, 2019; Barr et al, 2011; IMEA, 2019; Diário Oficial, 2019; Corag, 2019; ESALQ/USP, 2019; BiodieselBR, 2019) that contained model parameters. The model runs from 2008, when the policy started to be concretely implemented in the state and more consistent datasets started to be made available, until 2050, often the final year in climate research.

Interviews are important in this process because, as argued by Forrester (1992), eliciting non-written data is key to understand decisions. In the non-SD resilience literature, this is echoed by Rogers et al. (2013), who claims for the incorporation of unconscious knowledge and limitations in the context of research about change in social–ecological systems. Luna-Reyes and Andersen (2003) suggest interviews as one of the methods for model formulation. Semi-structured interviews were therefore conducted firstly with farmers until a convergence was observed in the description of systemic phenomena, as performed by Kopainsky, Hager, Herrera, & Nyanga (2017), also observing the disconfirmation strategies proposed by Andersen et al. (2012) (see interview scripts at Annex 2).

The interviews were conducted by the author, accompanied by an intern of the local agricultural extension office, in the Nova Prata and Veranópolis municipalities, located in Rio Grande do Sul, the main BD state and one of the most developed states in the country. Traditionally, agriculture in these municipalities used to be associated with corn for silage purposes, embedded in the milk supply chain. The transition to soybeans is still perceived as a recent phenomenon as milk is now perceived as a very low-margin product. Two BD processors are active in the region (hereby denominated Refinery A and Refinery B).

The interviewees were:

- 8 smallhoder farmers (average area 51 hectares, median 50 hectares, standard deviation 26.03; approximately 30% of the land they use is rented);

    - 3 of them have soybeans as the main crop, 3 as the 2nd main crop, 2 as the 3rd main crop
    - 3 of them sell soybean grains to BD Refinery A, 1 has sold to Refinery B in the past
- Refinery B founder and current executive director along with his supply manager;
- Manager of the local agricultural extension office.

A sequence of procedures described by Turner, Kim and Andersen (2014) from discovering themes to defining a model structure was adopted (see coding table at annex 3). Their price thresholds in terms of selling land and leaving the BE crops were elicited using nonlinearity elicitation procedures suggested by Ford and Sterman (1998).

As for documental analysis used to determine parameter values involving more consolidated causal relations, the procedure was to download all publicly available datasets involving soy and BD. 31 datasets were found online using this criterium, as shown in Table 4 below, and use them when necessary.

Table 4

Datasets used for documental analysis, elaborated by the author

Dataset	**Crop**	**Source**	**Period**	**Frequency**	**Scale**
Planted Area	Soybeans and others	Conab	1976-2019	Year	State, Region, National
Production	Soybeans and others	Conab	1976-2019	Year	State, Region, National
Productivity	Soybeans and others	Conab	1976-2019	Year	State, Region, National
Supply&Demand (Inventory, Import&Export, Supply, Consumption)	Soybeans and others	Conab	1999-2019	Year	National
Prices	Soybeans and others	Conab	2014-2018	Month	State

Farming costs	Soybeans and others	Imea	2009-2019	Year	State (Mato Grosso only)
Grain price	Soybeans	Imea	2016-2019	Daily	State (Mato Grosso only), Microregions within Mato Grosso
Soy meal price	Soybeans	Imea	2016-2019	Weekly	State (Mato Grosso only), Microregions within Mato Grosso
Soy oil price	Soybeans	Imea	2018-2019	Weekly	State (Mato Grosso only), Microregions within Mato Grosso
Producers (refinery list)	BD	SEAD	Current	NA	Municipal, State, National
Number of producers (refineries)	BD	SEAD	2015	Year	Region
Number of families in the Social Fuel Programme	BD	SEAD	2008-2017	Year	State, Region, National
Number of cooperatives in the Social Fuel Programme	BD	SEAD	2008-2017	Year	State, Region, National
Volume of crops acquired within Social Fuel Programme	BD	SEAD	2008-2017	Year	State, Region, National
Total value of crops acquired within Social Biodiesel Programme	BD	SEAD	2008-2017	Year	State, Region, National
BD Production	BD	SEAD	2008-2017	Year	National
Value of acquired crops (individual farmers vs cooperatives)	BD	SEAD	2008-2017	Year	National

Crop breakdown	Multiple	SEAD	2008-2017	Year	National
Crop and cooperative vs individual breakdown	Multiple	SEAD	2017	Year	State
Investment in technical assistance by producers	BD	SEAD	2010-2016	Year	National
Refinery Financial Statements	BD(from soy and palm) & wind energy	Procergs	2017	Year	National
Refinery Financial Statements	BD(from soy and palm) & wind energy	Corag	2011-2016	Year	National
BD Sales	BD	ANP	2016-2018	Month	State
Auctions (number of sellers, volume, price)	BD	ANP	2006-2019	Bimonthly	State, Region, National
BD Production	BD	ANP	2018	Month	Region
Crop breakdown - BD Production	Multiple	ANP	2018	Month	Region
Farming costs	Soybeans	Sec Agricultura RS	2009-2017	Year	State (Rio Grande do Sul only)
Crop prices	Soybeans and other major crops	ESALQ/USP	1997-2019	Daily	State (Paraná)
Crop prices	Soybeans and other major crops	ESALQ/USP	2006-2019	Daily	Port (Paranaguá)
Several	BD	BiodieselBR	2008-2019	NA	National
Land occupation	NA	IBGE	2006 and 2017	Year	Municipal, State

The fourth step (Herrera, 2017) is model testing and confidence building. Barlas (1996) guided model testing within this research. Each exogenous variable, including existing policies, was tested individually with a range of 10% positive and negative variation (20 runs for each variable, Latin Hypercube, uniform distribution).

Extreme value testing was also performed for all variables. Behaviour-structure tests were conducted during model calibration and helped refine model structure.

In example, in Figure 8 below, the final (year 2050) simulated number of smallholders and land prices are depicted on a phase diagram that results from this type of sensitivity test for a variable called “minimum farmer land sales price”. On this graph, each coloured dot results from a different sensitivity run. The variable is sensitive for both number smallholders and land price, indicating that this variable could be an important driver of regime shifts according to the *fast vs. slow variable approach* in resilience studies.

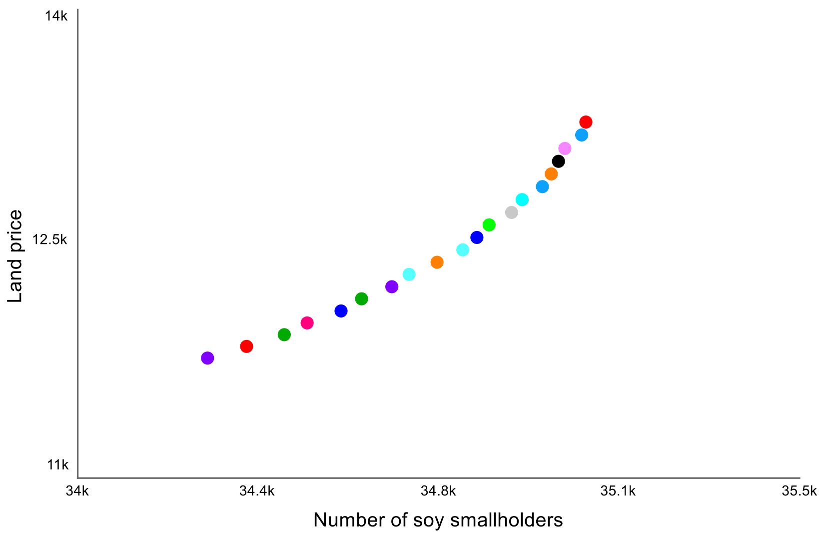

Figure 8. Phase diagram depicting sensitive analysis of “minimum farmer land sales price” for slow and a fast variable, elaborated by the author

Following the sensitivity analysis for each individual variable, all the variables that were deemed sensitive for ‘number of soy smallholder farmers’ were tested again in multiple combinations which each other (200 runs, Latin Hypercube, uniform distribution), in order to allow an analysis of the multiple possible simulation outcomes depending on their values.

Counting both the fourth and the fifth steps in Herrera (2017), 31 versions of the simulation model have been built. This includes model iteration from documental analysis (interview transcripts and other data sources), calibration (using reference modes of behaviour such as Figures 2 to 6) and structural corrections generated by structure tests.

Then - already in the fifth step of Herrera (2017), policy analysis - a third type of sensitivity analysis was conducted according to three policy paradigms inspired by Walker et al (2004):

- Resilience: 'number of soy smallholder farmers' must not plummet, which relates to the first objective of PNPB (*To implement a sustainable programme, promoting social inclusion);*

- Adaptability: farmer assets (including land and cash) must stay above bond-adjusted levels to allow livelihood change when needed or desired, responding to an almost unavoidable rural exodus detected on the interviews. Government bonds are used as a parameter for comparison with farmer assets as these virtually risk-free returns represent a cost of opportunity the farmers face. If their farming activity is not profitable, they would rather leave the money invested in public bonds, earning the government interest rate;

- Transformability: the policy objective is considered to be a change in the supply chain aiming to maximize the output of B100, which relates to the second and third objectives of PNPB (*To ensure competitive prices, quality and biodiesel supply;*
  To produce biodiesel from different oilseeds, strengthening the regional potentialities for the production of biodiesel supply).

Transformability in this research is intentionally reduced to the ability to conduct one specific transformation (an increased output of B100).

To be able to conduct this policy analysis, two scenarios were created besides the base case, based on a consolidated farmer migration typology known as the push-pull typology (Dorigo & Tobler, 1983; Jedwab, Christiaensen & Gindelsky, 2014; King, 2012). Table 5 depicts these scenarios, created to allow policy analysis under different circumstances. They were created by varying sensitive variables (see Results of sensitivity analysis) that relate to both "push" and "pull" farmer migration pressures to the limit of the tested (plus and minus 10% range). An exception was made to 'Min_farmer_land_sales_price' in the pull scenario, where the value (8000 BRL/hectare) is below the minimum tested value at parameter sensitivity analysis. This exception was made due to the need of testing a pull pressure strong enough to make farmers in the model sell their land at a price slightly above the initial price (6000 BRL/hectare).

Table 5

Definition of scenarios based on sensitive variables, elaborated by the author

Variable	Range	Scenario 1 - Base case	Scenario 2 – Agricultural "push" pressures	Scenario 3 – Urbanization" pull" pressures
Grain price	890-1090 BRL/tonnes	~1000 BRL/tonne (from dataset)	**890 BRL/tonne**	**1090 BRL/tonnes**
Initial_other_commodities	2700000-3300000 hectares	3000000 hectares	3000000 hectares	3000000 hectares
Initial_soy_land	2700000-3300000 hectares	3000000 hectares	3000000 hectares	3000000 hectares
Market_control_premium	1-1.2 [unitless]	1	1	1
Meal_price	1200 – 1450 BRL/tonne	~1320 BRL/tonne (from dataset)	**1200 BRL/tonne**	**1450 BRL/tonne**
Min_farmer_land_sales_price	10800-13200 BRL/hectare	12000 BRL/hectare	12000 BRL/hectare	***8000 BRL/hectare***
Minimum_crop_rotation	0.27-0.33 [unitless]	0.3	**0.33**	0.3
Ref_productivity	2.4-3.3 tonnes/hectare	2.7 tonnes/hectare	**2.4 tonnes/hectare**	2.7 tonnes/hectare

The three scenarios were also tested in the context of absolute absence of BD and BD policy in the system, to allow broader 'what if' analyses that attempt to assess PNPB as a whole.

The push scenario implies a negative variation in crop and meal prices and productivity that could expel farmers from rural areas, whereas in the push scenario the urban economy in the country goes hypothetically well, with soy meal being sold at high prices and the farmers being attracted to cities, therefore asking a low price for their land.

Another analytical tool called variance analysis (Brand, 2008; Brock & Carpenter, 2006; Wade, Ritters, Wickham & Jones, 2003; Wissel, 1984) was implemented to be able to determine in which cases there is a probable regime shift in the *system* of interest. This was an attempt by the author to give a model-based response to an operationalization need that is explicit in the resilience literature since Holling (1973), who discussed the limits of stability analyses (such as the model-based ones proposed by Herrera, 2017). Herrera (2017) employs a visual criterium to determine the cases where regime shift occurs: if, after recovering from a shock, a key analysed variable returns to a level similar to the original, Herrera (2017) considers there is no regime shift. The unanswered question is then how different from the original state the variable has to be for a regime shift to be assumed. Variance analysis looks for a firm criterium to detect regime shifts: the presence of abnormal variances in the key variables of the system.

Basically, the idea of variance analysis in the context of resilience studies is to track variance of key variables over time to be able to affirm how intense these variables' variations was in different periods. Given that key variables vary a lot just before and during regime shifts (Wissel, 1984), the periods of more intense variation (higher variance) of these key variables might indicate the occurrence of a regime shift in a given period. This calculation was accomplished by exporting model data from Stella to Microsoft Excel and calculating variances over time on Excel.

Regime shifts are here defined as "substantial, long-term reorganizations of complex systems such as societies, ecosystems or climate" (Brock & Carpenter, 2006).

Results

The model

The semi-structured interview process impacted the model dramatically from the initial hypothesis (Figure 7). Interviewees described two broader processes that they see as more important than the emergence of the BD supply chain.

The first process they describe is verticalization and bargaining throughout the entire supply chain, not only by refineries, but mostly by other players: (pesticide, seed and fertilizer) suppliers, harvester owners, storage companies. These players sometimes play several roles in the supply chain. They often buy land. Suppliers even take land as guarantee in the contracts they forge with farmers. Table 6 shows some of the role allocations within the supply chain as described by interviewees, demonstrating that the six key roles described by interviewees overlap each other.

Table 6

Description of some of the roles in the supply chain after interview analysis, elaborated by the author from interview transcripts

	Supplier	**Farmer**	**Harvester provider**	**Storage provider**	**Broker**	**Processor (includes refineries)**
Refinery A	Yes	Yes	No	Yes	Yes	Yes
Refinery B	Yes	Yes (not in the region)	No	No	No	Yes
Typical harverster provider	No	Yes	Yes	No	No	No
Typical storage player	No	Yes	No	Yes	Yes	No

The second process they describe is rural exodus dynamics, including attractiveness of urban areas, lack of succession as farmers' children do not want to stay in rural areas, subletting or selling land to bigger players and, sometimes, regretting and returning to rural areas. This second process, although not fully endogenized in the simulation model, is represented by the pull migration scenario.

Among all risks and difficulties reported by interviewees, not all of them were incorporated to the simulation model, as some of they were too far from this thesis' objectives and research questions. Table 7 shows the cited risks and their incorporation to the simulation model:

Table 7

Risks mentioned by interviewees, elaborated by the author from interview transcripts

Risks	**Consideration in the model**
Abuse of economic power and land acquisition by harvester owners	Yes
Land price variation	Yes
Lack of succession	No
Drought	Not directly, but through productivity shocks
Storms	Not directly, but through productivity shocks
Limits imposed by environmental regulation	No
Corrupt buyers	Yes
Physical exhaustion due to sun exposure	No
Truck driver strike	Not directly, but through logistical costs
Fertilizer and pesticide prices	Yes
Crop price instability	Yes
Lack of available land	Yes
Frost	Not directly, but through productivity shocks
Work burnout	No
Health risks due to exposure to pesticides	No
Risk of financial default from cooperative and brokers	No
Access to water	No
Low quality of roads	Not directly, but through logistics costs

Some of the risks that were previously hypothesized by the author, present in the interview scripts, such as food security of farmer families, have been rejected by the interviewees.

Not all the decision rules described by interviewees were incorporated to the model, as shown in Table 8. Some of them occur in a completely different level of aggregation, others would require an expansion of the model boundaries to such an extent that would be incompatible with the purpose of this study.

Regarding the destination of farmers who leave the farming activity (Research question 3), a unanimous reaction was that they migrate to urban areas. Some regret later and try to return.

Table 8

Decisions mentioned by interviewees, elaborated by the author from interview transcripts

Decisions	**Consideration in the model**
When to sell crops within the harvest year	Yes
Land acquisition	Yes
Land sales	Yes
Expansion of crop land by renting	Yes
Choice of crop buyer	Not directly, but through % biodiesel processed by refineries
Minimum acceptable soy price	Yes
Crop diversification/rotation	Yes
Migration to urban areas	Not directly, but through minimum land sales price
Difficult registration to sell to BD Refineries within SCS	Not directly
Acquisition and application of pesticides and fertilizers	Yes

Harvester ownership	Yes
Dependency of debt	No
Acquisition of microrefinery	No
Storage ownership	Yes

To be able to consider the supply chain dynamics described by the interviews, the model now incorporates not only farmers and refineries, but also suppliers, harvest owners, storage players and brokers. All these players can acquire land in the model. The author had not anticipated, at the beginning of this study, that these players would be treated with such importance by the interviewees.

Consequently, several stocks that did not exist in the initial versions of the model had to be introduced, as shown in Figure 9. Conversions among different types of land, to soy grain, soy meal, soy oil (not necessarily used for fuel) and B100 are possible in this model.

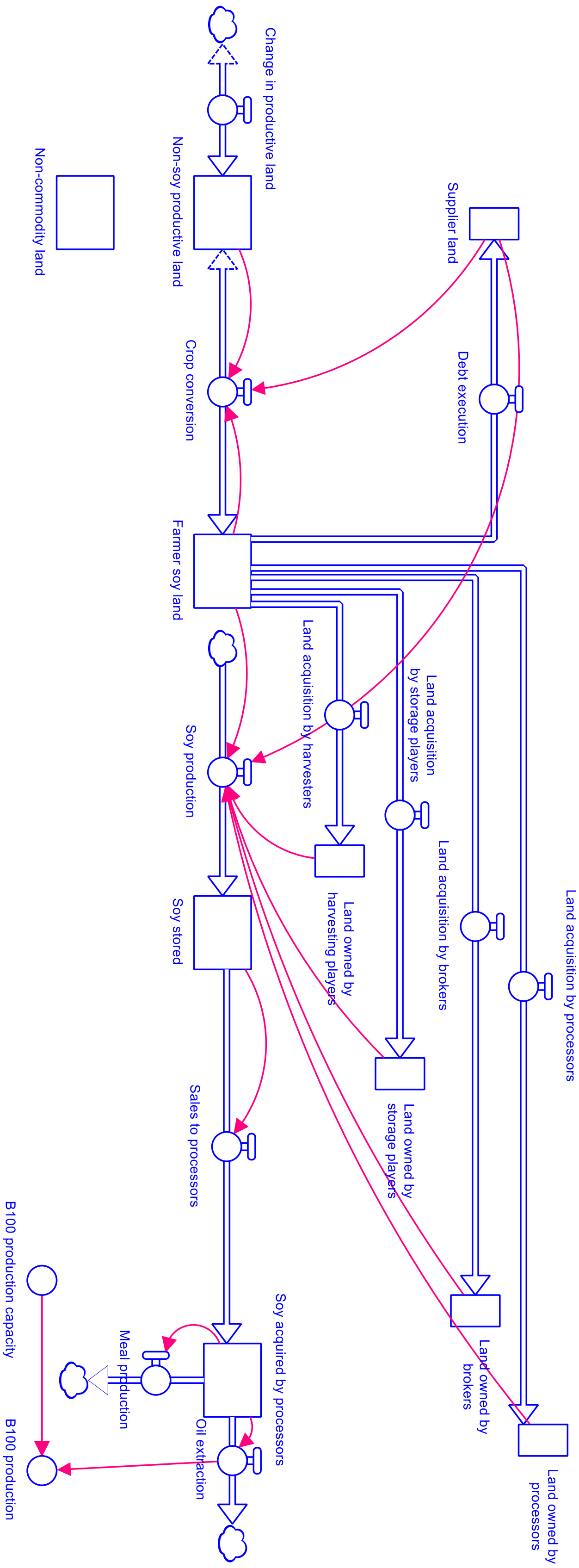

Figure 9. Extract from the model showing soy and BD production chain, elaborated by the author

The new model, summarized in the causal loop diagram below (Figure 10) and its respective feedback mechanism description (Table 9), is therefore able to simulate different types of land conversion (to/from other commodities, to other players, into soy, into soy oil, into soy meal).

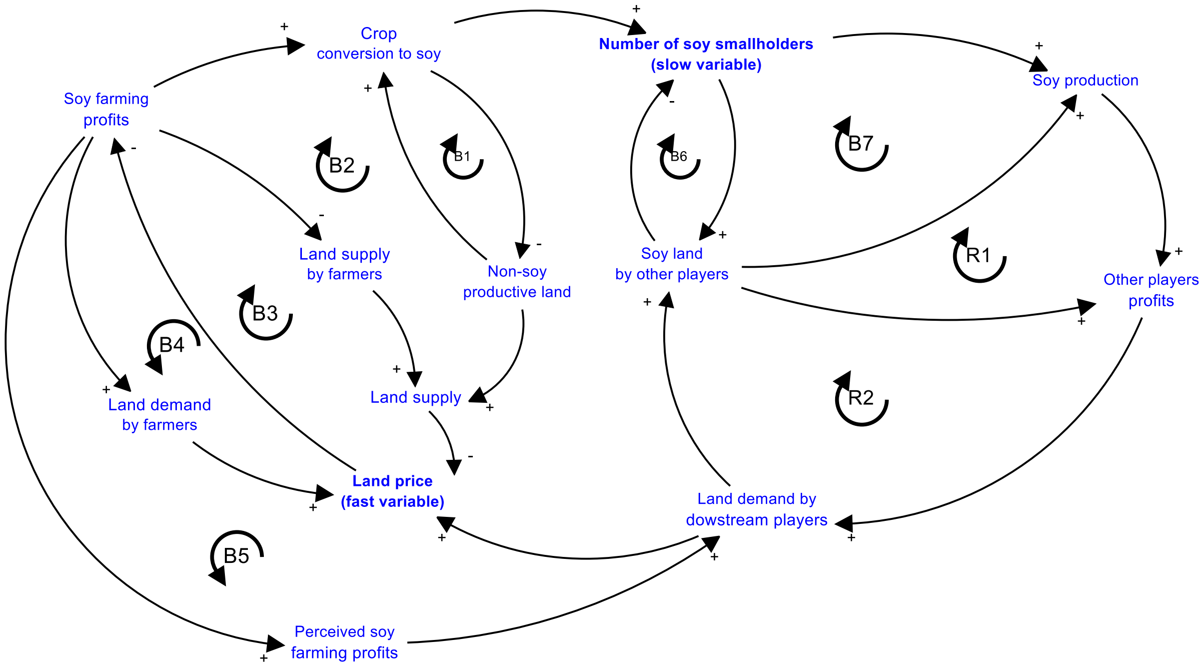

Figure 10. Second hypothetical causal loop diagram, elaborated by the author

Table 9

Feedback mechanisms on the second hypothesis, elaborated by the author

Feedback loop	**Description**
B1: crop choice balance	As soy requires a minimum level of crop rotation, other commodity crops cannot be infinitely depleted.
B2: land market control by limited supply	Lower land supply should generate higher prices and less conversion to soy.
B3: land market control by limited profits	When land is too expensive, farming is less profitable, which makes farmers willing to sell land, controlling land price.
B4: land market control by limited demand	Demand can only drive land price increase until before it starts affecting farming profits.

B5: land market balance by farmers and other players	Downstream players buy land when they perceive the farming activity as profitable, but their interest also makes land prices higher, which limits farming profits.
B6: land ownership balance	Farmer land ownership counteracts other players' ownership.
B7: production limits by lack of farmers	When other players verticalize too much, soybean production by farmers is smaller. Especially in the context of SCS, where a minimum level of smallholder presence must be maintained, this loop limits production.
R1: amplification of downstream profits by soy production	The more soy is grown in a given region, the more other players will profit from its production chain.
R2: amplification of downstream profits by land expansion	Other players, whenever they verticalize to agriculture, also benefit from farming profits, which makes them buy even more land.

The model also contains a cashflow calculation structure for each of these players with a cost structure that is more detailed in the case of farmers and refineries (and, therefore, less detailed for other actors).

An observer structure built to assess the assets (cash, land and installed capacity) of players with given combinations of market shares in different activities throughout this supply chain. In this research, this structure was mostly used to calculate smallholder farmers assets evolution over time.

Parameter sensitivity analysis

Of all exogenous variables in the model (see sensitivity documentation at Annex 4), only eight, depicted in Table 10 and on the causal loop diagram on Figure 11, impact the number of soy smallholders significantly. Six of them also impact land prices. It is important to observe that the biodiesel switch, that removes all the processes related to biodiesel when turned off, is not sensitive for 'number of soy smallholder farmers', which might indicate BD policies do not play such an important role as initially hypothesized.

Decision variables that were pointed by interviewees as important, such as '% land owned' (as opposed to rented), '% harvester owned', '% cash invested in land' do not appear on the list of sensitive variables. Other variables that are often treated as central in the local debate, such as the price premium and the prevalence of fraud also do not play such an important role according to sensitivity analysis.

Table 10

Sensitive variables, elaborated by the author

Variable	**Range**	**Also sensitive for 'land price'?**
Grain price	890-1090 BRL/tonnes	Yes
Initial_other_commodities	2700000-3300000 hectares	No
Initial_soy_land	2700000-3300000 hectares	No
Market_control_premium	1-1.2 [unitless]	Yes
Meal_price	1200 – 1450 BRL/tonne	Yes
Min_farmer_land_sales_price	10800-13200 BRL/hectare	Yes
Minimum_crop_rotation	0.27-0.33 [unitless]	Yes
Ref_productivity	2.4-3.3 tonnes/hectare	Yes

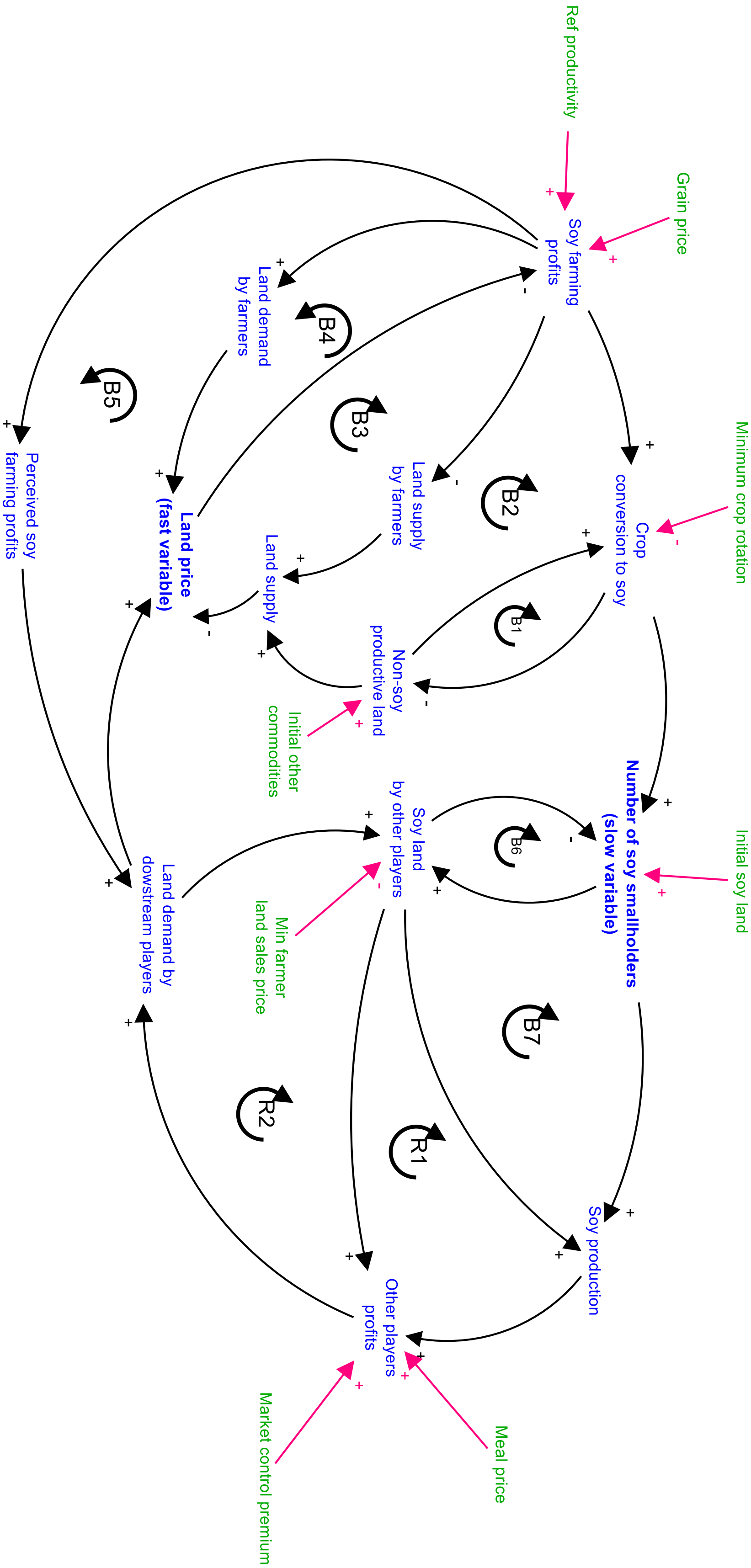

Figure 11. Second hypothetical causal loop diagram with sensitive variables, elaborated by the author

Aggregated sensitivity analysis of highly sensitive variables

If we test all these variables together (200 runs, Latin Hypercube, uniform distribution – Figure 12), we can see that, by the end of the simulation period (2050), the most probable outcome given the simulated ranges is the existence of less than 5,000 soy smallholders in the state. However, if we sum all possible outcomes between 25,000 and 40,000, these are more probable than the worst case.

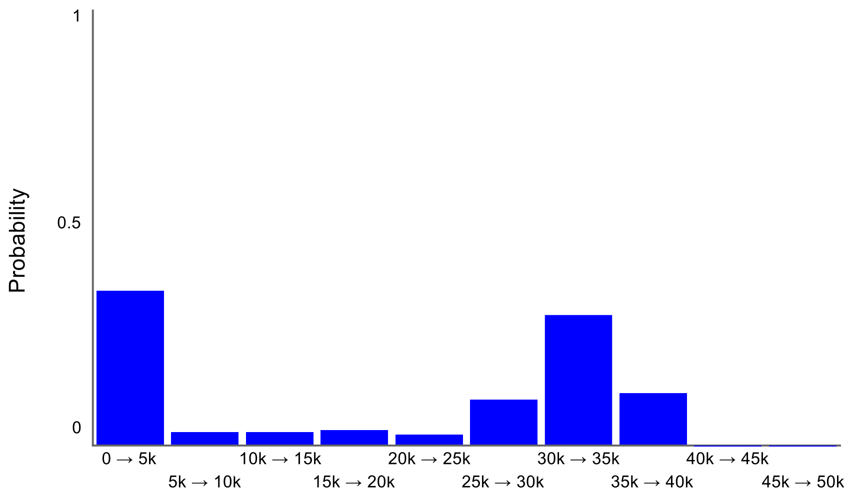

Figure 12. Probability distribution of the final simulation outcomes of number of soy smallholders given a 10% (+ and -) variation of sensitive variables, from model

Figure 13 shows that the level of uncertainty generated by this aggregated sensitivity test of the eight most sensitive variables in the model is high, as since the first ten years of simulation, a wide array of possible outcomes is seen. The fact that the 50% confidence interval is broad, shows that, although this is the more meaningful interval in terms of predictive power, this predictive power is very limited given the broad set of outcomes generated by the 20%-wide variation range in the sensitive variables.

This means these eight variables are either powerful leverage points, and therefore opportunities for policies, and/or deserve more attention to the way they are defined and parametrized. As their definition is straightforward and these are operational variables that can easily observed in reality, their potential for policymaking was considered enhanced. More analyses involving these variables are conducted in the next sections of this thesis.

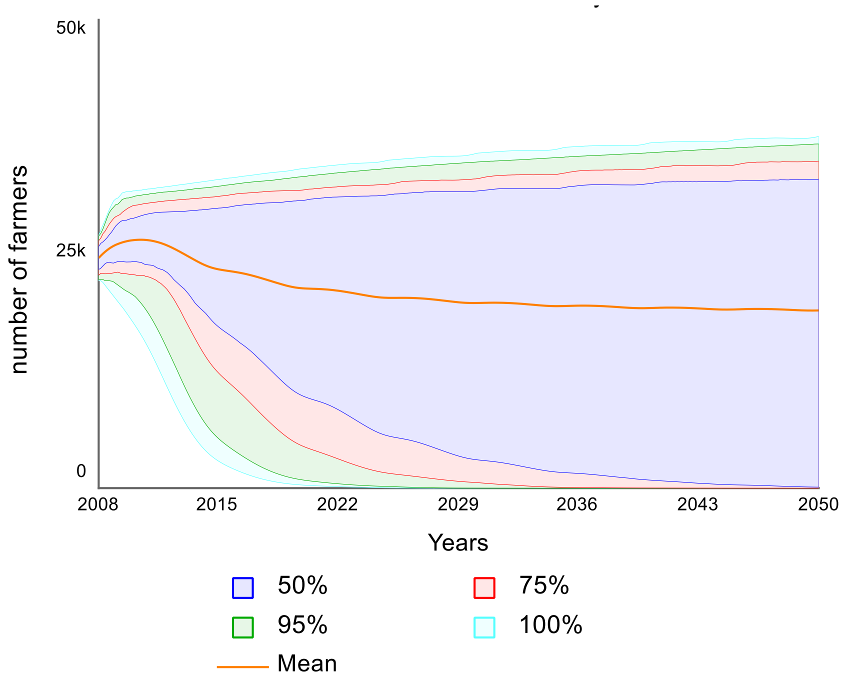

Figure 13. Confidence intervals over time for number of soy smallholders given a 10% (+ and -) variation of sensitive variables, generated by the model

Scenario analysis

Scenario analysis was conducted to assess the performance of each of the three scenarios considering three different criteria (see Methods): resilience (number of soy smallholders), adaptability (typical smallholder assets *versus* the same initial assets invested in government bonds), transformability (output of B100 *versus* the maximum capacity given the evolution of the diesel blend policy). A variation without BD in the system was tested in each of the three scenarios.

In the base case (Figures 14 to 16), the development of the soybeans supply chain in the first three years of simulation leads to an increase in the number of soy smallholders and in the assets of a typical smallholder. Part of this adjustment in assets (during the period where it shows a slightly convex curve in the very of beginning of simulation) is a consequence of a transient adjustment of the initial stock of cash

throughout the chain (see Moxnes & Davidsen, 2017) in combination with a relevant conversion from other commodities to soy that is present in the datasets. Interviewees indeed report a sudden increase in prices around 10 years ago, when the soy plantations started to be taken more professionally by local agents.
The base case shows a stable behaviour of the number of smallholders and their assets, therefore performing well for the adopted criteria on resilience and adaptability. The cases without BD do not represent a relevant difference in terms of resilience and adaptability.

Figure 14 below shows that there is no imminent threat to resilience in the base case, and the presence of BD also does not affect the *system* of interest too much.

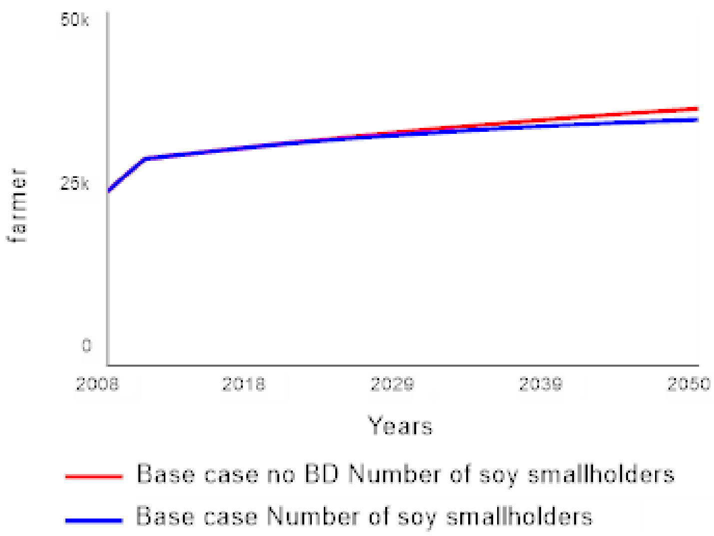

Figure 14. Number of soy smallholders over time in the base case with and without BD, generated by the model

Figure 15 shows that the initial adjustments create assets to smallholder farmers, who then profit from this adjustment in the next decades. However, it is possible to observe that the window of opportunity for farmers to enjoy this increase asset level seems to between 2020 and 2040, approximately.

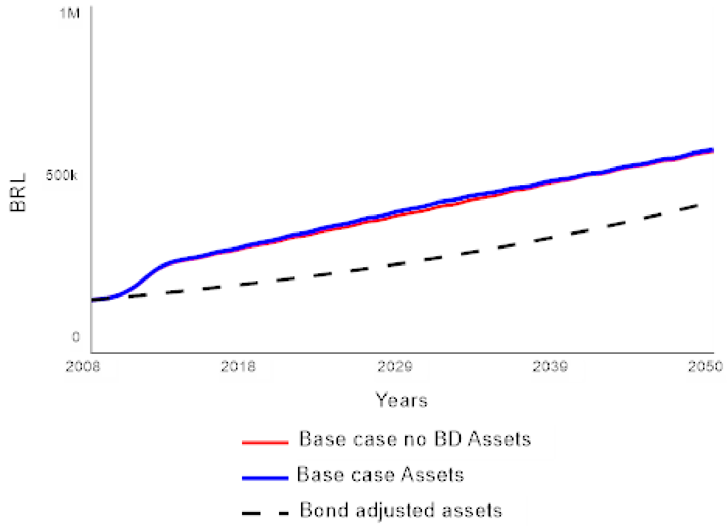

Figure 15. Assets of a typical smallholder over time in the base case with and without BD as compared to government bond-adjusted assets, generated by the model

Except for a period between 2021 and 2033 in Figure 16, when B100 production is catching up with the increased blend, the output is the maximum possible output, indicating that the transformation of the *system* is driving to the direction of the policy objectives set by the State.

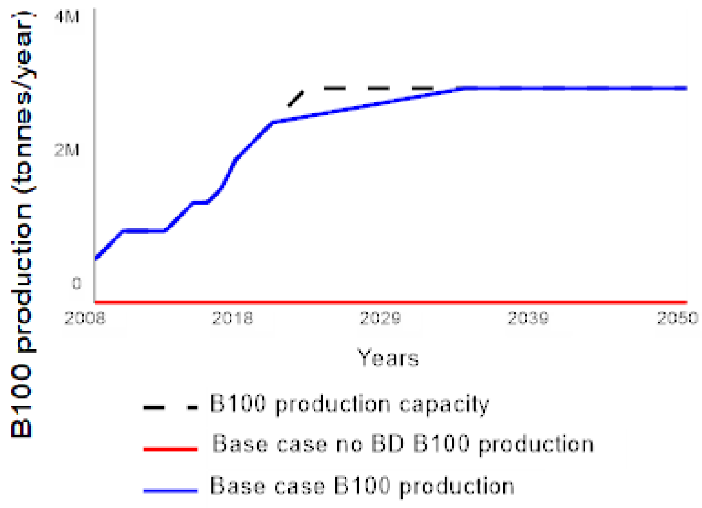

Figure 16. B100 production over time in the base case as compared to the maximum production capacity driven by the blend policy, generated by the model

In the push scenario (Figures 17 to 19), a strong decline in the number of soy smallholders occurs in both the usual and no BD scenarios, mainly due to conversion to other commodity crops. The assets of a typical smallholder present an initial decline and remain relatively stable until the small farming soybean activity disappears. The B100 output goals are not achieved, as seen in Figure 19.

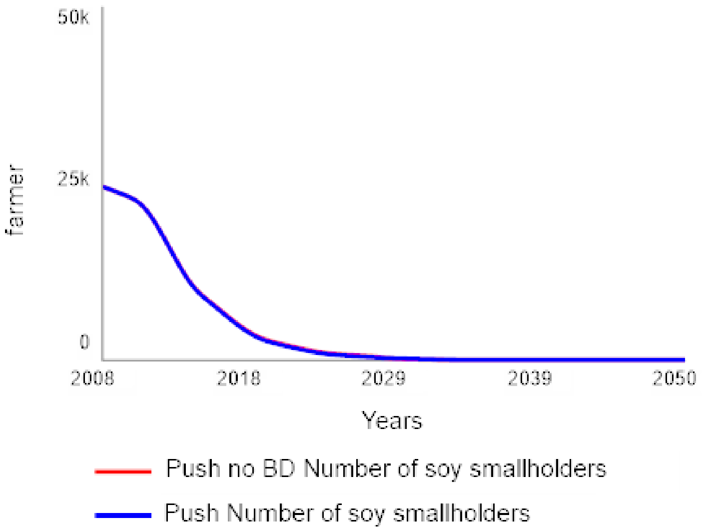

Figure 17. Number of soy smallholders over time in the push scenario with and without BD, generated by the model

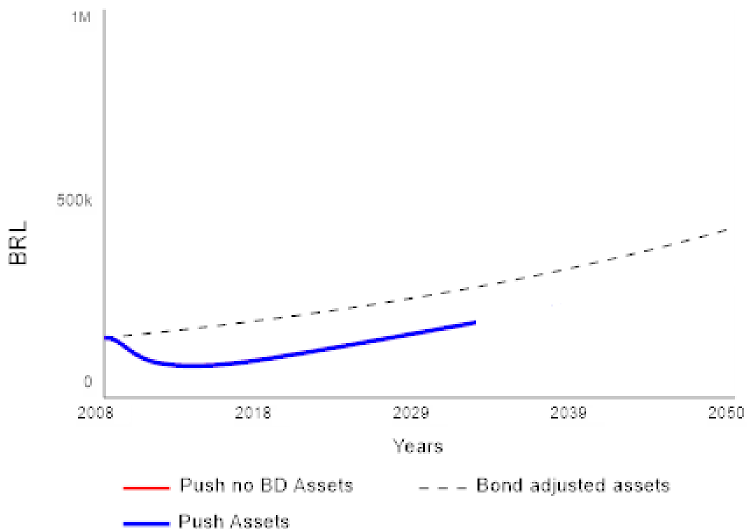

Figure 18. Assets of a typical smallholder over time in the push scenario with and without BD as compared to government bond-adjusted assets, generated by the model

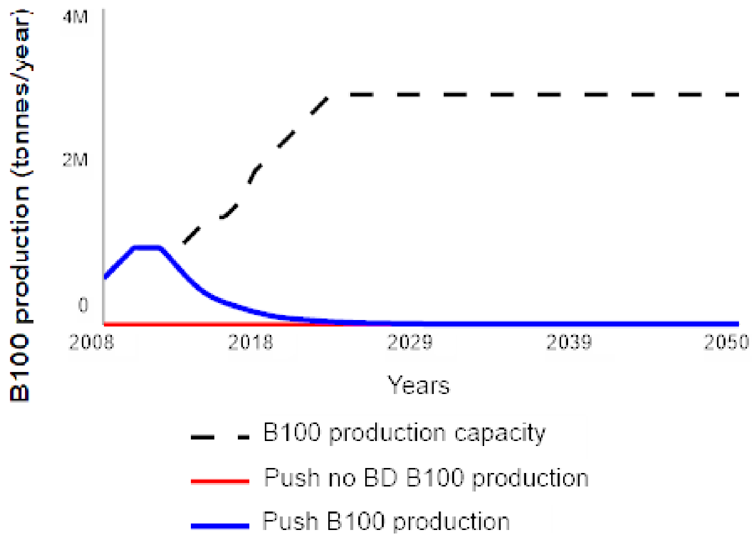

Figure 19. B100 production over time in the push scenario as compared to the maximum production capacity driven by the blend policy, generated by the model

In the pull scenario (Figures 20 to 22), there is a slower decline in terms of number of smallholders (Figure 20), and B100 output goes as planned (Figure 22). The effect of turning biodiesel off in the model is more important in this scenario, especially in terms of preventing smallholders to leave their farms. It is possible to identify a trade-off between resilience and adaptability, since, although the number of smallholders is lower with BD (Figure 20), the typical smallholder assets are higher (Figure 21). This is due to the effect of verticalization: more smallholders sell their land in this scenario exactly because land price (an important factor of their assets) is attractive for sale. As seen in Figure 20, this phenomenon happens more intensely when there is BD in the system.

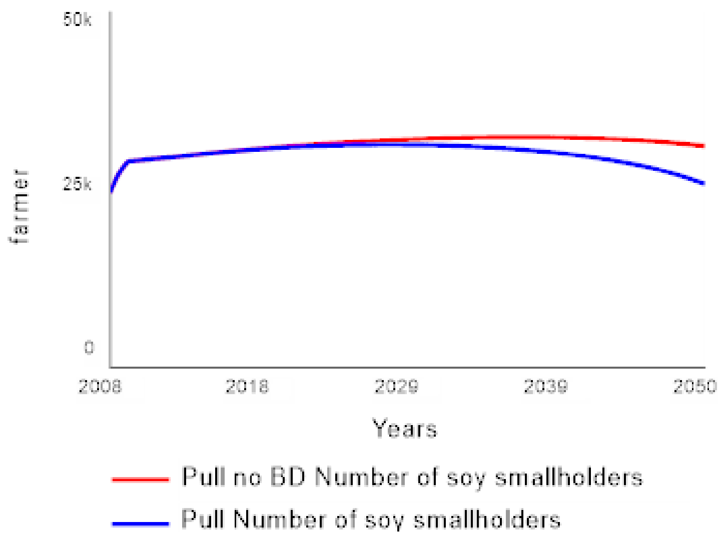

Figure 20. Number of soy smallholders over time in the pull scenario with and without BD, generated by the model

Figure 21 shows that BD plays a role in increasing the opportunity of farmers to increase their assets. The window of opportunity for them to sell their assets with a bond-adjusted profit is longer in the case where BD is present in the system. The oscillations between 2011 and 2017, caused by delays in adjustments of land price to demand that also adjust to perceived profitability of soybean agriculture, show that a farmer who sells land at a sub-optimal moment might be making a tragic decision for his future lifestyle.

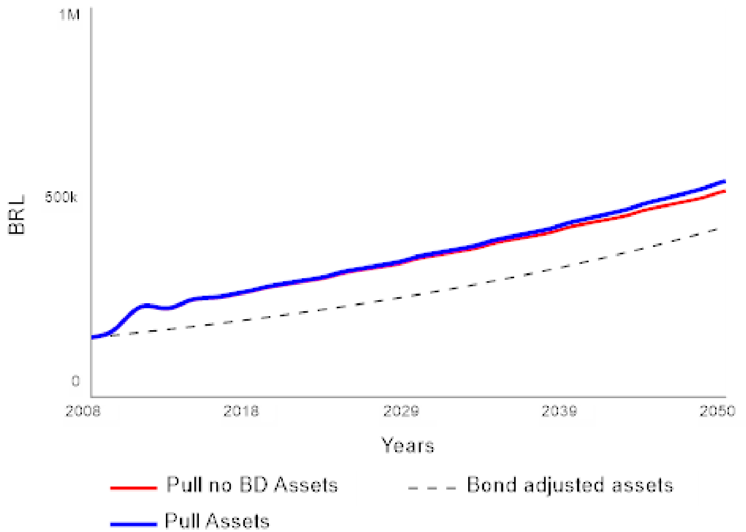

Figure 21. Assets of a typical smallholder over time in the pull scenario with and without BD as compared to government bond-adjusted assets, generated by the model

Figure 22 shows a behaviour of B100 production and, therefore, system transformation, similar to the base case (Figure 16).

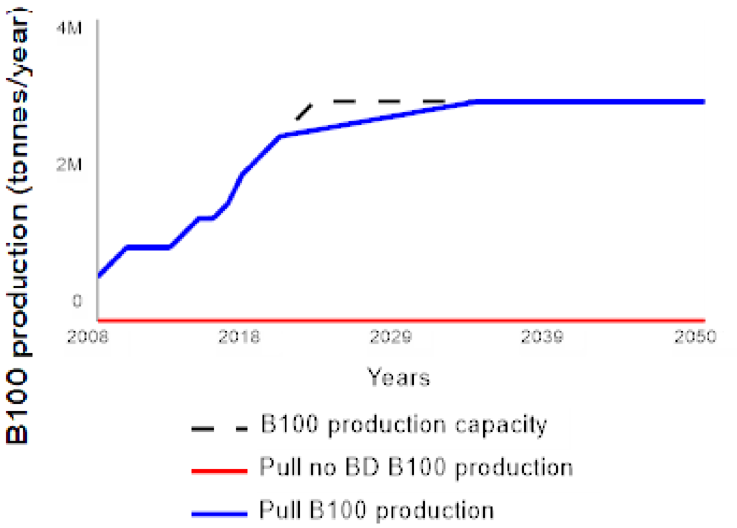

Figure 22. B100 production over time in the pull scenario as compared to the maximum production capacity driven by the blend policy, generated by the model

Variance analysis

The variances of the slow variable over time for each scenario (number of soy smallholder farmers variances – Figures 23 to 25) show what is already possible to be identified visually in the scenario analysis: only the push scenario generates a change that is strong enough to be considered a regime shift, which can be seen by the strong growth in variance from 2013 to 2024. Only this scenario generates *changes* that are strong enough not to be fully absorbed by the structure of the modelled *system*. The base case and the pull scenario allow the local small farming *system* to stay in the same regime, characterized by adherence to soy as an industrial crop.

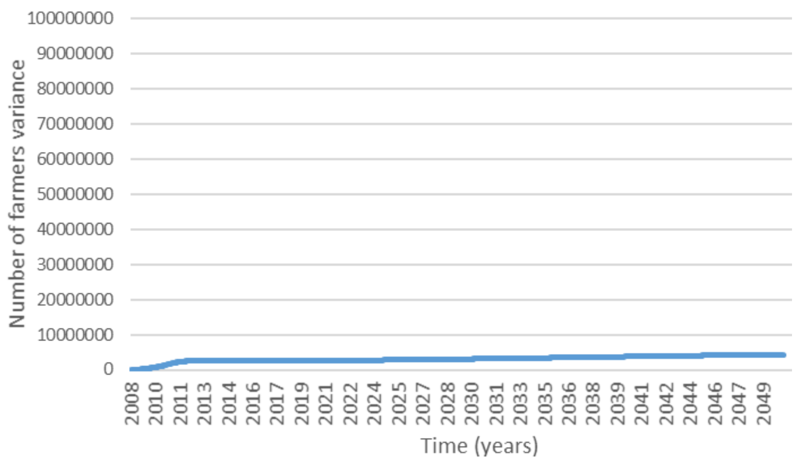

Figure 23. Variance over time of number of smallholder farmers in the base case, elaborated by the author

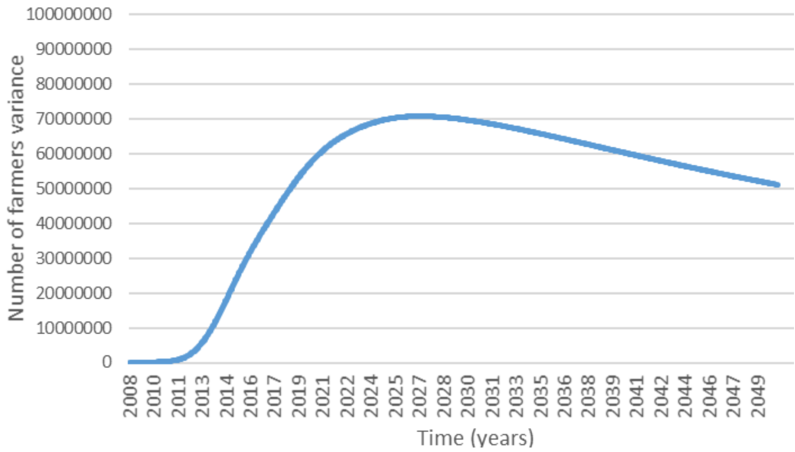

Figure 24. Variance over time of number of smallholder farmers in the push scenario, elaborated by the author

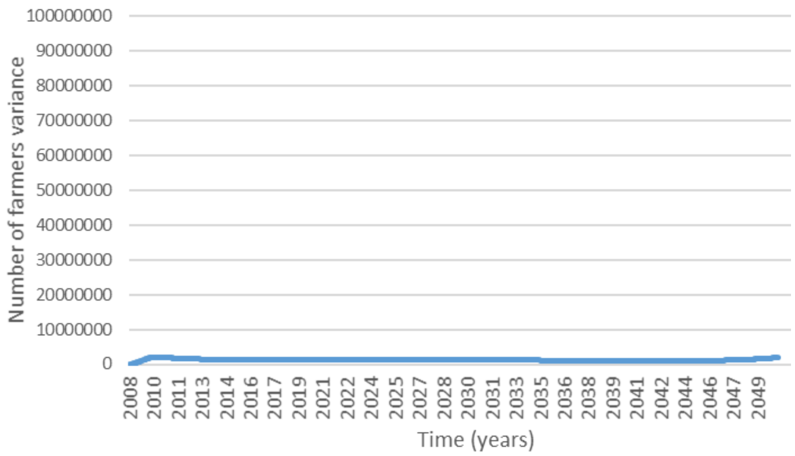

Figure 25. Variance over time of number of smallholder farmers in the pull scenario, elaborated by the author

In both the push and the pull scenarios (Figures 26 and 27), when we observe the variance of the fast variable (land prices) over time versus the behaviour of the slow variable, we may argue that a strong change in the fast variable anticipated the strong decline in the slow variable (number of smallholders), consistent with the observations by Brock and Carpenter (2006). The change is not as important in the pull scenario, as there is no regime shift.

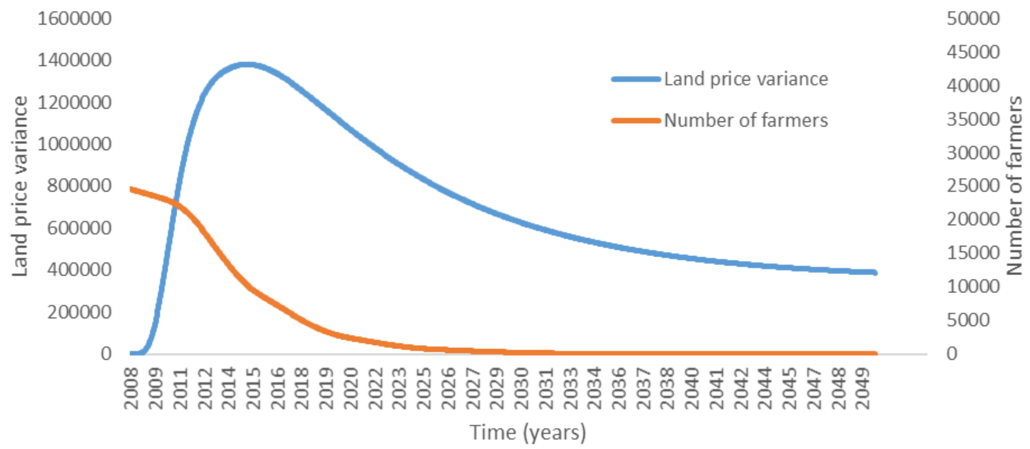

Figure 26. Variance of the fast variable (blue, left axis) vs behaviour of the slow variable over time (orange, right axis) in the push scenario, elaborated by the author

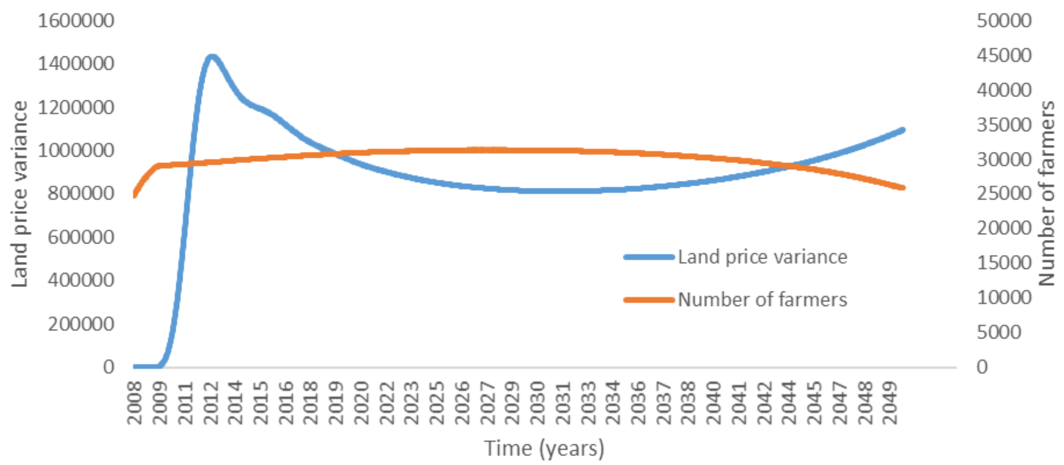

Figure 27. Variance of the fast variable (blue, left axis) vs behaviour of the slow variable over time (orange, right axis) in the pull scenario, elaborated by the author

Discussion and conclusions

This system dynamics model-based resilience study aimed to describe effects of the Brazilian social biodiesel policies on smallholder farming by uncovering their risks, decisions and effects (research questions 1, 2 and 3, respectively).

The results of sensitivity, scenario and variance analyses indicate that the presence of BD in the soybeans production chain does not undermine resilience of smallholder farmers in the base case, which means a rejection of the central hypothesis of this research, although a 20%-wide sensitivity analysis range in the most sensitive variables generates high levels of uncertainty.

The balancing loops (Figure 10) dominate the base case, generating stability by maintaining equilibrated land markets (B2, B3 and B4), crop conversion (B1) and soy supply (B7). To draw this conclusion, we build on Bueno (2012) loop dominance analysis for resilience studies. The author suggests a procedure to observe shifts in loop dominance in social-ecological systems by first defining variables of interest, then conducting sensitivity analysis and, finally, tracking the structural reasons behind sensitivity by identifying shifts in loop polarity.

Research Question 1: What are the threats for the resilience of smallholder farmers involved in the social biodiesel programme, especially those generated by the existence of the programme itself?

The dynamic hypothesis of this study and the BD policies alone do not explain the recent decrease in smallholder farmers in the programme seen in Figure 3. Smallholder resilience loss in the region depends on the prevalence of push and/or pull migration factors, which are connected to two larger-scale phenomena mentioned by the interviewees, involving risks that were not comprised by the initial hypothesis of this study, composing an unexpected answer for research question 1: the rise of industrial agriculture (where players across the supply chains may verticalize their activities, which includes acquisition of land) and rural exodus (connected to generational, succession issues). Should BE policies be implemented without articulating these two broader aspects? The question remains open for future studies.

The characterization of the BD production chain by Da Silva et al. (2018) is not completely supported by this model analysis, as smallholder crop conversion to soybeans happens regardless of the presence of BD in the *system*. Interview results and model analyses indicate that regional BD production schemes are one of the manifestations of a broader phenomenon, namely the rise of industrial agriculture.

However, scenario analysis indicates that BD and, therefore, the policies that created an entire BD supply chain in Brazil (PNPB and SCS) might amplify pull factors. In other words, when urban life is attractive, BD might make it even more attractive, and this combination might disrupt the smallholder farming *system* of entire regions by stimulating smallholder farmers to gradually sell their land and migrate to urban areas. As demonstrated in the pull scenario results (Figures 20 and 21), BD is relevant in augmenting this rural exodus process.

Despite the relative stability in the base case, probability of regime shift is significant given a 10% variation (up or down) in the set of eight sensitive variables and even higher when push factors are in place. As shown on Figure 11, the lowest ten percentiles for the final number of soy smallholders are the most probable set of ten percentiles among the possible outcomes, although highest outcomes are highly probable. This might be interpreted as a high level of vulnerability to external factors on this production chain that includes BD and other soy products. Should the Brazilian government decide on behalf of taxpayers to incentivize this economic sector so heavily given this vulnerability to external factors? This question also remains to be answered by future studies.

The impacts of push factors are connected to the dependency of farmers to one or few crops, as they become more susceptible to variations in the profit margins of few crops. The abrupt impact of push factors in scenario analysis, as well as the demonstration that the initial stocks of soy land *versus* other commodities is sensitive, allow us to endorse for BD what Egeskog et al. (2016) had already observed in the case of ethanol: crop diversification seems to be a potential risk-management policy for soy smallholders in the context of emerging BE schemes.

Most simulated regime shifts in the push scenario occur not because of the action of the reinforcing loops R1 and R2, but due to conversion from soy to other commodity crops, which, in the reality of the interviewed farmers, would be corn. It is therefore questionable if this situation should even be considered a regime shift, as they would only be jumping to a commodity from another.

Situations where R1 and R2 in fact dominate (Figure 28 below), generating a decline of smallholder farming, can be seen in three different cases: extremely high soy meal prices, coordination between market players to isolate small farmers by charging more for goods and services ('market control premium') or extremely low minimum land sales prices by farmers.

The latter two might be understood as components of a tragedy of the commons, involving different agents, that might reinforce each other. In the case of coordination between market players, suppliers and downstream players such as harvester and storage providers could end up without customers. In the case of extremely low minimum land sales prices, farmers would rush to sell their land as soon as they noticed land prices were up. Depending on the soy meal prices and the 'market control premium', this willingness to sell land by some farmers could end up isolating other small farmers in the region, generating a tragic situation for the ones who stay in the small-scale farming activity. This is a relevant risk dynamic to which farmers should pay attention. The capacity to understand and analyse land markets is key in these cases.

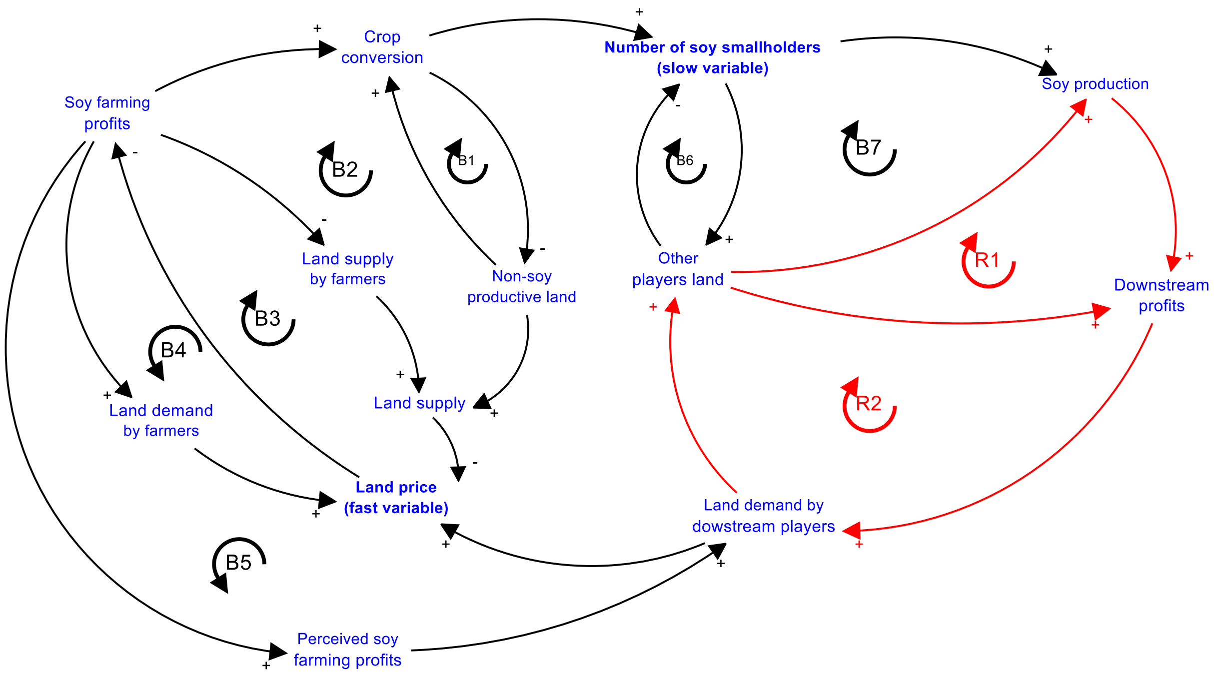

Figure 28. Causal loop diagram illustrating the dominance of reinforcing loops leading to a regime shift, generated by the model

Research Question 2: Which heuristics, decision rules and thresholds guide smallholder farmers' decisions that relate to their own resilience?

To answer the second research question of this study, regarding farmer decisions that bounce back to their own resilience, sensitivity analysis indicates that the key decisions farmers face are the following:

- How much soy to grow in their farms as compared to other commodities (expressed as 'Initial_soy_land' *versus* 'Initial_other_commodities'), as farmers might be too exposed to soy grain and meal prices;
- How much crop rotation to perform or, in agricultural terms, the choice of crops and seed varieties that require less rotation (expressed as 'Minimum_crop_rotation');
- From what price on to sell land (expressed as 'Min_farmer_land_sales_price), which relates to 'when' to sell land and leave the rural areas.

Efforts to increase soy productivity might pay off as well, as indicated by the high sensitivity of 'ref_soy_productivity'.

Relevant decisions across the supply chain

Besides the farmer decisions that impact their own resilience, an array of other decisions that are made by other stakeholders, especially policymakers and downstream players, have a demonstrated high level of importance.

Scenario analysis does not reveal a clear trade-off among the three analysed policy paradigms (smallholder resilience, smallholder adaptability and transformation of the *system* to maximize B100 output). As a matter of fact, they seem to rely on each other in most cases, which means PNPB objectives would most likely either fail completely or absolutely thrive. Given that the objectives of PNPB are not mutually exclusive, and, under the current rules, refineries rely on smallholders to be able to operate, the transformation of the production chain to maximize biodiesel output relies on smallholder resilience. As demonstrated in the analysis of the pull scenario, a trade-off might occur between resilience and adaptability, since maintaining farmers' lifestyle options contradicts with making sure they stay in the rural areas. This trade-off arises from a complex interaction between public policy at the federal level and individual farmer choices.

The relatively low importance of BD in this context, even when a 15% blend is taken into consideration, is not in line with previous literature such as Rathmann, Szklo, and Schaeffer (2012), who understood that from a 7% blend on, BD would start driving the soybean markets in general, gaining importance over other soy products and pushing prices.

Contrary to the initial hypothesis, simulation demonstrates that refineries (and even other players) do not control land prices, crop prices or the behaviour of the system in general. BD is still a minor phenomenon if we consider the entire context of commodity production chains, including high-volume commoditized products such as the soy grain itself or soy meal. Premium grain prices, when refineries intentionally manipulate grain prices to determine supply levels in the absence of soy smallholders (as depicted on Figure 28), are only observed in very specific situations.

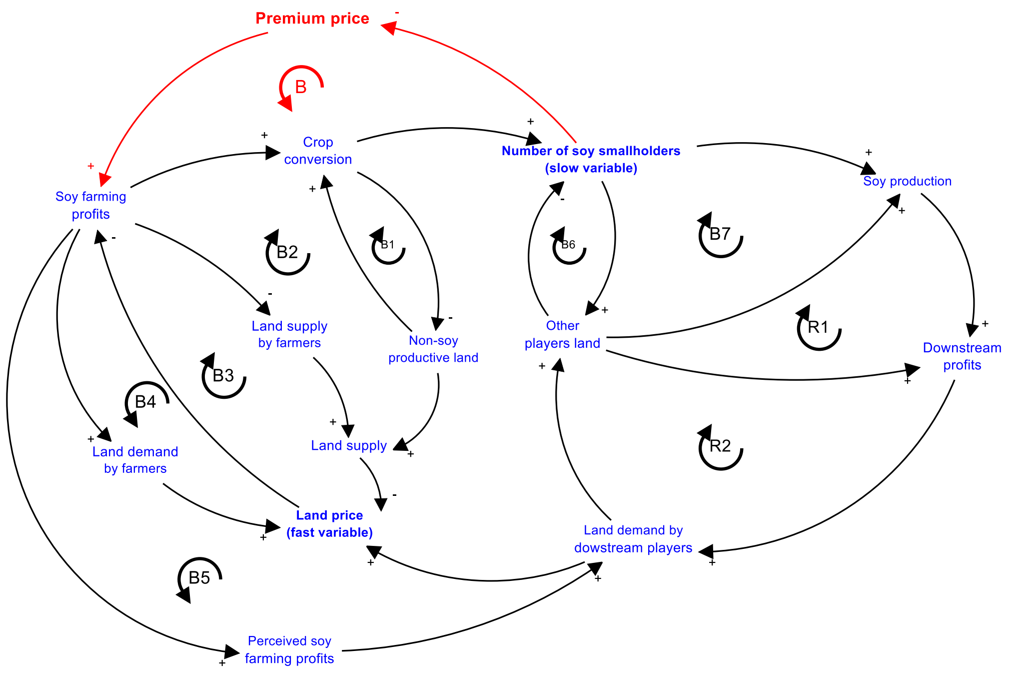

Figure 28. Causal loop diagram with premium price, elaborated by the author

For this additional 'Premium price' balancing loop (Figure 27) to dominate, pull pressures must be very intense (i.e. stronger than our pull scenario – compare Figures 20 and 29), and, at the same time, the premium has to be much higher than the one that has been paid in the past (reported both by the interviewees and by Da Silva et al, 2018). The model can be utilized to artificially create a forced 'last survivors win' scenario where the number of smallholders (Figure 30) would decline more intensely than in the pull scenario, and the ones staying as smallholder soy farmers would benefit from an important increase in their assets (Figure 31).

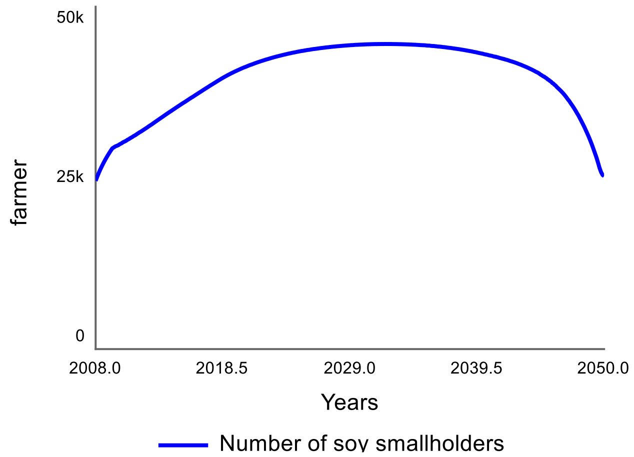

Figure 30. Number of soy smallholders over time in a forced scenario where the last survivors would benefit from this situation, generated by the model

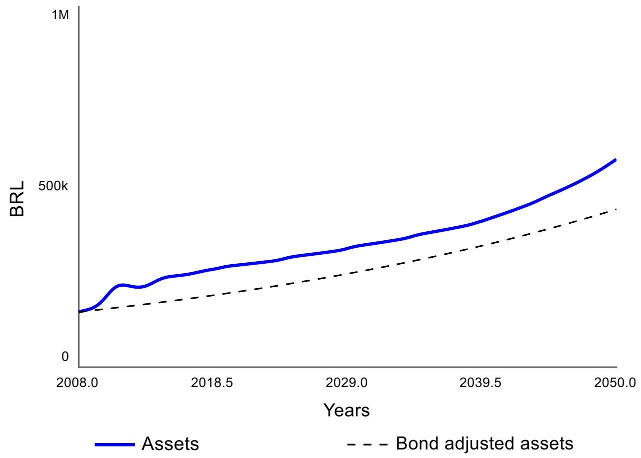

Figure 31. Evolution of assets over time in a forced scenario where the last smallholder survivors would benefit from this situation, generated by the model

In such cases, a desperate attempt by refineries to save their smallholder supply might lead to a situation where the more resistant smallholders who are able to stay in their lands until this extreme scenario occurs get a financial reward for their resistance (Figure 31). This resistance can be interpreted as a consequence of efficiency – meaning the most efficient farmers would survive this scenario. This situation might also be seen as a 'professionalize or give up' type of dilemma, typical of the rise of industrial agriculture. Those who decide to persist in the farming activity, must become much more efficient and professional.

However, the author considers the entire situation where the last survivors would win not probable, not only for the unusual combination of conditions that would be required but also because refineries would have other options, beyond the boundaries of this model-based study, to avoid being in the hands of the most successful small farmers, such as lobbying to change the legal requirements, increasing the acquisition form cooperatives that reduce the requirements, or even reducing production and invest their previous profits in other activities. Recent lobbying efforts led to the government to relax some SCS requisites (Agrolink, 2019). At least one refinery is reported by international sources for having offshore bank accounts to remove capital from Brazil (ICIJ, 2019). Forgive the opinionated note, but this extractive dynamic by commodity players is recurrent in the history of this young nation where the author was born.

Policies (Table 11) that create buffers to crop price and farming cost variations also seem to make sense to pursue the three proposed policy paradigms at the same time. One interviewed farmer claimed for longer term funding mechanisms (nowadays available in a yearly basis). When questioned about the possibility of acting as a long-term financier of smallholders, the interviewed refinery representative argued that this could generate irresponsible financial conduct.

Table 11

Suggested policies by stakeholder, based on sensitive variables, elaborated by the author

Variable	**Farmers**	**Governments**	**Downstream players (incl refineries)**
Grain price Initial_other_commodities Initial_soy_land	Crop diversification	Long-term credit subsidies for non-commodity crops Hedging mechanisms (insurance)	Long-term credit for farmers
Market_control_premium	Constant prospection of different suppliers and buyers	Market regulation (competition law) Subsidies to equipment and land	Avoid collusion

	Farmer cooperatives to gain bargain power in acquisitions and even compete downstream	acquisition by smallholders Enforce limits on pesticide prescription by suppliers	
Meal_price	NA	Hedging mechanisms (insurance)	Hedging mechanisms (derivatives, core business diversification)
Min_farmer_land_sales_price	Avoid premature land sales Dedicate to new generations' farming training	Limit contracts that include land as guarantee Subsidize land acquisition by smallholders Ensure proper land tenure regulations Distribute infrastructure (roads, electricity) fairly Enforce minimum smallholder presence on diesel auctions Vocational training for both young and mature populations	Focus on their core business instead of premature verticalization
Minimum_crop_rotation Ref_productivity	Adhere to best crop management practices	Technical assistance for farmers Sponsor agricultural research	Incentivize oilseed crop diversification

Perhaps one of the main counterintuitive behaviours observed by this research occurs in the pull scenario (Figures 20 and 21). It would be expected that, if soy farmers are getting richer (increasing their assets), they would remain as soy farmers. However, in this scenario, there is a relatively slow trend of rural exodus after the smallholder farmer population reaches a peak. At the same time, farmers assets remain above the bond-adjusted asset curve. This could mean an opportunity for them to leave the rural areas with some savings to restart their lives in the city (as supported by interviews as an answer for research question 3). This counterintuitive behaviour calls for the importance of training and capacity-building public policies for farmers that almost inevitably leave their rural lives. Their transition to city life is probably not easy without this support, even if they have savings.

Research Question 3: What happens to smallholder farmers involved in SCS when severe resilience loss (or regime shift, in the resilience jargon) occurs?

Transition to urban life in cities nearby and, in some cases, regret and return to rural areas has been pointed by the interviewees as the outcome of rural exodus. The journey of these 21st century migrants after moving to cities, and the feedback processes behind their adaptation there, is yet to be uncovered by future studies.

Future research

The *timing* of rural exodus seems to be a key aspect neglected by literature. The moment when farmers sell their land seems to be an important factor to determine how well off they will be when they do so. Building (crop and land) market intelligence for farmers is an envisioned next step for this research. Games and simulators could serve that purpose.

Adapting this research to other contexts (territories, sectors, crops) could lead to the construction of a set of tools to help farmers in general know their risks and potential ways out. Agriculture systems can vary a lot, though. It is expected that the structure of production chains and industrial agriculture policies (including BE policies), as well as the order of importance of the risks faced by farmers, is different depending on the case.

Model-based variance analysis might be an important pathway to understand simulation outcomes by specifying what decisions and scenarios would lead to disruptive regime shifts. It can allow the construction of simple simulation tools that indicate if a given decision generates collapse or not, which might be important to support political narratives in polarized political settings typical of our era.

Nevertheless, these tools should not refrain from allowing users to learn about model structure. As recommended by Stirling (2010), policy advice, in the context of complexity, must include risk-related knowledge transfer not to be used as scapegoat by decision makers

This work, including the policies suggested in Table 11, that, by the way, require continued testing and validation, has the potential to inform BE policies internationally. It might generate opportunities to inform mainstream climate models and studies that influence global climate policy. Comparative studies across different regions, as well as integration with mainstream climate models are in the author's horizon for future research endeavours.

This modest research project brought together three research traditions that seldom interact: system dynamics (often operationalized by stock-and-flow modelling), resilience studies (often based on the complex adaptive system paradigm, operationalized by agent-based, statistics and network models) and climate research (often operationalized by large input-output models programmed in languages such as Phyton, based on deductive decision assumptions). This is a demonstration of the potential for the integration of different knowledge systems and academic fields to increase our chances to survive challenges such as global climate change.

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Annex 1 – Model documentation

Modelling software: Stella Architect

Start Time: 2008

Stop Time: 2050

Timestep: 1/32 (necessary due to short processing delays at processor stage)

Method: Euler

This model relies on two data imports to run: 'Copy of data export.xlsx' (price data) and 'cost data export.xlsx' (cost data). On Stella, for both files, please use a dynamic link type to load time varying values with an extrapolation behaviour.

Variable	Equation/Parameter	Explanation
2019_B100_production_capacity_(volume)	(800+933.33+1300+600+650+1150+300+300+500+200)*365	Rio Grande do Sul state capacity of B100 production (refinery capacity) according to ANP (2019).
"%_acquired_from_cooperatives_above_0.8"	0.50	From SEAD (2018b) data we know that 0.78 of the soy in RS state comes from cooperatives. We assume a higher fraction of cooperatives above 0.8 smallholder prevalence because this is more advantageous for the refineries.
"%_acquired_from_cooperatives_below_0.8"	0.28	See "%_acquired_from_cooperatives_above_0.8"
"Cooperative_discount_if_smallholder_<0.8"	1.2	This is defined by SEAD (2018). There is a bigger discount on the mandatory smallholder blend if the cooperative has >0.8 smallholder fraction on its supply.
"Cooperative_discount_i	1.7	See "Cooperative_discount_if_smallholder_<0.8"

f_smallholder>0.8"		
"%_brokerage_market_share"	0	This is a parameter of an observer structure in the model, not affecting behavior. It is about the initial market-share of an observed actor in the brokerage market.
"%_cash_invested_in_land"	0.2	This is a parameter that defines the percentage of the current cash to be invested by farming and downstream players in land acquisition. There is no reference value available, but 0.2 is considered to be a maximum, as it is hard to imagine a player that usually operates in another segment spending all its investment capacity in land acquisition. For a farmer, higher values could apply, though.
"%_debt_supplier"	0.58	In case there is farmer debt, part of it is upstream (suppliers). 58% is adopted as it is the proportion of farming costs that are derived from supplies, as shown by the RS state Agriculture Department (Secretaria da Agricultura, 2018).
"%_direct_sales"	0.05	A minority of the soy harvest arrive to processors without going through a third-party storage and brokerage, also not going through a cooperative.
"%_farming_market_share"	0.00001/3	This is a parameter of an observer structure in the model, not affecting behavior. It is about the initial market-share of an observed actor in the farming market. This value will generate a 60 hectares initial land size (including rented land), which is a pretty usual case in the researched area.
"%_harvester_owned"	0.25	This describes how much of the harvest is made with harvesters

		owned by the farmers. The value is a perception from the interviews.
"%_harvesting_market_share"	0	This is a parameter of an observer structure in the model, not affecting behavior. It is about the initial market-share of an observed actor in the harvesting service/harvester renting market.
"%_land_owned"	0.6	The available data (IBGE-Sidra) about the % of land that is owned by the farmers who grow crops on them was judged not trustworthy due to its complete disconnection with the observed reality. A range between 0.6 and 0.7 seems closer to the observed reality.
"%_oil_mass_in_grain"	0.18	Only part of the soybean is oil. The number is a rule of thumb in the sector, comes from Cavalcante, Souza and Hamawaki (2011)
"%_processing_market_share"	0	This is a parameter of an observer structure in the model, not affecting behavior. It is about the initial market-share of an observed actor in the processing (refinery or not) market.
"%_soy_land_non-smallholder"	1-"%_soy_land_smallholder”	See "%_smallholder_land_among_farmers"
"%_soy_land_smallholder"	IF Farmer_soy_land>0 THEN IF (ref_smallholder_land_among_farmers+(Soy_land_acquired_by_smallholders/Farmer_soy_land))*(Farmer_soy_land/Total_soy_land) > 1 THEN 1 ELSE (ref_smallholder_land_among_farmers+(Soy_land_acquired_by_smallholders/Farmer_soy_land))*(Farmer_soy_land/Total_soy_land) ELSE 0	This equation considers the soy land acquired by smallholders and adjusts it to result in a proportion of the total soy land in the model (incl non-farmers’ land).

"%_soy_production_dedicated_to_biodiesel"	B100_production/Oil_extraction	Whenever soy is crushed, oil is extracted. However, biodiesel (in its purest form, B100) is not always a product of that process.
"%_storage_market_share"	0	This is a parameter of an observer structure in the model, not affecting behavior. It is about the initial market-share of an observed actor in the storage market.
"%_supplies_market_share"	0	This is a parameter of an observer structure in the model, not affecting behavior. It is about the initial market-share of an observed actor in the supplies (pesticides, fertilizers and seeds) market.
"%_land_supply_by_farmers"	IF Land_price>Min_farmer_land_sales_price THEN ((Land_price-Min_farmer_land_sales_price)/Min_farmer_land_sales_price) ELSE 0	In the context of land markets. Farmers only provide land as supply if the price is above their minimum accepted price.
Assets	Cash_owned+Land_value_owned+Other_assets_owned	In the context of assessing total assets of an observed actor.
Automatic_premium_SWITCH	IF Frauded_required_%>"%_soy_land_smallholder"*"%_soy_production_dedicated_to_biodiesel" THEN 1 ELSE 0	This switch regulates whether the processors will pay a premium price. If the required % of smallholder content in their supplies is higher than the percentage of smallholders among soy farmers, it starts to get more difficult to find smallholders, which justifies the payment of a premium price. If not all the soy production is crushed by processors able to produce B100, the supply market become less competitive for refineries.

Avg_premium_paid	Premium*Fraction_smallholders_subject_to_premium*(1-Prevalence_of_fraud)*Premium_SWITCH*"%_soy_land_non-smallholder"	Whenever processors pay a premium price, they only have to pay it to a fraction of the smallholders. Moreover, this is alleviated by some widespread identity frauds.
Avg_smallholder_area	IF Ref_smallholder_area*(1+(Soy_land_acquired_by_smallholders/Farmer_soy_land))*(1+(Fraction_new_soy_farmers*((Farmer_soy_land-Initial_soy_land)/Initial_soy_land)))> Max_smallholder_area THEN Max_smallholder_area ELSE Ref_smallholder_area*(1+(Soy_land_acquired_by_smallholders/Farmer_soy_land))*(1+(Fraction_new_soy_farmers*((Farmer_soy_land-Initial_soy_land)/Initial_soy_land)))	Whenever smallholders buy land, the average smallholder area has to grow, but it cannot surpass the maximum area to be considered smallholder.
Ref_smallholder_area	40 hectares	There is no data available about it, but as the maximum area to be considered smallholder in the region is 80 hectares, we assume a value of 40, which would be an equally-distributed average.
B100_density	0.87	Oil is less dense than water.
B100_price	Exogenous.	The values come from an ANP (2018) time series that is repeated until the end time of the model.
B100_production	IF Oil_extraction<B100_production_capacity THEN Oil_extraction ELSE B100_production_capacity	B100 production can be limited either by refinery capacity or by lack of supply.
biodiesel_mixture	Exogenous	This is the biodiesel (B100) mixture on diesel. The time series comes from the laws and regulations that establish the mandatory blend in Brazil. As there is no prevision in law for blends higher than 0.15, this is the adopted plateau.
biodiesel_switch	1	A switch to define whether there is biodiesel production in this system or not.

Bond_adjusted_assets(t)	Bond_adjusted_assets(t - dt) + (Rate) * dt {NON-NEGATIVE} INIT Bond_adjusted_assets = Initial_assets Rate = ("Gov_bond_interest_rate_(nominal)"-Inflation_rate)*Bond_adjusted_assets {UNIFLOW}	This is a stock that is embedded in an observer structure to analyze the evolution of assets of a given agent over time as compared to a risk-free asset allocation (government bonds).
Broker_cash(t) = Broker_cash(t - dt) + (cashflow + Broker_farming_cashflow) * dt	Broker_cash(t) = Broker_cash(t - dt) + (cashflow + Broker_farming_cashflow) * dt INIT Broker_cash = Initial_cash INFLOWS: cashflow = (1-"%_direct_sales")*(Sales_to_processors*Brokerage_margin*Grain_price)	A stock that accumulates the cash derived from brokerage activities and farming activities in farms owned by original brokers. Whenever there is a direct sale from farmer to processor, there is no brokerage, so this does not generate cash.
Broker_farming_cashflow	(Soy_farming_margin*Land_owned_by_brokers)-(Land_acquisition_by_brokers*Land_price)	The cashflow of farming activities performed by original brokers. Land acquisition counts negatively.
Brokerage margin	0.1	Brokerage activities have zero margin in efficient markets. In commodity markets this margin cannot be higher than 0.1.
Capacity_expansion_costs	0	Just outlining a limitation of the model: capacity expansions costs, that would be important for storage players and processors, are not taken into account.
Cash_owned	IF is_smallholder?< 1 THEN ("%_supplies_market_share"*Supplier_cash)+(Farmer_cash*"%_farming_market_share")+(Harvesting_player_accumulated_profits*"%_harvesting_market_share")+(Storage_players_cash*"%_storage_market_share")+(Broker_cash*"%_brokerage_market_share")+("%_processing_market_share"*Processor_cash)-(Premium_Paid*"%_farming_market_share") ELSE ("%_supplies_market_share"*Supplier_cash)+(Farmer_cash*"%_farming_market_share")+(Harvesting_player_accumulated_profits*"%_harvesting_market_share")+(Storage_players_cash*"%_storage_mar	In the observer structure, this measures the cash of agents with respect to their presence in different markets. A distinction was needed to calculate the effects of premium solely on smallholders.

	ket_share")+(Broker_cash*"%_brokerage_market_share")+("%_processing_market_share"*Processor_cash)-(Premium_Paid*"%_farming_market_share")+(Premium_Paid*"%_farming_market_share"*(1-"%_soy_land_smallholder"))	
Conversion time	10 years	Land conversion is not a fast process.
Debt execution time	2 years	Typical debt execution time for suppliers that take land as guarantee. It does not happen in the first year because the first year is the expected payment time, then on the second year they can execute the debt in the form of land.
Farmer_cash(t)	Farmer_cash(t - dt) + (Farming_cashflow - Livelihood_expense) * dt INIT Farmer_cash = Initial_cash INFLOWS: Farming_cashflow = (Soy_farming_margin*Farmer_soy_land)+(Avg_premium_paid*Sales_to_processors)+("Non-soy_margin"*"Non-soy_productive_land")+("Non-commodity_crops_margin"*"Non-commodity_land")+Interest-((Harvester_price*Harvester_depreciation)*("%_harvester_owned"))+ Farmer_revenue_from_land_sales OUTFLOWS: Livelihood_expense = Number_of_soy_smallholder_farmers*Farmer_family_expenditure	Farners' cash depend on the farming activity cashflow and their livelihood expenses.
Farmer_family_expenditure	36000 BRL/year	3 yearly minimum wages approximately.

Farmer_revenue_from_land_sales	Land_price*Land_acquisition_from_farmers	Whenever farmers sell land, their cash reserve increases.
Farmer_soy_land(t)	Farmer_soy_land(t - dt) + (Crop_conversion - Land_acquisition_by_harvesters - Debt_execution - Land_acquisition_by_storage_players - Land_acquisition_by_brokers - Land_acquisition_by_processors) * dt {NON-NEGATIVE} INIT Farmer_soy_land = Initial_soy_land INFLOWS: Crop_conversion = IF Perceived_soy_margin>"Non-soy_margin" AND "Non-soy_productive_land"/("Non-soy_productive_land"+Farmer_soy_land+Land_owned_by_downstream_players+Supplier_land) > Minimum_crop_rotation THEN (((Perceived_soy_margin-"Non-soy_margin")/"Non-soy_margin")*"Non-soy_productive_land")/Conversion_time ELSE IF Perceived_soy_margin> Min_perceived_margin_not_to_convert_back THEN 0 ELSE IF ((("Non-soy_margin"+Perceived_soy_margin)/"Non-soy_margin")*Farmer_soy_land)/Conversion_time < 0 THEN ((("Non-soy_margin"+Perceived_soy_margin)/"Non-soy_margin")*Farmer_soy_land)/Conversion_time ELSE 0 OUTFLOWS: Land_acquisition_by_harvesters = IF Land_price> Min_farmer_land_sales_price AND Perceived_soy_margin>0 THEN ((Land_price-Min_farmer_land_sales_price)/Min_farmer_land_sales_price)*(Harvesting_player_accumulated_profits)*"%_cash_invested_in_land"/Land_price/Time_to_acquire_land ELSE 0 {UNIFLOW} Debt_execution = IF Farmer_cash<0 THEN (-Farmer_cash/Land_price/debt_execution_time)*("%_debt_supplier"*SWTICH_debt_guaranteed_by_land) ELSE 0 {UNIFLOW} Land_acquisition_by_storage_players = IF Land_price>Min_farmer_land_sales_price AND Perceived_soy_margin>0 THEN ((Land_price-Min_farmer_land_sales_price)/Min_farmer_land_sales_price)*(Storage_players_cash)*"%_cash_invested_in_land"/Land_price/Time_to_acquire_land ELSE 0 {UNIFLOW} Land_acquisition_by_brokers = IF Land_price>Min_farmer_land_sales_price AND Perceived_soy_margin>0 THEN ((Land_price-	Stock of soy lands in the hands of original farmers. Whenever there is land acquisition by downstream players or debt execution by suppliers, this stock is deducted. Crop conversion to soy can only happen if the perceived soy margin is better than the other crops' and, at the same time, there is land available even considering crop rotation needs. Conversion back can also happen. The logic of land acquisition is similar among all downstream players. They buy land if they have investment capacity derived from their past activities and if the farmers are willing to sell for current prices. Debt execution by suppliers is different, as indebted farmers do not have a choice but selling their land.

	Min_farmer_land_sales_price)/Min_farmer_land_sales_price)*(Broker_cash)*"%_cash_invested_in_land"/Land_price/Time_to_acquire_land ELSE 0 {UNIFLOW} Land_acquisition_by_processors = IF Land_price>Min_farmer_land_sales_price AND Perceived_soy_margin>0 THEN ((Land_price-Min_farmer_land_sales_price)/Min_farmer_land_sales_price)*(Processor_cash)*"%_cash_invested_in_land"/Land_price/Time_to_acquire_land ELSE 0 {UNIFLOW}	
Fertilizer_expenditure	Exogenous	This comes from a time series by the Department of Agriculture. The time series is simply repeated until the end of the simulation time.

Fiscal_module_area	20 hectares	In Brazilian policies, a farmer is considered a smallholder if the land he grows is less than 4 fiscal modules, which vary according to the region. In most of the RS state, as in the specific researched area, this value is 20 hectares.
Fraction_new_soy_farmers	0.5 [unitless]	Whenever farmers buy land, a fraction of the land acquisitions is performed by newcomers or farmers who did not grow soy before that.
Fraction_smallholders_subject_to_premium	IF"%_smallholder_land_among_farmers">Required_%_of_smallholder_acquisition THEN Required_%_of_smallholder_acquisition/"%_smallholder_land_among_farmers" ELSE 1	Premium price is only paid to part of the farmers when there is scarcity of smallholders.
Frauded_required_%	Required_%_of_smallholder_acquisition*(1-Prevalence_of_fraud)	Identity frauds area relatively common and make the actual required % of smallholders to be smaller than it should be by law.
"Gov_bond_interest_rate_(nominal)"	0.065 per year	This asset (government bonds) is as close as one can get to a risk-free investment in Brazil. It currently pays 6.5% per annum.
Grain price	Exogenous	A time series from Conab (2018) which is repeated until the end of the simulation time.
Harvester_capacity	1000 hectares	The area that a single harvester can cover, approximately. This is the reality of more modern harvester, but the actual number is unknown.
Harvester_depreciation	0.033 per year	This assumes a 30 year longevity of a harvester. The actual number is unknown and changing as new technologies are introduced.
Harvester_price	1300000 BRL	This is the price tag that was cited by the interviewed farmers, although

		more modern harvesters can be even more expensive.
Harvester_rent	151.09 BRL/hectares/year	From Department of Agriculture (Secretaria de Agricultura, 2018)
Harvesting_player_accumulated_profits(t)	Harvesting_player_accumulated_profits(t - dt) + (Harvesting_profits + Harvester_farming_cashflow) * dt INIT Harvesting_player_accumulated_profits = Initial_cash INFLOWS: Harvesting_profits = ((Harvester_rent*Farmer_soy_land*Market_control_premium)-(Harvester_price*Harvester_depreciation))*(1-"%_harvester_owned") Harvester_farming_cashflow = (Land_owned_by_harvesting_players*Soy_farming_margin)-(Land_acquisition_by_harvesters*Land_price)	A stock that accumulates the cash derived from harvesting service/harvester rent activities and farming activities in farms owned by original harvesters. Whenever harvesters are owned by farmers, there is no harvester cash generation. Land acquisition is represented as an expenditure.
Harvests per year	1 per year	Self-explanatory
Inflation rate	0.04	Inflation rate in Brazil. The model is in 2008 values (no inflation accounted). The only use for this rate is when accounting the risk-free government bonds, because inflation is embedded in that interest rate and needs to be removed.
Initial_assets	Initial_cash*("%_supplies_market_share"+"%_farming_market_share"+"%_harvesting_market_share"+"%_storage_market_share"+"%_brokerage_market_share"+"%_processing_market_share")+Initial_land_price*(Initial_soy_land+Initial_other_commodities+Initial_non_commodity_land)*("%_farming_market_share")+Harvester_price*("%_harvesting_market_share"+"%_supplies_market_share"+"%_storage_market_share"+"%_brokerage_market_share"+"%_processing_market_share")*Initial_soy_land/Harvester_capacity	In the context of an observer structure, these are the initial assets of the observed market player.

Initial cash	2*30000000000/6	The same value was adopted for all the aggregated roles in the supply chain, so that the model would not start with a disparity in terms of bargain power. The value is approximately twice the state agricultural GDP of one year.
Initial_land_price	6000 BRL/hectare	This value came from the farmer interviews
Initial_non_commodity_land	4000000 hectares	Approximated level of non-commodity land in the state in 2008 based on 2006 data by IBGE (2019)
Initial_other_commodities	3000000 hectares	Approximated level of other commodity land in the state in 2008 based on 2006 data by IBGE (2019). This value excludes natural fields used for bovines, although bovines can be considered a commodity. As this land is not agricultural, it was removed.
Initial_soy_land	3000000 hectares	Approximated level of soy land in the state in 2008 based on 2006 data by IBGE (2019)
Interest	IF Farmer_cash < 0 THEN Farmer_cash*Interest_rate ELSE 0	This is the interest paid by farmers who finish an year with negative cash, which means their debt goes beyond harvest-related that.
Interest_rate	0.055 per year	This interest rate was mentioned on the interviews, which is the usual rate in their subsidized credit contracts.
Is smallholder?	IF"%_farming_market_share"*(Initial_non_commodity_land+Initial_other_commodities+Initial_soy_land) > 0 AND "%_farming_market_share"*(Initial_non_commodity_land+Initial_other_commodities+Initial_soy_land)<Max_smallholder_area THEN 1 ELSE 0	Within the context of the observer structure, a variable to determine if the observer farmer is a smallholder.

Land_acquisition_from_farmers	Debt_execution+Land_acquisition_by_brokers+Land_acquisition_by_harvesters+Land_acquisition_by_processors+Land_acquisition_by_storage_players	A sum of all forms of land acquisition from farmers
Land_demand_by_downstream_players	Perceived_soy_margin>0 THEN ((+Harvesting_player_accumulated_profits+Storage_players_cash+Broker_cash+Processor_cash)*"%_cash_invested_in_land") ELSE 0	There is land demand by downstream players if there is a perceived soy margin and they are willing to invest cash in this.
Land_demand_by_farmers	IF Farmer_cash>0 THEN (Farmer_cash*"%_cash_invested_in_land") ELSE 0	Farmers expand if they have the means to.
Land_owned_by_brokers(t)	Land_owned_by_brokers(t - dt) + (Land_acquisition_by_brokers) * dt {NON-NEGATIVE} INIT Land_owned_by_brokers = 0 INFLOWS: Land_acquisition_by_brokers = IF Land_price>Min_farmer_land_sales_price AND Perceived_soy_margin>0 THEN ((Land_price-Min_farmer_land_sales_price)/Min_farmer_land_sales_price)*(Broker_cash)*"%_cash_invested_in_land"/Land_price/Time_to_acquire_land ELSE 0 {UNIFLOW}	A stock of land owned by original brokers who acquire land. They only buy soy land if there is a positive perceived margin and if the farmers are willing to sell.
Land_owned_by_downstream_players	Land_owned_by_harvesting_players+Land_owned_by_storage_players+Land_owned_by_brokers+Land_owned_by_processors	A sum of all the land owned by downstream players
Land_owned_by_harvesting_players(t	Land_owned_by_harvesting_players(t - dt) + (Land_acquisition_by_harvesters) * dt {NON-NEGATIVE} INIT Land_owned_by_harvesting_players = 0 INFLOWS: Land_acquisition_by_harvesters = IF Land_price> Min_farmer_land_sales_price AND Perceived_soy_margin>0 THEN ((Land_price-Min_farmer_land_sales_price)/Min_farmer_land_sales_price)*(Harvesting_player_accumulated_profits)*"%_cash_invested_in_land"/Land_price/Time_to_acquire_land ELSE 0 {UNIFLOW}	A stock of land owned by original harvesting service providers/harvester renters who acquire land. They only buy soy land if there is a positive perceived margin and if the farmers are willing to sell.

Land_owned_by_processors(t)	Land_owned_by_processors(t - dt) + (Land_acquisition_by_processors) * dt {NON-NEGATIVE} INIT Land_owned_by_processors = 0 INFLOWS: Land_acquisition_by_processors = IF Land_price>Min_farmer_land_sales_price AND Perceived_soy_margin>0 THEN ((Land_price-Min_farmer_land_sales_price)/Min_farmer_land_sales_price)*(Processor_cash)*"%_cash_invested_in_land"/Land_price/Time_to_acquire_land ELSE 0 {UNIFLOW}	A stock of land owned by original processors (refineries or not) who acquire land. They only buy soy land if there is a positive perceived margin and if the farmers are willing to sell.
Land_price	SMTH3(((Initial_land_price)*(((Land_demand_by_downstream_players+Land_demand_by_farmers)/Land_supply)^Sensitivity)), 2, Initial_land_price)	A typical price equation smoothed due to the usual lack of liquidity of land markets.
"Land_rent/price"	0.025	According to the interviewees, this ratio between rent and price can vary between 0.02 and 0.033
Land_supply	(("Non-soy_productive_land"-(Minimum_crop_rotation*(Farmer_soy_land+Land_owned_by_downstream_players+Supplier_land)))*Land_price)+Land_supply_by_farmers	Supply of land for soy is the non-soy commodity land that is not reserved for crop rotation plus the land that is on sale by farmers.
Land_supply_by_farmers	Farmer_soy_land*"%_supply_by_farmers"*Land_price	See "%_supply_by_farmers"
Land_value_owned	Land_price*(("%_supplies_market_share"*Supplier_land)+("%_farming_market_share"*("Non-commodity_land"+Farmer_soy_land+"Non-soy_productive_land"))+("%_harvesting_market_share"*Land_owned_by_harvesting_players)+(Land_owned_by_storage_players*"%_storage_market_share")+(Land_owned_by_brokers*"%_brokerage_market_share")+(Land_owned_by_processors*"%_processing_market_share"))	In the context of an observer structure, this is the land value owned by an observed player.
Logistical costs	Exogenous	Data coming from Department of Agriculture (Secretaria de Agricultura, 2018) time series. Repeated until the end time of this model.

Market_control_premium	IF "%_soy_land_non-smallholder">0.7 AND Market_control_switch>0 THEN 1+(0.2*"%_soy_land_non-smallholder") ELSE 1	When there are too few smallholders in a territory, suppliers and other players might feel it is better to corner them by raising prices. This hypothetical mechanism, that is not turned on by default, serves to this purpose.
Market_control_switch	0	This is a switch for the hypothetical mechanism described above.
Max_smallholder_area	4*Fiscal_module_area	As defined by Brazilian law, farmers are only considered smallholders if they have 4 fiscal modules or less.
Meal price	Exogenous	From an IMEA (2019) time series, these are the soy meal prices observed over time. The time series is repeated until the end of simulation time.
Min_farmer_land_sales_price	12000 BRL/hectare	Based on the interviews, the farmers would not sell below this 2008-adjusted value, which is about double the value of the land at the time.
Min_perceived_margin_not_to_convert_back	20 BRL/tonnes/year	Based on the interviews, they would not convert back above this value. On the interview, they talked about BRL 60/sack which is very close to zero margin, but probably some supplies would also deflate in that case, so we considered adding 20.
Minimum_crop_rotation	0.3	We know the value is below 0.5 because not every farmer does a 50-50 rotation (some do not perform it at all), but the exact value is unknown. Usually soy rotation is done with corn.

Money_spent_from premium	Money_spent_from_premium(t) = Money_spent_from_premium(t - dt) + (Premium_expenditure) * dt {NON-NEGATIVE} INIT Money_spent_from_premium = 0 UNITS: BRL INFLOWS: Premium_expenditure = IF Money_spent_from_premium<Premium_Paid THEN Land_acquisition_by_smallholders*Land_price ELSE 0 {UNIFLOW} UNITS: BRL/Year	To be able to calculate the real % smallholders, there is a need to understand the land acquisitions they might perform due to the fact they have access to premium prices that other farmers cannot access.
"Non-commodity_crops_margin"	200 BRL/hectare/year	Non-commodity crops are usually high-value crops, but with a difficult crop management when compared to commodities, which explains why they rarely figure in the minds of farmers as alternatives to soy. Therefore, conversion from and to non-commodity land is ignored in this model.
"Non-commodity_land"(t)	"Non-commodity_land"(t - dt) {NON-NEGATIVE} INIT "Non-commodity_land" = Initial_non_commodity_land	See "Non-commodity_crops_margin"
"Non-soy_margin"	100 BRL/hectare/year	Non-soy commodity margin, in the minds of the interviewed farmers, is usually corn margin. Corn is a low-margin crop with low risk and simple crop management requirements. It serves as food for milk cows, which is an activity that does not require a lot of land. Summing the margin of these two activities per hectare, the value is certainly lower than current soy margin.

"Non-soy_productive_land"(t)	"Non-soy_productive_land"(t - dt) + (Change_in_productive_land - Crop_conversion) * dt {NON-NEGATIVE} INIT "Non-soy_productive_land" = Initial_other_commodities INFLOWS: Change_in_productive_land = 100000 OUTFLOWS: Crop_conversion = IF Perceived_soy_margin>"Non-soy_margin" AND "Non-soy_productive_land"/("Non-soy_productive_land"+Farmer_soy_land+Land_owned_by_downstream_players+Supplier_land) > Minimum_crop_rotation THEN ((((Perceived_soy_margin-"Non-soy_margin")/"Non-soy_margin")*"Non-soy_productive_land")/Conversion_time ELSE IF Perceived_soy_margin> Min_perceived_margin_not_to_convert_back THEN 0 ELSE IF ((("Non-soy_margin"+Perceived_soy_margin)/"Non-soy_margin")*Farmer_soy_land)/Conversion_time < 0 THEN ((("Non-soy_margin"+Perceived_soy_margin)/"Non-soy_margin")*Farmer_soy_land)/Conversion_time ELSE 0	Non-soy commodity land changes if there is conversion from non-productive land or conversion to/from soy, which can happen if there is a positive perception of soy margin as compared to other commodities. Crop rotation prevents all the land to be converted to soy. The value adopted for Change_in_productive_land is about 30% below the average of the last ten years, due to the fact that land is not infinite.
Number_of_soy_smallholder_farmers	("%_soy_land_smallholder"*Total_soy_land)/Avg_smallholder_area	Self-explanatory
Number of farmers assessed	1 [farmer]	In the context of the observer structure, this variable serves the purpose of indicating to how many agents the observed market share corresponds to.
Other_assets_owned	Harvester_price*("%_harvesting_market_share"+"%_supplies_market_share"+"%_storage_market_share"+"%_brokerage_market_share" +"%_processing_market_share")*Initial_soy_land/Harvester_capacity	In the context of an observer structure, this is an approximation to calculate the value of pre-existing assets such as harvesters, supply, storage, brokerage and processing businesses. Harvester price is used for a proxy for all the businesses.
Other_costs	Exogenous	An aggregation of other soy farming cost beyond the key ones, according to Department of Agriculture (Secretaria de Agricultura, 2018). The values are repeated after the end of the available time series.

Perceived_soy_margin	SMTH3(Soy_farming_margin, 2)	Farmers take time to perceive changes in soy margin, especially due to the existence of opportunity costs from land, harvester ownership, among others. However, crop decisions are annual, and this pushes the value lower.
Pesticide_expenditure	Exogenous	Time series from Department of Agriculture (2018) repeated until the end of the simulation.
Premium	(1.00/60*1000) BRL/tonne	When asked about premium price paid to smallholders, Processor B mentioned they used to pay a little more than BRL 1 per sack in the past. Each sack has 60kg, and the unit of the model is metric tonne.
Premium_Paid	Premium_Paid(t) = Premium_Paid(t - dt) + (Premium_Payment) * dt {NON-NEGATIVE} INIT Premium_Paid = 0 UNITS: BRL INFLOWS: Premium_Payment = Avg_premium_paid*Soy_production {UNIFLOW} UNITS: BRL/Year	In the context of an observer structure, this represents the payment of price premiums from processors, exclusively to smallholders.
Premium_SWITCH	Automatic_premium_SWITCH	Premium price paid by refineries on this model can be activated manually or follow the automatic premium policy (default).
Premium/Cash	IF Farmer_cash>0 THEN(Premium_Paid-Money_spent_from_premium)/Farmer_cash ELSE IF Farmer_cash+(Premium_Paid-Money_spent_from_premium)>0 THEN 1 ELSE 0	This is to calculate the importance of premium money in comparison to the cashflow of farmers who do not have access to premium prices.

Prevalence_of_fraud	0.5/2.7	Interviews revealed two types of identity fraud: one consists in disaggregating families to generate several independent smallholder entries in the government systems. The other consists in making farmers invoice refineries even if a part of that productions is actually going to other buyers. The extent of these practices is hard to determine, but they cannot be prevailing enough to distort official productivity data of biodiesel soy above the usual distortion which is around 0.5/2.7.
Processing_costs	50 BRL/tonnes	Very hard to derive from refineries financial data because they aggregate sourcing, logistics and processing costs on the same line. As we know the other two approximately, we know it is below 100 BRL/tonnes.
Processor_cash(t)	Processor_cash(t - dt) + (Processor_cashflow + Processor_farming_cashflow) * dt INIT Processor_cash = Initial_cash INFLOWS: Processor_cashflow = ((Oil_extraction*(B100_price-Grain_price)*"%_soy_production_dedicated_to_biodiesel")+(Meal_production*(Meal_price-Grain_price)))-(Processing_costs*Sales_to_processors)-(Avg_premium_paid*"%_smallholder_land_among_farmers"*Sales_to_processors*"%_soy_production_dedicated_to_biodiesel")-(Logistical_costs*Share_of_downstream_logistical_costs_paid_by_processor*Sales_to_processors*"%_soy_production_dedicated_to_biodiesel")-Capacity_expansion_costs Processor_farming_cashflow = (Soy_farming_margin*Land_owned_by_processors)-(Land_acquisition_by_processors*Land_price)	A stock that accumulates the cash derived from processing activities and farming activities in farms owned by original processors. Downstream logistical costs are sometimes subsidized by processors, and therefore have to be deducted as well as premium prices. Land acquisition is treated as an expenditure.
Production_time	0.1 year	Crushing and the other physical processes that happen within processors (incl refineries) are simple and fast.

Productivity	IF Productivity_shocks_switch > 0 THEN Ref_productivity*Productivity_shocks ELSE Ref_productivity	Productivity changes when there are productivity shocks.
Productivity_shocks	GRAPH(TIME)	A discretionary variable to be used for productivity shock simulation.
Productivity_shocks_switch	0	A switch for productivity shocks.
ref_smallholder_land_among_farmers =	0.3276 UNITS: unitless DOCUMENT: https://sidra.ibge.gov.br/tabela/1421#resultado - 32.76% in 2006	2006 data from SIDRA/IBGE (2019).
Ref_productivity	2.7 tonnes/hectare	This is the reference productivity used by Department of Agriculture (Secretaria de Agricultura, 2018) to calculate costs. The actual productivity has increased over time since 2008, but this variation is ignored by the model, because it would make the cost structure impossible.
Required_%_of_smallholder_acquisition	("%_acquired_from_cooperatives_below_0.8"*("Required_%_of_smallholder_acquisition_-_South"/"Cooperative_discount_if_smallholder_<0.8"))+("%_acquired_from_cooperatives_above_0.8"*("Required_%_of_smallholder_acquisition_-_South"/"Cooperative_discount_if_smallholder>0.8"))+((1-"%_acquired_from_cooperatives_below_0.8"-"%_acquired_from_cooperatives_above_0.8")*"Required_%_of_smallholder_acquisition_-_South")	Ordinance 515 (SEAD, 2018) defines the minimum % of smallholder acquisition by refineries according to the origin of their supplies.
"Required_%_of_smallholder_acquisition_-_South"	0.4	See Required_%_of_smallholder_acquisition

Seeds_expenditure	Exogenous	From the cost time series by Department of Agriculture (Secretaria de Agricultura, 2018)
Sensitivity	0.44	Elasticity, specific to Brazil, from Barr et al (2010)
Share_of_downstream_logistical_costs_paid_by_processor	0	This is a processor policy to subsidize farmer logistics.
Smallholder_soy_farmer_land	"%_smallholder_land_among_farmers"*Farmer_soy_land	Self-explanatory
Soy_acquired_by_processors(t)	Soy_acquired_by_processors(t - dt) + (Sales_to_processors - Oil_extraction - Meal_production) * dt {NON-NEGATIVE} INIT Soy_acquired_by_processors = 375 INFLOWS: Sales_to_processors = Soy_stored/Time_to_sell {UNIFLOW} OUTFLOWS: Oil_extraction = Soy_acquired_by_processors*("%_oil_mass_in_grain")/Production_time {UNIFLOW} Meal_production = Soy_acquired_by_processors*(1-"%_oil_mass_in_grain")/Production_time {UNIFLOW}	Stock of soy waiting to be processed. Initial value to minimize short-term transient.
Soy_farming_margin	(Grain_price*Productivity)-((Harvester_rent*Market_control_premium*(1-"%_harvester_owned"))+(Land_price*"Land_rent/price"*(1-"%_land_owned"))+(Market_control_premium*(Seeds_expenditure+Fertilizer_expenditure+Pesticide_expenditure))+(Market_control_premium*Storage_price/Harvests_per_year*Productivity*(1-"%_direct_sales"))+(Logistical_costs*Productivity*(1-Share_of_downstream_logistical_costs_paid_by_processor))+Other_costs)	Soy farming margin according to the implemented cost structure. The payment of a market control premium only happens when this policy is activated and only applies to supplies and storage. Logistical costs are sometimes partially paid by processors.

Soy_land_acquired_by_smallholders	Soy_land_acquired_by_smallholders(t) = Soy_land_acquired_by_smallholders(t - dt) + (Land_acquisition_by_smallholders) * dt {NON-NEGATIVE} INIT Soy_land_acquired_by_smallholders = 600000 UNITS: hectares INFLOWS: Land_acquisition_by_smallholders = IF Farmer_soy_land>Soy_land_acquired_by_smallholders THEN (Farmer_soy_land*"Premium/cash")/Time_to_acquire_land ELSE 0 {UNIFLOW} UNITS: Hectares/Years	Stock of land acquired by smallholders using their premium price money. Initial value to minimize short-term transient.
Soy_stored(t)	Soy_stored(t - dt) + (Soy_production - Sales_to_processors) * dt {NON-NEGATIVE} INIT Soy_stored = 4000000 INFLOWS: Soy_production = (Farmer_soy_land+Supplier_land+Land_owned_by_downstream_players)*(Productivity) {UNIFLOW} OUTFLOWS: Sales_to_processors = Soy_stored/Time_to_sell {UNIFLOW}	Soy stored in silos that are sometimes pre-sold or post-sold. In any case the storage player margin is paid by someone (farmer or acquirer). Initial value to minimize short-term transient.
Storage_cost	5 BRL/tonne/year	Very little information available about this. The marginal cost is treated as near zero, but, as we do not have amortization nor depreciation of storage infrastructure on the model, it is important to have a positive value here.

Storage_players_cash(t)	Storage_players_cash(t - dt) + (Storage_cashflow + Storage_player_farming_cashflow) * dt INIT Storage_players_cash = Initial_cash INFLOWS: Storage_cashflow = (1-"%_direct_sales")*((Soy_stored*Storage_price*Market_control_premium)-(Soy_stored*Storage_cost)) Storage_player_farming_cashflow = (Land_owned_by_storage_players*Soy_farming_margin)-(Land_acquisition_by_storage_players*Land_price)	A stock that accumulates the cash derived from storage activities and farming activities in farms owned by original storage players. Whenever there is a direct sale from farmer to processor, there is no storage, so this does not generate cash.
Storage_price	77.16*2.7 BRL/tonnes/year	From Department of Agriculture (Secretaria de Agricultura, 2018), adapted to be treated per tonne instead of per hectare.
Supplier_cash(t)	Supplier_cash(t - dt) + (Supplier_cashflow) * dt INIT Supplier_cash = 30000000000/6 INFLOWS: Supplier_cashflow = Market_control_premium*Supplier_margin*(Farmer_soy_land)*(Pesticide_expenditure+Fertilizer_expenditure+Seeds_expenditure)	A stock that accumulates the cash derived from supplier activities and farming activities in farms owned by original suppliers. Pesticide, fertilizer and seed expenditures (from a farmer perspective) are revenues for suppliers.
Supplier_land(t)	Supplier_land(t - dt) + (Debt_execution) * dt {NON-NEGATIVE} INIT Supplier_land = 0 Debt_execution = IF Farmer_cash<0 THEN (-Farmer_cash/Land_price/debt_execution_time)*("%_debt_supplier"*SWTICH_debt_guaranteed_by_land) ELSE 0 {UNIFLOW}	Supplier land is acquired by debt execution whenever farmers owe money to suppliers that sign contracts using land as guarantee.
Supplier_margin	0.3	A typical retail market for niche products.
SWTICH_debt_guaranteed_by_land	1	A switch to define the supplier policy of taking land as guarantee.

Time_to_acquire_land	10 years	Land transactions take time from the moment they become attractive.
Time_to_sell	0.5 year	Soy grain sales to processors happen throughout the inter-harvest period that takes one year. The average is considered to be half year.
Total_soy_land	Farmer_soy_land+Land_owned_by_downstream_players+Supplier_land	Total soy land in the model.

Annex 2 – Interview guides

Objectives of the interview:

- to detect threats to farmers' resilience
- to elicit decision rules related to the adherence to BE crops and BE programmes, buying/selling land and to abandoning the farming activity
- to make sure the interviewee is available for more interviews & surveys if needed
- to obtain more contacts for further interviews & surveys

The 'why' questions will be inverted to 'why not' when interviewing farmers who do not participate in BE schemes.

Interview guide:

First of all, thanks for having me today. As we talked before, my name is Igor and I'm interviewing you for a research project that aims to understand the reality of small biodiesel crops farmers. As a farmer [and cooperative leader], your point of view is key to understand the options farmers have in terms of growing these crops, joining the social programmes *et cetera*.

May I record this conversation? I can send you the results later if you'd like. Everything will be treated anonymously. I will make sure that no one is able to trace your answers back to you.

First I need to ask some questions to get to know you a bit better… how many are you in your family? Do your children live with you?

Where is your farm located? How big is it?

Is it yours or do you lease part of it?

What crops do you have on it now? How much of each?

Why don't you grow more [crop 1]?

Why don't you grow more [crop n]?

How do you decide if you'll grow more food crops or biofuel crops?

Why do you diversify crops?

How do you learn about crop management (*manejo*)?

Do you maintain inventories? How do you decide how much stock to maintain?

Who is your main client for soybeans?

Lately, have you increased or decreased the area with biodiesel crops? Why?
How does the climate (incl. water) influence that decision? Have you perceived any changes on the climate in the last years? How is it affecting the biodiesel crops?
Can you tell me the story of how you got into biodiesel? What made you enter this world? What was the role of the social biodiesel programme?
How does it work to sell your harvest to the biodiesel producers that are certified by the social biodiesel programme? Can you describe the process a bit?
Is it a good deal nowadays to sell your harvest to them? Why?
Do you negotiate the price with them? How does that happen?

The 3 questions below will be supported by a threshold elicitation drawing as suggested by Ford and Sterman (1998):

How low should the price be for you to stop selling it to BE processors?
How high should the price be for you to expand the BE crops?
Would this BE crop still be useful for anything else? How low should the price be for you to stop growing this BE crop even for other clients?

Is your family making a living from the biodiesel crops? What else do you guys have to do to make a living? Tell me more about how you decide on where to try to earn money from…
How much of the food you eat is planted at your farm? Is it hard to put food on the table? Why?
What could make you buy more land?
What could make you sell your land?
Is the land price in your region getting higher or lower lately? Why?

The 2 questions below will be supported by a threshold elicitation drawing as suggested by Ford and Sterman (1998):

How high would an acquisition offer have to be for you to sell it?
How low would your neighbours' land price have to be for you to buy it?

In your region, is there land being acquired or abandoned? What do the farmers do after leaving their land? Why do you think they leave it?

Do you fear having to abandon your current livelihood? What makes you fear? What risks do you see that could make your life worse? What would you do if you had to leave?

Is there anything else you'd like to tell me about the things we talked?

Thank you so much for your time and answers. I'm really happy to be able to know more about your reality. You guys are heroes.

Could you provide some contacts of other farmers? Telephone number, whatsapp, email…

Once more, thank you. I'll be in touch with the results. May I contact you again if I need some more details?

Annex 3 – Interview coding form (each interviewee is a column)

RQ1: What are the threats for the resilience of smallholder farmers involved in the social biodiesel programme, especially those generated by the existence of the programme itself?
RQ2: Which heuristics, decision rules and thresholds guide smallholder farmers' decisions that relate to their own resilience?
RQ3: What happens to smallholder farmers involved in the social biodiesel programme when severe resilience loss (or regime shift, in the resilience jargon) occurs?

Family size (n)
Family description
Farm size (ha)
Equipment (tractors, computers, software…)
Associations and cooperatives
Credit lines
Farm ownership
Crop 1
Crop 1 Area (ha)
Why not more crop 1?
Crop 2
Crop 2 Area (ha)
Why not more crop 2?
Crop 3
Crop 3 Area (ha)
Why not more crop 3?
Other crops
Why not more other crops?
Why to diversify
BE vs other crops decision rule
Climate influence on crop decision
How do you learn about crop management (*manejo*)?
To whom is the BE crop sold (incl non-BE and non-SCS buyers)
Priority between BE and non-BE clients
How got into BE incl role of social programme

Sales process to BE producer

How good is the deal of selling to BE producer?

How price is negotiated

Quantity and schedule - how it is negotiated and executed

Bureaucracy/technical visits

How high should the price be for you to expand the BE crops?

How low should the price be for you to stop growing this BE crop even for non-BE clients?

What else besides farming to make a living

% of food eaten grown

Hard to put food on the table?

What would have to happen to buy/sell land

Recent land prices variation

Elicitation of land buy/sell thresholds

Are there people moving out?

Why? What do they do afterwards?

Perceived risks?

What would you do if you left?

Anything else you wanna say?

Contacts for later

Contacts of other participants

Annex 4 – parameter sensitivity analysis

Variable	Sensitivity	Confidence interval number smallholders	Confidence interval land price	Extreme values	Comments	Useful for analysis
2019_B100_ production_capacity_(volume)	Not sensitive					
"%_acquired_from_cooperatives_above_0.8"	Not sensitive			ok		
"%_acquired_from_cooperatives_below_0.8"	Not sensitive			ok		
"Cooperative_discount_if_smallholder_<0.8"	Not sensitive			Zeros generate problems		
"Cooperative_discount_if_smallholder>0.8"	Not sensitive			Zeros generate problems		
"%_cash_invested_in_land"	Sensitive mostly for land prices	50%	50%	OK	Testing with smaller ranges show less sensitivity for number of smallholders	Yes
"%_debt_supplier"	Not sensitive			OK		

"%_direct_sales"	Not sensitive			OK		
"%_harvester_owned"	Not sensitive			OK		Yes
"%_land_owned"	Not sensitive			OK		
"%_oil_mass_in_grain"	Not sensitive					
ref_smallholder_land_among_farmer	Sensitive mostly for number of smallholders	50%		ok	Impacts number of smallholders directly, but does not have sensitivity beyond that arithmetic causation.	
"%_soy_production_dedicated_to_biodiesel"	Not sensitive				Turned off biodiesel mixture to test this variable	
Automatic_premium_SWITCH	Not sensitive	50%				Yes
Avg_smallholder_area	Sensitive mostly for number of smallholders	50%			Impacts number of smallholders directly, but does not have sensitivity	No

					beyond that arithmetic causation .	
B100_density	Not sensitive					
B100 price	Not sensitive					Yes
biodiesel_switch	Not sensitive			OK		Yes
Brokerage margin	Sensitive mostly for land prices		50%	OK		
Capacity_expansion_costs	Not sensitive					
Conversion time	Sensitive mostly for land prices	50%	50%	Zeros gener ate proble ms		
Debt execution time	Not sensitive			OK		
Farmer_family_expenditure	Sensitive mostly for land prices		50%	OK		Yes
Fertilizer_expenditure	Not sensitive					
Fiscal_module_area	Not sensitive					Yes
"Gov_bond_interest_rate_(nominal)"	Not sensitive					
Grain price	Sensitive for number of	50%	50%			Yes

	smallholder farmers and land prices					
Harvester_capacity	Not sensitive					
Harvester_depreciation	Not sensitive					
Harvester_price	Not sensitive					
Harvester_rent	Not sensitive					Yes
Harvests per year	Not sensitive					
Inflation rate	Not sensitive					
Initial cash	Not sensitive			ok		Yes
Initial_land_price	Not sensitive	50%	50%	Zeros generate problems		Yes
Initial_non_commodity_land	Not sensitive					
Initial_other_commodities	Sensitive mostly for number of smallholders	50%	50%			Yes
Initial_soy_land	Sensitive mostly for number of	50%				Yes

	smallholders					
Interest_rate	Not sensitive			ok		
"Land_rent/price"	Not sensitive					
Logistical costs	Sensitive mostly for land prices		50%			
Market_control_premium	Sensitive for number of smallholder farmers and land prices	50%	50%		Made the variable independent to be able to test it	Yes
Market_control_switch	Not sensitive					
Meal price	Sensitive for number of smallholder farmers and land prices	50%	50%			Yes
Min_farmer_land_sales_price	Sensitive for number of smallholder farmers	50%	50%			Yes

	and land prices					
Min_perceived_margin_not_to_convert_back	Not sensitive			ok		
Minimum_crop_rotation	Sensitive for number of smallholder farmers and land prices	50%	50%	Zeros generate problems	Testing with smaller ranges maintains sensitivity for number of smallholders	Yes
"Non-commodity_crops_margin"	Not sensitive					
"Non-soy_margin"	Not sensitive			Ok	Testing with smaller ranges show less sensitivity for number of smallholders	No
Other_costs	Not sensitive					
Pesticide_expenditure	Not sensitive					Yes
Premium	Not sensitive	100%	100%	ok	See automatic switch above	
Premium_SWITCH	Not sensitive					

Prevalence_of_fraud	Not sensitive					
Processing_costs	Not sensitive					
Production_time	Not sensitive					
Productivity_shocks_switch	Not sensitive				Tested through 'ref producviti vity'	
Ref_smallholder_area	Not sensitive				Sensitivit y due to direct relationsh ip	
Ref_productivity	Sensitive for number of smallhol der farmers and land prices	95%	75%		Testing with smaller ranges maintains sensitivity for number of smallhold ers	Yes
"Required_%_of_smallholder_acquisition_-_South"	Not sensitive					
Seeds_expenditure	Not sensitive					
Sensitivity	Sensitive mostly for land prices		50%	ok		Yes
Share_of_downstream_logistical_costs_paid_by_processor	Not sensitive			Ok	Testing with smaller	No

					ranges show less sensitivity for number of smallholders	
Storage_cost	Not sensitive					
Storage_price	Not sensitive					
SWTICH_debt_guaranteed_by_land	Not sensitive					
Time_to_acquire_land	Not sensitive			ok		
Time_to_sell	Not sensitive			Ok		