From Fields to Ballots: Droughts and Electoral Shifts in Brazil

Lou Chiani*

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Abstract

Climate change is expected to intensify the frequency and severity of droughts in developing countries, where rural livelihoods remain highly dependent on rainfed agriculture. Yet the political consequences of such shocks are theoretically ambiguous: dry spells may heighten concern for environmental protection, but they may also depress rural incomes and thereby reduce support for parties advocating more stringent—and potentially costly—environmental policies. This paper examines how growing-season droughts shape voting behavior in Brazil, a large developing democracy characterized by strong climate vulnerability, deep agrarian inequalities, and polarized environmental politics. Combining high-resolution weather data with a panel of ideology- and environment-weighted vote shares for all presidential elections between 2002 and 2022, I exploit within-municipality variation in hydrological stress aligned with crop-specific growing seasons. I find that drier growing seasons systematically reduce support for green and left-leaning coalitions. Exploration of potential mechanisms reveals that these effects operate through lower agricultural revenue per hectare, with off-season droughts having little explanatory power. Heterogeneity analyses reveal stronger electoral penalties in smallholder-dominated areas and substantially weaker reactions in agribusiness regions, with social protection and rural organization mitigating these effects in smallholder areas. Taken together, the results indicate that in rural Brazil, the adverse economic impacts of drought dominate any countervailing rise in environmental concern, ultimately shifting votes away from environmental and redistributive platforms.

Keywords: climate change, drought, voting behavior, agricultural income, Brazil.

*Paris-Dauphine University (PSL), LEDa, DIAL. Email: `lou.chiani@dauphine.psl.eu`.

1 Introduction

Climate change is expected to intensify the frequency and severity of extreme weather events worldwide, with disproportionately large impacts on developing countries (IPCC, 2022). In many of these settings, a substantial share of the population depends directly on rainfed agriculture for income and employment (FAO, 2018). Deviations from usual climatic conditions therefore have immediate and far-reaching economic consequences. Beyond agricultural losses, such shocks may also reshape political preferences, especially where rural livelihoods are fragile and where environmental and land-use policies carry highly salient distributive implications.

A growing body of research examines the socioeconomic and political consequences of short-run climatic variability. Work in the climate–economy literature shows that temperature and precipitation anomalies reduce agricultural yields, particularly in tropical and semi-arid regions where reliance on rainfed production remains high (Dell et al., 2014; Schlenker and Roberts, 2009). Parallel strands in political economy find that negative income shocks can trigger electoral realignments, shifts in turnout, or changes in political trust (Cole et al., 2012; Margalit, 2019). At the same time, an expanding literature in high-income democracies shows that climate-related disasters can heighten environmental concern and increase support for green parties or pro-climate policies (Hoffmann et al., 2022; Baccini and Leemann, 2021; McAllister and Oslan, 2021). Taken together, these findings reveal a fundamental tension: weather shocks can simultaneously generate economic hardship—pushing voters away from parties perceived as constraining local economic opportunities—and heighten awareness of environmental risks—potentially shifting support toward greener platforms. Both reactions are theoretically plausible, leaving ambiguous predictions about how drought shapes electoral preferences.

This ambiguity is especially relevant in Brazil. The country combines features that make it a particularly revealing case: high climate vulnerability, a large rural population dependent on rainfed agriculture, and a political landscape in which environmental protection and agribusiness are openly contested. On the one hand, recurrent droughts impose substantial income losses on family farmers, a group historically aligned with redistributive and left-leaning coalitions; such income shocks could therefore reduce support for these political groups. On the other hand, Brazil plays a pivotal role in the global climate system, and weather shocks may heighten awareness of environmental risks and the stakes of conservation policy. Brazilian voters are thus unusually well placed to influence policies that affect not only local livelihoods but also global climate outcomes.[1] As a result, weather shocks could in principle strengthen support for green candidates, as observed after climate disasters in several high-income democracies.

This paper takes these tensions as its starting point and examines how growing-season droughts affect voting behavior in Brazil. I focus on presidential elections between 2002 and 2022 and ask whether municipalities exposed to drier-than-normal conditions during the crop cycle subsequently reallocate support across ideological and environmental coalitions. Empirically, I

[1] A nationally representative survey finds that 77% of Brazilians expect climate change to have serious effects on their lives; 37% identify the federal government as the actor that should act first (the most frequently cited response), compared to 24% who point to civil society; and 45% report having already voted for a candidate because of their environmental position (ITS-Rio, 2022).

combine high-resolution weather data with a new panel of ideology- and environment-weighted vote shares at the municipal level and exploit within-municipality variation in growing-season hydrological stress. By tracing how these shocks translate into changes in support for green and left-leaning coalitions, the analysis sheds light on how weather-induced income losses reshape electoral competition in a context where environmental regulation and agricultural interests are highly salient.

While existing research shows that both economic shocks and climate-related events can shape political behavior, we still know little about how weather-induced fluctuations in agricultural income affect electoral preferences in large, unequal democracies. Yet much of the Brazilian literature has focused on the politics of formal drought declarations and the discretionary allocation of emergency relief resources, leaving the electoral consequences of yield-driven shocks essentially unexplored.

First, it provides what is, to my knowledge, the first municipal-level panel analysis of presidential elections in Brazil over two decades that links high-resolution weather data to within-municipality changes in vote shares. Second, it isolates an agriculturally grounded mechanism by aligning monthly SPEI data with municipality-specific crop calendars, allowing the analysis to isolate hydrological stress during the growing season rather than generic climatic discomfort or the political dynamics associated with accessing and distributing drought-related relief. Third, it introduces continuous ideology- and environment-weighted vote measures that allow electoral responses to drought to be traced along both the left–right and the green–brown dimensions, rather than focusing on a single candidate or party label. This dual-dimension perspective provides a richer account of how weather-related income shocks shift electoral outcomes in a major developing democracy.

To quantify drought conditions, I use the Standardized Precipitation–Evapotranspiration Index (SPEI), computed from monthly precipitation and potential evapotranspiration data obtained from the TerraClimate dataset (Abatzoglou et al., 2018). Unlike raw temperature or precipitation measures, SPEI provides a standardized indicator of hydrological stress relative to local historical norms (Vicente-Serrano, Beguería, and López-Moreno, 2010; Beguería et al., 2014; Harari and Ferrara, 2018). I then combine these SPEI measures with state-level crop calendars from CONAB (CONAB, 2022) and phenological information from MIRCA-OS (Kebede et al., 2025) to align drought exposure with each municipality's main growing season. The empirical strategy exploits within-municipality variation over time, isolating short-run, weather-driven variation in growing-season water balance that is effectively independent of local political dynamics.

The results show that droughts meaningfully reshape electoral preferences. Drier growing seasons lead to significant declines in support for green and left-leaning coalitions, and these effects are robust across a wide range of supplementary exercises. Mechanism tests reveal that droughts depress agricultural revenue per hectare during the growing season, while hydrological conditions outside this window have little explanatory power—consistent with an income-based channel. Heterogeneity analyses further demonstrate that electoral responses are strongest in municipalities dominated by family farming and weakest in agribusiness regions, and that agricultural protection programs and rural unionization mitigate these electoral penalties among smallholder-dominated municipalities. Finally, lagged-SPEI specifications indicate that voters respond primarily to recent and second-most-recent growing-season shocks rather than to long-term climatic trends.

The remainder of the paper proceeds as follows. Sections 2 and 3 situate the paper within the related literature and provide additional background. Section 4 presents the data and construction of key variables. Section 5 outlines the empirical strategy. Sections 6.1-6.3 present the main results and explore mechanisms and heterogeneity. Section 6.4 discusses robustness checks. Section 7 concludes.

2 Related literature

This paper builds on research connecting climatic variability, agricultural production, and political behavior. Three areas of work are particularly relevant. The first documents how weather shocks affect crop yields; the second examines how economic and environmental shocks shape electoral outcomes; and the third studies how exposure to climate-related events influences environmental attitudes and voting.

A large literature shows that weather variability has substantial effects on agricultural production. Seminal work demonstrates that crop yields respond nonlinearly to heat, with sharp declines when temperatures exceed biological thresholds (Schlenker and Roberts, 2009), and that recent climatic trends have already depressed global yields of major staples such as maize and wheat (Lobell et al., 2011). Broader reviews highlight that agriculture is one of the sectors most sensitive to weather shocks (Dell et al., 2014; Carleton and Hsiang, 2016), and that long-run adaptation has so far offset only a limited share of heat-related damages (Burke and Emerick, 2016). Similar evidence for Sub-Saharan Africa suggests large and highly probable yield losses under warming (Schlenker and Lobell, 2010). Recent studies also show that increasingly frequent dry spells and hydrological deficits have measurable adverse effects on crop productivity in Brazil (Cavalcanti et al., 2023; Miyamoto and Hackmann, 2025). Together, this literature establishes that weather-induced fluctuations in agricultural output are economically meaningful—particularly in rainfed systems—and provides the basis for analyzing their downstream behavioral consequences.

A second strand examines how exogenous shocks—whether economic, weather-related, or disaster-induced—shape political behavior. Trade disruptions and labor-market shocks can trigger electoral realignments, shifts toward anti-establishment or radical parties, and reduced trust in political institutions (Margalit, 2019; Colantone and Stanig, 2018; Dippel et al., 2015). A growing body of work focuses specifically on weather-driven income shocks in agrarian economies: in India, adverse rainfall shocks depress rural incomes and reduce support for incumbents unless governments respond effectively through relief (Cole et al., 2012), while Amirapu et al. (2022) show that extreme temperatures reduce agricultural productivity and, in turn, alter turnout patterns and candidate selection. Related work exploits natural disasters—such as tornadoes, floods, hurricanes, and wildfires—as plausibly exogenous sources of local economic loss. These studies show that voters engage in retrospective evaluations of incumbents in ways that depend critically on governmental responses: inadequate relief leads to electoral punishment, while timely and effective assistance can generate sizable and persistent electoral rewards (Healy and Malhotra, 2010; Gasper and Reeves, 2011; Bechtel and Hainmueller, 2011). In developing countries, droughts also influence political trust, with heterogeneous responses across politically favored and disfavored regions (Ahlerup et al., 2024). Together, this research highlights that shocks—whether economic, weather-related, or disaster-induced—affect political behavior both through their material impacts and through voters' evaluations of state capacity and responsiveness.

A third body of work examines how exposure to extreme or unusual environmental conditions influences attitudes toward climate change and political support for environmental policies. Temperature anomalies, heatwaves, floods, and wildfires have been shown to heighten concern for environmental risks and, in several high-income democracies, increase support for green parties or pro-climate referenda (Böhmelt, 2020; Egan and Mullin, 2012; Howe et al., 2019; Hoffmann et al., 2022; McAllister and Oslan, 2021; Baccini and Leemann, 2021; Hazlett and Mildenberger, 2020). These effects, however, depend strongly on local political and economic contexts, with the largest shifts often occurring where environmental issues are already salient.

Evidence from large and politically fragmented democracies facing high climate vulnerability—such as Brazil—remains more limited. Pianta and Rettl (2023) show that large-scale fires increase support for green candidates only in municipalities unlikely to benefit economically from newly cleared land, suggesting that local economic incentives shape whether environmental shocks translate into greener voting. At the municipal level, existing Brazilian research focuses primarily on droughts and the politics of discretionary relief. Miller and Bastos (2013) document that municipalities governed by mayors aligned with the president are more likely to issue formal drought declarations prior to elections, and that such declarations reinforce incumbents' advantages. In Northeast Brazil, Cooperman (2022) show that drought declarations—which unlock access to emergency spending—are strategically concentrated in election years, increasing incumbents' re-election chances even under normal rainfall. Related evidence indicates that drought exposure raises voters' reliance on aligned local incumbents to secure assistance (Cavalcanti, 2018), while partisan bias in the allocation of relief intensifies in the run-up to municipal elections (Boffa et al., 2024). Together, these studies portray drought-related shocks as tightly intertwined with distributive politics and the strategic use of relief. However, the political consequences of weather-induced fluctuations in agricultural production—operating through changes in crop yields and rural incomes rather than through discretionary disaster declarations—remain largely undocumented.

3 Institutional background and setting

3.1 Brazil's agricultural sector and climate vulnerability

Brazil is one of the world's leading agricultural producers, with agribusiness playing a central role in exports and rural employment. Agriculture and agribusiness together account for roughly 20% of GDP and more than 30% of jobs (World Bank Group, 2025). Yet despite its global importance and abundant freshwater resources, Brazilian agriculture remains predominantly rainfed: only 2–4% of cultivated land was irrigated between 2002 and 2022 (World Bank, 2025). This limited reliance on irrigation does not reflect water scarcity, but rather the historical path of agricultural modernization, which has emphasized biological and agronomic adaptation—such as drought-tolerant crop varieties, adjustments in cropping calendars, and the expansion of rainfed production—over large-scale irrigation infrastructure. Structural constraints, including very large farm sizes, high fixed costs, and the geographic distance between cropland and water sources, have further limited the diffusion of irrigation (FAO, 2015). As a result, agricultural production remains highly sensitive to the seasonal distribution of rainfall and to the timing of dry spells.

Brazil is also strongly exposed to climate change. Recent decades have brought rising temperatures and declining rainfall in several regions, especially the Northeast and South (World Bank Group, 2025). Projections indicate further warming, a shorter rainy season, and more frequent heat extremes and drought episodes. Because of the country's vast ecological diversity, exposure to drought is heterogeneous: semi-arid areas of the Northeast, frontier regions of the Center-West (including the Cerrado and southern Amazon), and portions of the Southeast are repeatedly affected. Cunha et al. (2018) document intense multi-year droughts in the Northeast during the 2010s and major drought episodes in the Amazon in 2005, 2010, and 2016.

This combination of strong global agricultural integration, heavy reliance on rainfed production, and increasing exposure to rainfall deficits makes Brazil an especially relevant case for examining how weather-induced fluctuations in agricultural productivity translate into downstream economic and political outcomes.

3.2 Brazil's political system, parties, and ideological cleavages

Brazil is a federal presidential republic with 27 states and more than 5,500 municipalities. Its multiparty system is highly fragmented and personalistic, and only a subset of parties maintains consistent programmatic positions (Zucco and Power, 2021). Although Brazilian party politics is structured by multiple and evolving cleavages, two partially overlapping dimensions are especially relevant for the analysis developed here: a traditional left–right axis and a green–brown environmental axis. These axes are correlated but not redundant. Several left-leaning parties (such as MDB, PDT, or PCdoB) place little emphasis on environmental protection, while segments of the center-right—most notably within PSDB—have at times supported stronger environmental regulation. Environmental positions therefore do not map neatly onto the left–right divide.

On the left, the Workers' Party (PT) has long advanced a social-democratic agenda (Samuels and Zucco, 2018), while parties such as PSOL adopt more progressive and pro-environmental platforms. The Green Party (PV) and, more recently, the Sustainability Network (REDE)—a party founded in 2013 by Marina Silva—explicitly emphasize ecological politics. Marina Silva, a central figure in Brazil's environmental movement and former Minister of the Environment (2003–2008), provides a salient illustration of this cross-cutting pattern: she ran for president in 2010 under the Green Party (PV), in 2014 under the Brazilian Socialist Party (PSB), and in 2018 as the candidate of REDE. Since 2023, she has returned to government as Minister of the Environment and Climate Change, further underscoring the cross-partisan relevance of environmental issues in Brazilian politics.

Environmental cleavages interact closely with broader ideological competition. Left-leaning coalitions generally support stronger environmental enforcement, whereas right-leaning parties tend to prioritize agribusiness interests, deregulation, and flexible land-use rules. This contrast became particularly salient during the Bolsonaro presidency (2019–2022), marked by weaker environmental oversight, and again under Lula's subsequent return to office, which reinstated environmental priorities.

Given the consequential but imperfect alignment between ideological and environmental orientations—and their salience for distributive politics in rural Brazil—I focus on how drought affects support for green and left-leaning coalitions rather than on individual candidates or parties.

3.3 Drought, agrarian structures, and rural political dynamics

Drought has long shaped political and economic life in rural Brazil, particularly in the semi-arid Northeast. Historical accounts describe how recurrent dry spells became intertwined with local power structures, forming the so-called *indústria da seca*—a system in which political elites and large landowners leveraged drought relief, public works, and water infrastructure to consolidate patronage networks (Zambiasi, 2025). Under this model, drought was less a climatic misfortune than an opportunity for political control.

Since the early 2000s, federal social policies have altered this landscape. Programs such as *Bolsa Família*, *Garantia-Safra*, and *Bolsa Estiagem* expanded protection for low-income rural households and created income-support mechanisms explicitly designed to buffer smallholders against drought-related crop failures (Bedran-Martins and Lemos, 2017). As shown by Bedran-Martins, Ribeiro, et al. (2022), these reforms gave rise to two coexisting drought-governance paradigms: a "fight-the-drought" paradigm centered on large-scale hydraulic infrastructure and capital-intensive agricultural expansion, and a "cope-with-drought" paradigm emphasizing decentralized water access, social protection, and local resilience-building.

This duality reflects deeper structural cleavages within Brazilian agriculture. Family farming (*agricultura familiar*) is characterized by small-scale, labor-intensive, rainfed production and has historically aligned with redistributive and social-protection agendas (Sauer, 2008). These producers are highly vulnerable to drought-induced income losses. In contrast, the agribusiness sector—dominated by large mechanized farms in the Center-West soybean frontier—benefits from irrigation, technological inputs, and stronger political influence (Sauer, 2019). It has long shaped federal policy through alliances with conservative congressional coalitions and the rural caucus.

These structural differences imply that drought impacts are unlikely to be uniform across rural Brazil. Smallholder-dominated municipalities depend more directly on rainfed agriculture and on income-support programs, making them more exposed to weather-induced income losses and more sensitive to their political consequences. Conversely, agribusiness-dominated municipalities tend to benefit from larger scale, better access to credit, and a broader set of adaptive margins—including limited but relatively greater use of irrigation, technological inputs, and crop management practices—which can partially buffer weather shocks and dampen electoral responses. Because these structural differences align with long-standing ideological and environmental divides, heterogeneity in voting responses to drought likely reflects both differential economic vulnerability and pre-existing political coalitions.

4 Data

Data on presidential elections come from the Tribunal Superior Eleitoral (TSE), the institution responsible for administering and overseeing elections in Brazil (Tribunal Superior Eleitoral, 2025). Following standard practice, I focus on first-round results only. This choice avoids strategic behavior related to expectations about the runoff—documented by Fujiwara (2011)—and therefore better reflects voters' revealed preferences. For each presidential election between 2002 and 2022, I observe municipal vote shares for all candidates and use these to construct two main outcomes: ideology-weighted and environment-weighted voting measures.

These continuous indicators capture how the distribution of votes in each municipality aligns with the ideological and environmental profiles of competing parties and coalitions. They are based on the Brazilian Legislative Survey (BLS), a periodic expert survey of federal deputies that provides information on legislators' positions along several ideological dimensions (Power and Zucco, 2012). I use BLS responses to obtain normalized left–right and green–brown scores at the party-by-election level and assign these scores to presidential candidates according to the parties supporting their coalitions.

Importantly, these BLS-based party scores closely mirror qualitative accounts of Brazilian party politics. Candidates supported by PT and PSOL consistently appear on the left and on the green side of the environmental dimension, in line with their long-standing emphasis on social protection and environmental regulation. Green parties such as PV and REDE—most notably Marina Silva—occupy the greenest positions, even when their ideological placement is more moderate. By contrast, conservative and evangelical parties, as well as Bolsonaro-led candidacies, fall on the right and toward the brown end of the environmental spectrum, reflecting programmatic priorities centered on deregulation, agribusiness interests, and weaker environmental oversight. Together, these patterns confirm that the BLS-based scores recover well-established ideological and environmental cleavages in Brazilian politics, supporting their use as continuous measures of political orientation in this setting.

This measurement strategy offers two advantages relative to common approaches in the literature. First, by using continuous ideology- and environment-weighted voting measures rather than discrete party classifications, it avoids imposing arbitrary thresholds and exploits the full variation in party positions. Second, it does not restrict attention to a single candidate—such as Marina Silva, often used as a proxy for environmental voting—but instead incorporates the broader ideological and environmental structure of party coalitions. This provides a richer depiction of green–brown and left–right electoral behavior over a longer period. Further details on the construction of these indicators are provided in Appendix A.

In a robustness exercise, I also use a more traditional proxy for environmental voting: the municipal vote share for Marina Silva in the elections in which she ran for president. Although this candidate-specific measure is narrower, it facilitates comparison with previous studies (Pianta and Rettl, 2023; Araujo et al., 2024). In some specifications, I additionally control for voter turnout. Turnout is observed in TSE data as the ratio of valid votes to registered voters.[2]

4.1 Weather, crops, and growing-season alignment

I combine high-resolution weather data with municipality-level information on agricultural production to construct drought exposure measures aligned with local growing seasons. Weather variables come from the TerraClimate dataset (Abatzoglou et al., 2018), which provides monthly precipitation and potential evapotranspiration (PET) at a spatial resolution of approximately 4 km globally since 1958.

These variables are then used to compute the Standardized Precipitation–Evapotranspiration Index (SPEI) (Vicente-Serrano, Beguería, and López-Moreno, 2010), which combines precipitation and PET into a standardized measure of water balance, capturing the extent to which rainfall is effectively available to crops—a function of both water supply and atmospheric water demand. Operationally, SPEI is a standardized index expressed in standard-deviation units: negative values indicate drier-than-average conditions and positive values wetter-than-average conditions. I compute it using the full 1958–2022 TerraClimate baseline. Because evapotranspiration rises with global warming, SPEI has become a widely used index for detecting agriculturally meaningful droughts, and recent work identifies it as particularly suitable for applications to Brazil (Beguería et al., 2014; Vicente-Serrano, Beguería, Lorenzo-Lacruz, et al., 2012; Cavalcanti et al., 2023). It therefore provides a more accurate representation of drought conditions than raw precipitation or temperature measures.

An important advantage of SPEI is its multiscalar structure, allowing the index to capture short-, medium-, or long-term water balance anomalies. Following agronomic and climate-science conventions, as well as previous applied work (Beguería et al., 2014; Harari and Ferrara, 2018), I use the four-month aggregate (SPEI-4). This scale reflects short- and medium-term moisture conditions relevant for plant growth and crop stress, making it particularly well suited

[2] Formally, voting is compulsory in Brazil for literate citizens aged 18 to 70, with optional voting for 16–17 and 70+ year-olds. In practice, enforcement is loose, and abstention remains non-negligible despite the compulsory-voting rule.

for capturing agriculturally meaningful drought intensity at the municipal level.

To identify the relevant period of exposure, I first determine each municipality's main crop over 2002–2022 using annual harvested-area data from the *Pesquisa Agrícola Municipal* (PAM) compiled by IBGE (IBGE, 2024). The main crop is defined as the crop with the largest cultivated area in the largest number of years. This provides a stable proxy for the municipality's dominant rainfed activity and therefore the production most sensitive to growing-season drought.

Growing seasons are assigned at the crop–state level using planting and harvesting calendars from CONAB's *Calendário de Plantio e Colheita* (CONAB, 2022), supplemented with phenological information from MIRCA-OS (Kebede et al., 2025). This yields municipality-specific growing seasons that capture the months during which drought conditions most directly affect agricultural productivity.

My treatment variable is defined as the average SPEI-4 over the last completed growing season prior to each election. In some specifications, I also construct complementary drought measures based on months *outside* the growing season ("off-season SPEI"). The off-season is defined as the set of months in the election year that do not belong to the crop-specific growing season. For municipalities whose growing season spans the entire calendar year—typically those whose main crop is perennial—no such off-season period exists. As a result, off-season SPEI cannot be computed for these municipalities, and they are therefore excluded from specifications that include this variable. This mechanical restriction explains the smaller sample size in regressions using off-season SPEI.

To examine the persistence of drought effects, I also construct *lagged* growing-season drought measures. For each election, I compute the average SPEI-4 not only for the growing season that directly precedes the election, but also for the one-, two-, and three-year lagged growing seasons (i.e., the growing seasons in years $t-1$, $t-2$, and $t-3$ relative to the election year). These lagged indices are constructed analogously to the contemporaneous measure and are included as separate regressors in extended specifications. Further details on crop classifications, growing seasons, and drought measurement are provided in Appendix B.

4.2 Agricultural outcomes and agrarian structure

To explore mechanisms, I construct municipality-by-election measures of agricultural performance for each municipality's main crop. Using PAM data (IBGE, 2024), I combine harvested area and production value at the crop–municipality–year level, deflate nominal values to constant 2015 reais using the INPC price index from IPEA (IPEA, 2024), and compute real agricultural revenue per hectare. Because these yields correspond to the main crop, they capture the agricultural activity most directly exposed to the relevant growing-season conditions.

I also incorporate information on agricultural structure using the 2017 *Censo Agropecuário* (IBGE, 2019). The census provides municipality-level indicators on the organization of agriculture. First, I distinguish between family-based and commercial agriculture using: (i) the share of establishments classified as *agricultura familiar*; and (ii) the share of agricultural land operated by large farms ($\geq$200 ha). Within family farming, I compute the share of establishments benefiting from PRONAF credit—the main federal credit line for small-scale farmers. Distinguishing PRONAF from non-PRONAF family farms helps identify the most credit-constrained segment of family agriculture.

Second, I construct indicators of collective organization: the shares of family-farming establishments whose producer is affiliated with a cooperative or rural union versus those unaffiliated. These variables proxy for differences in bargaining power, resilience, and potential political mobilization. All variables are defined at the municipality level and standardized before entering regressions as interaction terms.

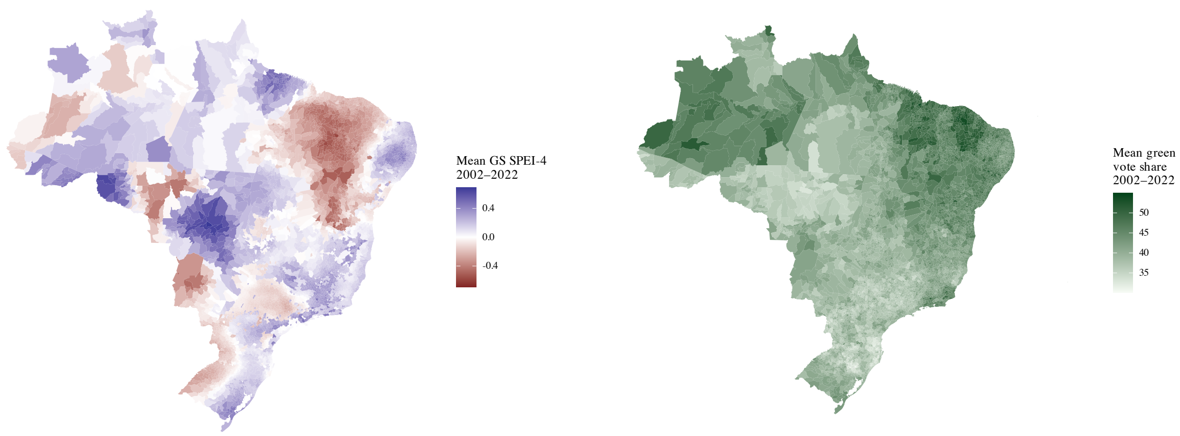
Together, real yields and structural agricultural characteristics provide complementary dimensions for understanding the channels through which drought shapes political preferences, either by generating direct income losses or by influencing exposure and adaptive capacity across agrarian contexts.

4.3 Descriptive statistics

Figure 1 provides descriptive maps for two key variables. Panel (a) shows the 2002–2022 average growing-season SPEI-4, highlighting substantial spatial heterogeneity: long-run negative averages—indicating a greater propensity for hydrological deficits—are concentrated in the semi-arid Northeast, parts of the Center-West, and pockets of the South, whereas more humid conditions are found across much of the North and along parts of the Southeast and southern coast.

Panel (b) shows the average environmentally weighted vote share ("green vote"). Higher values appear in much of the Amazon region and in large parts of the Northeast, whereas comparatively lower values are concentrated in the southern states and in a swath running through the Center-West and Southeast.

Importantly, these maps summarize long-run spatial averages and do not capture the within-municipality temporal variation that underlies the empirical identification strategy.



(a) Average growing-season SPEI-4

(b) Average green vote share

Figure 1: Spatial patterns of growing-season drought exposure and green voting

Table 1 reports descriptive statistics for the main variables. Panel A shows that, in the analysis sample, the average values of the green and left vote-share indices are about 42% and 65%, respectively. These relatively high figures reflect the fact that both variables are continuous weighted vote-share measures rather than raw party vote shares. Turnout is high and tightly distributed, with a mean close to 80%. Marina Silva's vote share, available for the 2010–2018 elections only[3], is much smaller and more dispersed.

Panel B summarizes weather indicators. By construction, growing-season SPEI has a mean close to zero, with substantial dispersion across municipalities and elections. Off-season and lagged SPEI variables exhibit similar variability.

Panel C describes agrarian structure. Family farms represent roughly three-quarters of establishments, but large farms account for about 30% of land, highlighting the coexistence of small- and large-scale systems. Agricultural revenue per hectare is highly dispersed, motivating its log transformation.[4] PRONAF-type family farms constitute the majority of family establishments, while union participation varies widely across municipalities.

Table 1: Descriptive statistics

	Mean	SD	Min	Max	N
Panel A: Electoral variables					
Green voting	41.79	17.88	5.81	94.20	26 322
Left voting	65.01	18.36	8.04	96.15	26 322
Marina Silva vote share	6.96	7.01	0.02	74.19	13 127
Turnout	79.73	6.26	47.61	96.39	26 322
Panel B: Weather variables					
SPEI Growing Season t	0.03	0.64	−2.18	2.51	26 322
SPEI Off-season t	−0.12	0.81	−2.84	2.36	17 268
SPEI Growing Season $t-1$	−0.30	0.67	−2.33	1.91	26 322
SPEI Growing Season $t-2$	−0.14	0.82	−2.51	2.25	26 322
SPEI Growing Season $t-3$	−0.05	0.55	−2.14	1.99	26 322
Panel C: Agricultural and agrarian structure variables					
Yield (BRL/ha, 2015 prices)	3.78	6.18	0.00	184.41	25 717
Share of family farms (%)	75.0	13.0	6.0	98.0	26 322
Share of land in large farms (%)	30.0	26.0	0.0	100.0	26 322
Share of PRONAF family farms (%)	99.0	2.0	60.0	100.0	26 322
Share of unionized family farmers (%)	21.0	21.0	0.0	92.0	26 322
Share of non-associated family farmers (%)	61.0	23.0	2.0	100.0	26 322

Notes: Mean, standard deviation (SD), minimum (Min), maximum (Max), and number of non-missing observations (N) are reported for each variable. The sample corresponds to the rural subsample used in the main regressions. Off-season SPEI is defined only for municipalities whose growing season does not span the full calendar year; municipalities with year-round growing seasons are therefore excluded (see Section 4.1).

[3] Marina Silva ran for president in 2010 (PV), 2014 (PSB), and 2018 (REDE), which are the only years for which a comparable candidate-specific environmental vote measure exists. See Section 3.2 for additional background.

[4] The upper tail includes municipalities whose main crop is a high-value specialty such as tomatoes or grapes.

5 Empirical strategy

5.1 Main specification

The empirical analysis is conducted on a panel of Brazilian municipalities defined using the 2001 IBGE municipal grid (IBGE, 2001), which provides a stable set of units prior to the numerous administrative splits of the 2000s. Anchoring all variables to this pre-split grid avoids spurious changes in electoral totals or crop areas mechanically induced by boundary redefinitions.

Because weather shocks affect livelihoods primarily through agriculture, and because agrarian structures differ sharply between urban and rural economies, the analysis focuses on municipalities with substantial rural populations. Following the classification scheme proposed by Braga et al. (2015) and subsequently applied in Ishak (2022), I use 2010 Census population distributions to group municipalities into predominantly urban (rural share $< 15\%$), intermediate rural (15–50%), and predominantly rural ($> 50\%$). I exclude predominantly urban areas, yielding 4,389 rural municipalities,[5] which represent the economic and institutional environments where drought plausibly operates as an income shock.

The main specification is:

$$vote_{it} = c + \beta\, \mathrm{SPEI}_{it}^{\mathrm{GS}} + \alpha_i + \lambda_{s,t} + \varepsilon_{it}, \tag{1}$$

where $vote_{it}$ is the ideology- or environment-weighted vote share in municipality i and election t, and $\mathrm{SPEI}_{it}^{\mathrm{GS}}$ is the municipality's average SPEI-4 index during the most recent completed growing season. Municipality fixed effects α_i capture all time-invariant political, geographic, and agrarian characteristics, while state-by-election fixed effects $\lambda_{s,t}$ absorb election-specific conditions common to municipalities within the same state (for example, macroeconomic shocks, state-level politics, or national campaign dynamics). Standard errors are clustered at the municipality level.

5.2 Identification assumptions

The key identifying variation comes from within-municipality fluctuations in growing-season SPEI. Monthly precipitation and potential evapotranspiration are determined by large-scale atmospheric circulation patterns and are not manipulable by local actors. Conditional on the fixed effects, short-run deviations from historical water balance are thus plausibly orthogonal to local political dynamics. This assumption follows the standard logic of the climate–economy literature (e.g. Dell et al. 2014; Carleton and Hsiang 2016).

The coefficient β is identified from short-run hydrological deviations relative to each municipality's own long-run climatic norm. Municipality fixed effects absorb persistent ideological orientation, historical settlement patterns, agrarian structure, and other stable determinants of voting. State-by-election fixed effects capture any contemporaneous political or economic force affecting all municipalities within a state-year. Given this structure, the identifying assumption

[5] The working sample contains 4,387 units after excluding two municipalities without PAM data.

is a parallel-trends condition: absent drought shocks, municipalities within a state would exhibit similar election-year changes in ideological voting.

A further concern is whether crop composition or growing seasons respond endogenously to political trends. This risk is limited. First, each municipality's main crop is defined as the modal crop over the full 2002–2022 period, smoothing over short-run adjustments. Second, crop growth cycles reflect agronomic and biological constraints and do not vary with political cycles. Hence both the identity of the main crop and the timing of its growing season can be treated as predetermined for the purposes of election-year analysis.

Under these assumptions, the two-way fixed-effects estimator in equation (1) recovers the causal effect of growing-season drought intensity on ideological voting patterns.

5.3 Extensions and heterogeneity analyses

Beyond the benchmark estimates, I develop a series of extensions that shed light on the mechanisms linking drought exposure to electoral behavior and on the distribution of effects across agrarian contexts.

To structure the heterogeneity analysis, I augment equation (1) with interaction terms of the form:

$$vote_{it} = c + \beta\,\mathrm{SPEI}_{it}^{\mathrm{GS}} + \theta(\mathrm{SPEI}_{it}^{\mathrm{GS}} \times Z_i) + \alpha_i + \lambda_{s,t} + \varepsilon_{it}, \tag{2}$$

where Z_i denotes a time-invariant municipal characteristic (for example agrarian structure, credit access, or producer organization). All Z_i variables are standardized before entering the interaction. The coefficient θ captures differential sensitivity to drought across municipal contexts.

Agricultural income as a mechanism Growing-season droughts may influence local conditions through several channels. Beyond farm income, dry shocks can affect non-agricultural employment opportunities, municipal public finances, or migration patterns, any of which could in principle shape voting behavior. In the reduced-form framework of this paper, such pathways are captured in the baseline coefficient on growing-season SPEI. To assess whether the agricultural-income channel plays a central role, I begin by examining the effect of drought on real agricultural performance. Formally, I estimate the same specification as in equation (1), but replace the voting outcome $vote_{it}$ with the logarithm of real agricultural revenue per hectare for the municipality's main crop. If drought reduces farm income and if income losses translate into political preferences—as suggested by theories of economic voting—one would expect drought to depress yields, and yield declines to be associated with systematic shifts in ideological voting patterns.

Heterogeneity across agrarian structures I then test whether drought affects voting behavior differently in municipalities with distinct agricultural structures. Using the indicators constructed from the 2017 *Censo Agropecuário*, I interact growing-season drought with: (i) the share of establishments classified as family farming (*agricultura familiar*); (ii) the share of agricultural land operated by large farms; and (iii) the share of family farms benefiting from

PRONAF credit. These interactions capture heterogeneity in capital intensity, market integration, and credit constraints.

Collective organization among family farmers I next examine whether drought effects vary with the degree of collective organization among family farmers. Interactions with the local shares of cooperative members and unionized producers (Section 4.2) test whether more organized producer groups are better insulated from the economic consequences of drought or, alternatively, more politically responsive to adverse weather conditions.

Lagged drought exposure I also consider whether political responses reflect persistent weather conditions rather than only contemporaneous shocks. To do so, I compute lagged versions of the treatment by averaging SPEI-4 over the growing seasons that immediately precede the baseline growing season (that is, one, two, and three years prior to the election). I then estimate:

$$Y_{it} = c + \sum_{\ell=0}^{3} \beta_\ell \,\mathrm{SPEI}^{\mathrm{GS}}_{i,t-\ell} + \alpha_i + \lambda_{s,t} + \varepsilon_{it}, \tag{3}$$

where $\mathrm{SPEI}^{\mathrm{GS}}_{i,t-\ell}$ denotes the average growing-season SPEI in the ℓ-th growing season before election t. The coefficients β_ℓ trace the temporal profile of electoral responses to recent and past droughts.

Additional robustness checks Finally, I perform a series of robustness exercises: (i) re-estimating the benchmark specification on the full sample of municipalities (including predominantly urban areas), (ii) controlling explicitly for voter turnout[6], (iii) using the vote share of Marina Silva—the canonical "green" candidate in Brazilian presidential elections—as an alternative proxy for environmental support, and (iv) exploiting SPEI-4 values outside the growing season. If growing-season shocks are the main drivers of electoral responses, off-season drought should display weaker or null effects. Across all checks, the main findings remain stable.

6 Results

6.1 Main effects

Table 2 reports the benchmark relationship between growing-season drought and ideological voting outcomes. Because higher values of the SPEI-4 index indicate wetter-than-normal conditions, the positive coefficients mean that wetter growing seasons increase green and left voting. Equivalently, drier growing seasons systematically reduce these measures. In column (1), a one-unit decrease in the growing-season SPEI-4 index lowers green voting by about 1.15 percentage points; column (2) shows a corresponding decline of roughly 0.77 percentage points in left voting.

[6]Indeed, one might be concerned that drought affects electoral outcomes partly through changes in turnout rather than shifts in candidate preferences. If adverse weather alters the composition of participating voters, the baseline estimates could partly reflect differential abstention rather than preference-driven responses.

These estimates provide a first resolution of the conceptual ambiguity highlighted in Section 1. Ex ante, it was unclear whether droughts would primarily act as salient weather shocks that strengthen support for environmental platforms, or as adverse income shocks that erode backing for green and left coalitions. The fact that drier growing seasons consistently reduce both green and left voting indicates that, in predominantly rural Brazil, the economic consequences of drought—operating primarily through reduced agricultural incomes—dominate any countervailing "greening" effect. When agricultural incomes fall, voters in these municipalities shift away from parties and candidates that are more closely associated with environmental protection and redistributive agendas.

Table 2: Benchmark effects of growing-season SPEI on ideological voting

	(1) Green vote	(2) Left vote
SPEI Growing Season t	1.155***	0.766***
	(0.090)	(0.091)
Observations	26322	26322
Municipalities	4387	4387
Municipality FE	Yes	Yes
State × Election FE	Yes	Yes

Notes: Each observation is a municipality–election. The dependent variables are the green and left voting indices (continuous 0–100 measures obtained by weighting municipal vote shares by party ideology and environmental orientation). Coefficients are interpreted in percentage points. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

In Section 6.4, I show that these findings are robust to (i) re-estimating the specification on the full sample of municipalities, (ii) controlling for turnout, and (iii) replacing the green vote with the vote share of Marina Silva as an alternative proxy for environmental support.

6.2 Mechanisms

6.2.1 Agricultural income channel

Table 3 examines whether growing-season droughts translate into measurable changes in agricultural performance. The dependent variable is the logarithm of real agricultural revenue per hectare for the municipality's main crop.

Column (1) shows that a one-unit increase in growing-season SPEI raises yields by roughly 3.5%. Columns (2)–(4), estimated on the subsample with well-identified growing seasons, confirm that drier-than-normal conditions during the crop cycle systematically depress yields, whereas off-season conditions have little consistent effect. These patterns are consistent with a standard agronomic mechanism: water availability matters for agricultural productivity primarily during the growing season, while hydrological conditions outside this window have little systematic impact on yields. In the context of this paper, this supports interpreting the electoral responses documented in Section 6.1 as operating mainly through weather-induced fluctuations in agricultural income rather than through non-agricultural channels.

Table 3: Effects of growing-season and off growing-season SPEI on agricultural yields

	(1)	(2)	(3)	(4)
	Agri. yields	Agri. yields	Agri. yields	Agri. yields
SPEI Growing Season t	0.035***	0.058***		0.056***
	(0.009)	(0.010)		(0.010)
SPEI Off Growing Season t			−0.019*	−0.012
			(0.009)	(0.009)
Observations	25717	16921	16921	16921
Municipalities	4387	2878	2878	2878
Municipality FE	Yes	Yes	Yes	Yes
State × Election FE	Yes	Yes	Yes	Yes

Notes: Each observation is a municipality–election. The dependent variable is the logarithm of real agricultural revenue per hectare for the municipality's main crop in the election year. Columns (2)–(4) report results for the subsample of municipalities for which the growing-season window can be measured reliably. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

6.2.2 Heterogeneity by agrarian structure

Table 4 shows that the electoral effects of growing-season drought vary systematically with local agrarian structures.

Table 4: Heterogeneous effects of growing-season SPEI by agrarian structure on ideological voting

	(1)	(2)	(3)	(4)
	Green vote	**Left vote**	**Green vote**	**Left vote**
	Family farming	Family farming	Agribusiness	Agribusiness
SPEI Growing Season t	1.109***	0.775***	1.269***	0.820***
	(0.089)	(0.091)	(0.090)	(0.090)
SPEI Growing Season t × Family farming	0.365***	−0.073		
	(0.058)	(0.056)		
SPEI Growing Season t × Agribusiness			−0.543***	−0.257***
			(0.054)	(0.055)
Observations	26322	26322	26322	26322
Municipalities	4387	4387	4387	4387
Municipality FE	Yes	Yes	Yes	Yes
State × Election FE	Yes	Yes	Yes	Yes

Notes: Each observation is a municipality–election. Columns (1)–(2) interact growing-season SPEI with the share of family farms; columns (3)–(4) interact growing-season SPEI with the share of large-scale farms. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Columns (1) and (2) indicate that drought penalties differ across municipalities dominated by family farming. For the green vote (column 1), the positive interaction term implies that the baseline drought effect is amplified where smallholder agriculture is prevalent: in these municipalities, water deficits translate more directly into income losses and thus into sharper electoral reactions. By contrast, the interaction is small and statistically insignificant for the left vote (column 2). This asymmetry is consistent with the political history of family farming in Brazil (Section 3.3). Smallholders have long-standing ties to left-wing parties through social programs, rural unions, and redistribution-oriented coalitions. It is therefore plausible that drought-induced economic stress disproportionately dampens support for environmentally oriented platforms—perceived as potentially constraining agricultural expansion—without generating an equally strong backlash against the left more broadly, whose redistributive agenda remains attractive to vulnerable rural households.

Columns (3) and (4) show that drought effects are substantially attenuated in municipalities dominated by large-scale farming. The negative interaction terms indicate that in agribusiness regions, a comparable decline in SPEI generates a much smaller reduction in support for both green and left candidates. This attenuation is consistent with the greater resilience of capital-intensive production systems, which benefit from scale, better access to credit, and a wider range of adaptive margins—including mechanization, input use, crop management practices, and, in some cases, irrigation—partially buffering the economic impacts of drought.

Overall, these heterogeneous effects underscore that drought-induced electoral responses are shaped by the structure of local agriculture: sharpest where vulnerability is highest (family farming), and muted in agribusiness regions.

6.2.3 Heterogeneity by social protection and rural organization

Table 5 examines how the electoral impact of growing-season drought varies within the universe of family farming, depending on access to rural credit and the degree of collective organization.

Columns (1) and (2) show that where the share of PRONAF-eligible family farms is higher, the sensitivity of both green and left voting to drought is attenuated. This aligns with the buffering role of social policy: by stabilizing incomes in the face of drought-induced losses, PRONAF reduces the extent to which economic stress translates into ideological realignment. PRONAF also carries a clear political dimension, as it is widely seen as a flagship program of left-wing governments, reinforcing voters' perception that these coalitions provide protection during adverse shocks.

Columns (3)–(6) further explore the role of collective organization. Where unionization among family farmers is high, drought-induced shifts away from left-wing candidates are substantially dampened (column 3), consistent with the historical alignment of rural unions with redistributive and labor-oriented agendas. By contrast, the corresponding interaction for the green vote (column 4) is small and insignificant, reflecting that environmental issues are not a central axis of union-based political identity. In municipalities with many non-associated family farmers, drought effects on left voting become stronger (column 6), suggesting that weaker collective structures heighten vulnerability and amplify the political consequences of income losses.

Table 5: Heterogeneous effects of growing-season SPEI by family farm type on ideological voting

	(1)	(2)	(3)	(4)	(5)	(6)
	Green vote	**Left vote**	**Green vote**	**Left vote**	**Green vote**	**Left vote**
	PRONAF	PRONAF	Unionized	Unionized	Non-assoc.	Non-assoc.
SPEI Growing Season t	1.176***	0.780***	1.157***	0.755***	1.160***	0.754***
	(0.091)	(0.091)	(0.090)	(0.091)	(0.090)	(0.090)
SPEI Growing Season t × PRONAF	−0.530***	−0.368***				
	(0.070)	(0.038)				
SPEI Growing Season t × Unionized			0.032	−0.248***		
			(0.056)	(0.052)		
SPEI Growing Season t × Non-associated					−0.110*	0.237***
					(0.051)	(0.049)
Observations	26322	26322	26322	26322	26322	26322
Municipalities	4387	4387	4387	4387	4387	4387
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
State × Election FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Each observation is a municipality–election. Columns report interactions between growing-season SPEI and PRONAF shares, unionization, or non-association. Interaction variables are standardized. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels.

Overall, these heterogeneous effects indicate that drought penalties are smallest where social protection and rural organization are strongest, and largest where smallholders face both weather and institutional vulnerability.

6.3 Recency and persistence of drought effects

Table 6 examines whether the electoral effects of growing-season droughts reflect only the most recent crop cycle or also incorporate information from past growing seasons.

Columns (1)–(2) show that for the green vote, both contemporaneous drought (SPEI GS t) and drought in the second-most-recent growing season (SPEI GS $t-2$) significantly reduce support, whereas more distant shocks have little explanatory power. For the left vote, the effect is predominantly contemporaneous, with lagged coefficients small and imprecisely estimated.

Columns (3)–(4), estimated on the subsample with well-defined growing seasons, confirm the same pattern: recent and second-most-recent droughts matter for the green vote, while electoral responses along the left–right dimension are more short-lived.

Overall, the lag structure in Table 6 shows that electoral responses are concentrated in the most recent one or two crop cycles rather than reflecting slow-moving or cumulative climatic trends. This is exactly what one would expect under an income-driven mechanism, whereby voters react most strongly to recent and salient shocks to agricultural livelihoods.

Table 6: Lagged effects of growing-season SPEI on ideological voting

	(1) Green vote	(2) Left vote	(3) Green vote	(4) Left vote
SPEI Growing Season t	1.006***	0.749***	1.120***	0.599***
	(0.087)	(0.093)	(0.103)	(0.115)
SPEI Growing Season $t-1$	0.241*	0.118	0.367**	0.497***
	(0.112)	(0.105)	(0.126)	(0.130)
SPEI Growing Season $t-2$	0.988***	−0.018	0.620***	−0.041
	(0.102)	(0.114)	(0.125)	(0.136)
SPEI Growing Season $t-3$	−0.050	−0.177	0.177	−0.070
	(0.098)	(0.116)	(0.118)	(0.140)
Observations	26322	26322	17268	17268
Municipalities	4387	4387	2878	2878
Municipality FE	Yes	Yes	Yes	Yes
State × Election FE	Yes	Yes	Yes	Yes

Notes: Each observation is a municipality–election. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

6.4 Robustness checks

Table 7: Benchmark effects of growing-season SPEI on ideological voting (full sample)

	(1) Green vote	(2) Left vote
SPEI Growing Season t	0.949***	0.808***
	(0.080)	(0.078)
Observations	33120	33120
Municipalities	5520	5520
Municipality FE	Yes	Yes
State × Election FE	Yes	Yes

Notes: Each observation is a municipality–election. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 7 re-estimates the benchmark specification on the full sample of municipalities for which both electoral and agricultural data are available (5,520 out of the 5,561 units in the 2001 municipal grid).[7] The coefficients on growing-season SPEI remain positive, precisely estimated, and similar in magnitude to those obtained in the rural subsample: a one-unit decrease in the SPEI index reduces the green voting by about 0.95 percentage points and the left voting by about 0.81 percentage points. This robustness check shows that the main results are not driven by the restriction to predominantly rural municipalities; rather, that restriction is a modeling choice motivated by the proposed mechanism.

[7] The difference reflects 41 municipalities not covered by the *Pesquisa Agrícola Municipal* (PAM).

Table 8: Benchmark effects of growing-season SPEI on ideological voting with turnout control

	(1) Green vote	(2) Left vote
SPEI Growing Season t	1.151***	0.761***
	(0.090)	(0.091)
Observations	26322	26322
Municipalities	4387	4387
Controls	Yes	Yes
Municipality FE	Yes	Yes
State × Election FE	Yes	Yes

Notes: Each observation is a municipality–election. The dependent variables are the green and left voting indices (continuous 0–100 measures obtained by weighting municipal vote shares by party ideology and environmental orientation). Coefficients are interpreted in percentage points. All specifications include turnout as a control (coefficient not reported). Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 8 shows that controlling for turnout leaves the coefficients virtually unchanged: a one-unit decrease in growing-season SPEI continues to lower support for green and left candidates by economically and statistically significant magnitudes. This indicates that the benchmark effects are not primarily driven by changes in the composition of participating voters, but instead reflect shifts in the distribution of votes among those who turn out. In other words, droughts in the growing season reorganize support across ideological and environmental coalitions rather than simply inducing differential abstention.

Table 9: Effects of growing-season SPEI on the vote for Marina Silva

	(1) Marina Silva
SPEI Growing Season t	0.811***
	(0.089)
Observations	13127
Municipalities	4387
Municipality FE	Yes
State × Election FE	Yes

Notes: Each observation is a municipality–election. The dependent variable is the first-round vote share for Marina Silva in 2010, 2014, and 2018. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 10: Effects of growing-season and off growing-season SPEI on ideological voting

	(1)	(2)	(3)	(4)
	Green vote	Left vote	Green vote	Left vote
SPEI Growing Season t	1.228***	0.674***		
	(0.106)	(0.113)		
SPEI Off Growing Season t			0.007	−0.252**
			(0.079)	(0.093)
Observations	17268	17268	17268	17268
Municipalities	2878	2878	2878	2878
Municipality FE	Yes	Yes	Yes	Yes
State × Election FE	Yes	Yes	Yes	Yes

Notes: Each observation is a municipality–election. The sample is restricted to municipalities with well-defined growing seasons. Standard errors are clustered at the municipality level (in parentheses). *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 9 replaces the green vote with the first-round vote for Marina Silva. The estimated coefficient on growing-season SPEI remains large, positive, and precisely estimated, indicating that the main results extend to a candidate-specific measure of environmental support.

Table 10 presents a placebo test using an off-season SPEI index capturing hydrological conditions outside the crop cycle. Off-season SPEI displays no consistent relationship with green voting and only weak and unstable effects on left voting. By contrast, growing-season SPEI retains strong and precisely estimated coefficients. If the benchmark estimates were driven by slow-moving socioeconomic trends or omitted political factors, one would expect comparable effects during off-season months. Instead, only agriculturally salient water deficits translate into systematic ideological shifts.

7 Conclusion

This paper investigates how growing-season droughts shape electoral behavior in Brazil, a major developing democracy marked by strong climate vulnerability, deep agrarian inequalities, and polarized environmental politics. While climate change is expected to intensify drought frequency and severity, the political effects of such shocks are theoretically ambiguous: droughts may heighten awareness of environmental risks, yet they also depress agricultural incomes in ways that may push voters away from environmentally oriented or redistributive platforms.

By aligning high-resolution weather data with crop-specific growing seasons and combining them with a new panel of ideology- and environment-weighted vote shares for the 2002–2022 presidential elections, I show that drier growing seasons systematically reduce support for green and left-leaning coalitions. Mechanism tests reveal that these electoral reactions operate through drought-induced declines in agricultural revenue per hectare, while hydrological conditions outside the crop cycle have little explanatory power. The effects exhibit substantial heterogeneity: penalties are largest in municipalities dominated by family farming, where exposure to rainfall deficits and income volatility is highest, and much weaker in agribusiness regions. Moreover, social protection programs and collective rural organization mitigate these responses, underscoring the role of institutional buffers in shaping political reactions to weather shocks.

These findings carry three broader implications. First, they demonstrate that weather-induced income shocks can generate systematic ideological shifts, highlighting the importance of distributive channels in the political economy of climate change. Second, they show that weather disasters do not necessarily increase support for environmental platforms, especially where environmental regulation is perceived as constraining agricultural opportunities. Third, they reveal that the electoral consequences of weather variability are mediated by agrarian structures, safety nets, and collective organization, which jointly shape both exposure to shocks and the capacity to cope with them. A further implication concerns the dynamic interplay between climate change and political preferences. If droughts become more frequent and severe—as projected for Brazil—and simultaneously reduce support for coalitions advocating stronger climate mitigation, the result may be a self-reinforcing cycle in which weather shocks erode political demand for the very policies needed to curb future climatic deterioration.

Future research could extend this analysis to other climate-related hazards within Brazil. The country is also highly exposed to floods, landslides, and extreme rainfall events, which disproportionately affect urban and peri-urban populations and may trigger distinct political responses. Investigating how these shocks interact with local vulnerability, governance capacity, and partisan dynamics would provide a more comprehensive understanding of how different types of climate risks shape electoral behavior.

Overall, the findings suggest that in climate-vulnerable rural settings, climate change is likely to reshape not only economic livelihoods but also the composition of electoral coalitions and the politics of environmental protection.

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A Additional details on ideological and environmental voting

This appendix provides additional detail on the construction of the ideology- and environment-weighted vote shares used in the empirical analysis. These measures are built by combining municipal-level presidential election results (Tribunal Superior Eleitoral, 2025) with party-level ideological and environmental scores derived from the Brazilian Legislative Survey (BLS) (Power and Zucco, 2012).

A.1 Brazilian Legislative Survey (BLS)

The BLS is a recurring survey administered to federal deputies by Brazilian political scientists, notably David Samuels and Timothy Power. It has been conducted nine times between 1990 and 2021, always in the year preceding general elections. This timing allows each wave to be directly paired with the subsequent presidential contest for the 2002–2022 period.

Participation in the survey is voluntary, which implies that the composition of respondents may vary across waves: some parties tend to be overrepresented or underrepresented, and small parties without federal deputies are, by design, absent from the survey. Nevertheless, these limitations do not materially affect the coverage of presidential candidates.

Figure A1 shows that the national share of votes cast for candidates unsupported by any BLS-covered party is below 1% in every election in the 2002–2022 period; in other words, 99% of votes cast in each election are covered by the BLS-based coding used in this study. These unsupported candidates are typically fielded by very small parties with no congressional representation—such as PSTU[8], PCO[9], or PCB[10]—that play only a marginal role in national electoral politics.

Figure A2 displays municipal-level dispersion in the share of uncovered votes. This share remains extremely low in almost all municipalities, with the exception of a modest uptick in 2018, when a small number of municipalities reach values around 4–6% (and a few isolated outliers above that range). Overall, more than 99% of votes are consistently cast for candidates backed by parties covered in the BLS.

Despite these constraints, the BLS provides uniquely rich information on the ideological, environmental, and broader value orientations of Brazilian deputies, making it well suited for identifying party ideologies and tracking their evolution over time. Existing alternatives used in the literature either cover a much smaller set of Brazilian parties—for instance manifesto-based datasets such as the Manifesto Project—or do not offer meaningful temporal variation in party positions, which is problematic in a context where parties frequently shift their ideological profiles, new parties emerge and others disappear, and mergers and splits are common. In principle, programmatic text analysis could provide finer-grained information, but presidential manifestos are not systematically available before 2010, when electoral programs first became mandatory, limiting the feasibility of a long-run panel. In this sense, the BLS appears to be the most appropriate data source currently available for capturing evolving ideological and

[8] Partido Socialista dos Trabalhadores Unificado.
[9] Partido da Causa Operária.
[10] Partido Comunista Brasileiro.

environmental cleavages in Brazilian party politics.

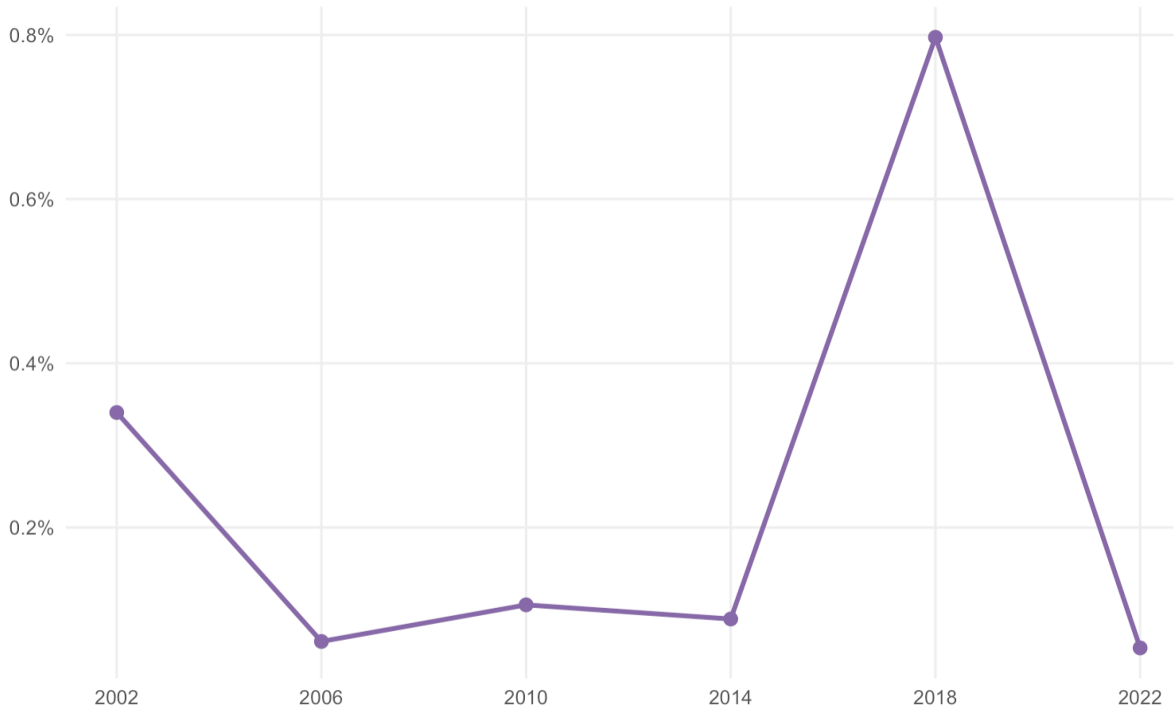


Figure A1: Uncovered electorate: national average share of votes for non–BLS parties

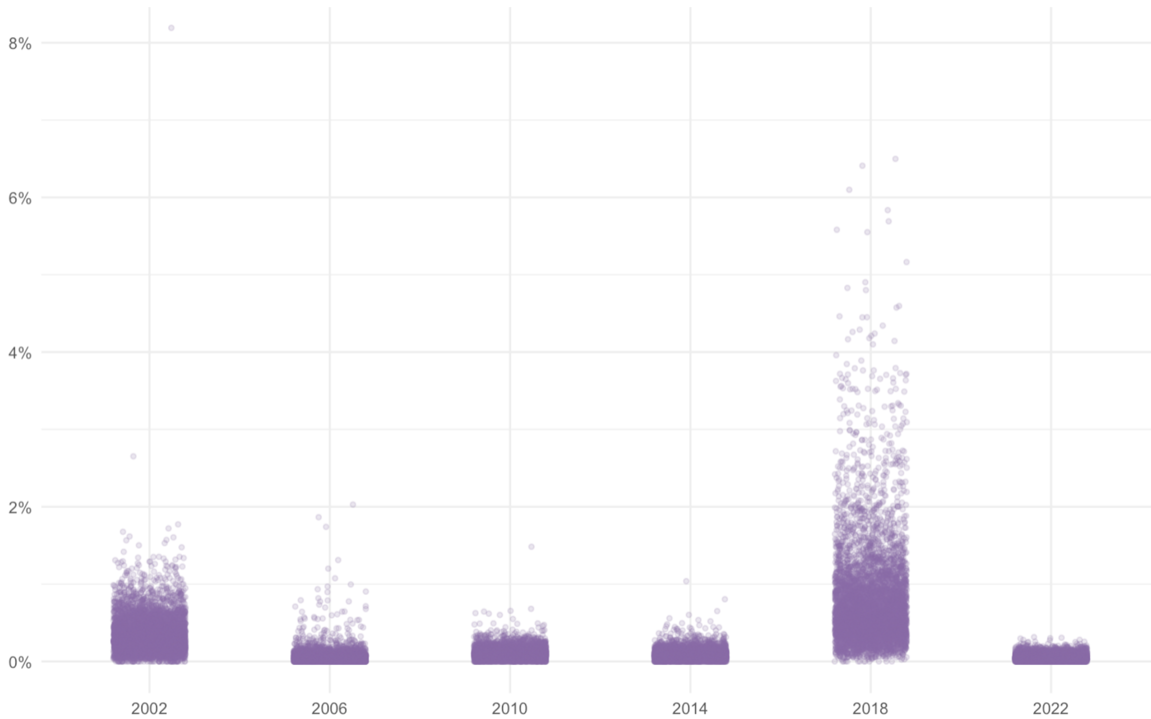


Figure A2: Uncovered electorate: municipal distribution of votes for non–BLS parties

A.2 Construction of ideology scores

To construct a measure of ideological orientation, I rely on the standard left–right self-placement question in the BLS, where deputies position themselves on a 0–10 scale[11]. Because self-placement may reflect strategic recentring or heterogeneous interpretations of the scale across survey waves, I use rescaled self-placement scores already provided in the BLS dataset, which correct for these issues[12] .

I then aggregate the adjusted scores to the party-by-wave level, obtaining an average ideological position for each party in each BLS wave. Missing values for parties that do not appear in a given wave are imputed using the closest available wave in time, which allows for complete coverage across all presidential elections between 2002 and 2022.

For each election, party scores are normalized to lie between 0 and 1 within that election, so that only the relative ordering of parties on the left–right spectrum matters. This normalization deliberately abstracts from any common programmatic drift of the party system over time—for instance, a general shift of all parties toward the right—so that changes in the ideology-weighted vote share capture re-allocations of support across parties within a given ideological space rather than changes in the overall location of that space. These normalized scores are then used to weight municipal vote shares: for each municipality–election pair, I compute a weighted average of the local vote shares of all candidates, where weights correspond to the ideological scores of their supporting parties or coalitions. The resulting municipal-level indicator is a continuous measure of ideological voting and constitutes one of the main dependent variables in the empirical analysis. Because the measure is constructed on a single normalized left–right scale, left- and right-oriented vote shares are mechanically symmetric: an increase in the left vote reflects a shift in support away from more right-leaning options toward more left-leaning ones (and vice versa). Changes in the weighted municipal vote shares should therefore be interpreted as shifts along the left–right spectrum rather than independent movements in "left" and "right" vote shares.

A.3 Construction of environmental scores

To construct a measure of environmental orientation, I rely on an item from the BLS that explicitly measures the relative importance deputies attach to environmental protection. In the 2013, 2017, and 2021 waves, deputies are asked to choose between two statements: (i) "prioritize environmental protection over economic development and job creation," or (ii) "prioritize economic development and job creation over environmental protection"

Since environmental items are available only in the 2013, 2017, and 2021 waves, earlier years are imputed using the 2013 wave—the closest in time—ensuring full coverage over the 2002–2022 period. As with ideology, responses are aggregated to the party-by-wave level and then normalized within each election year.

[11] Deputies are asked: "On a scale from 1 to 10, where 1 = left and 10 = right, where would you place yourself ideologically?"

[12] These rescaled estimates are obtained using a one-shot Bayesian scaling procedure described in Power and Zucco (2012).

The resulting election-specific party scores are used to weight municipal vote shares. For each municipality–election pair, I compute a weighted average of the vote shares of all candidates, where weights correspond to the environmental orientation of their supporting parties or coalitions. This yields a continuous indicator of "green" versus "brown" voting, which serves as an additional dependent variable in the empirical analysis. Because the measure is constructed on a single normalized green–brown scale, greener and browner vote shares are mechanically symmetric: an increase in green voting reflects a shift in support away from more brown options toward greener ones (and vice versa). Changes in this weighted municipal vote share should therefore be interpreted as shifts along the green–brown spectrum rather than independent movements in "green" and "brown" votes.

A.4 Party positions across elections

The figures below (Figures A3–A8) display normalized party positions on the ideological (left–right) and environmental (green–brown) dimensions for each presidential election between 2002 and 2022. These visualizations illustrate the relative ordering of candidates within each election year and highlight two systematic patterns. First, ideological and environmental orientations are positively associated but not perfectly aligned, which reinforces the relevance of considering ideological and environmental orientations separately in the empirical analysis. Second, the degree of dispersion varies across elections. Although 2002 is already markedly polarized, the 2006 and 2010 contests display a broader distribution of candidates along both ideological and environmental dimensions. In contrast, the later elections—especially 2018 and 2022—are characterized by renewed polarization and a sharper split between green left-leaning and brown right-leaning candidates.

Figure A3: Party positions in the 2002 election

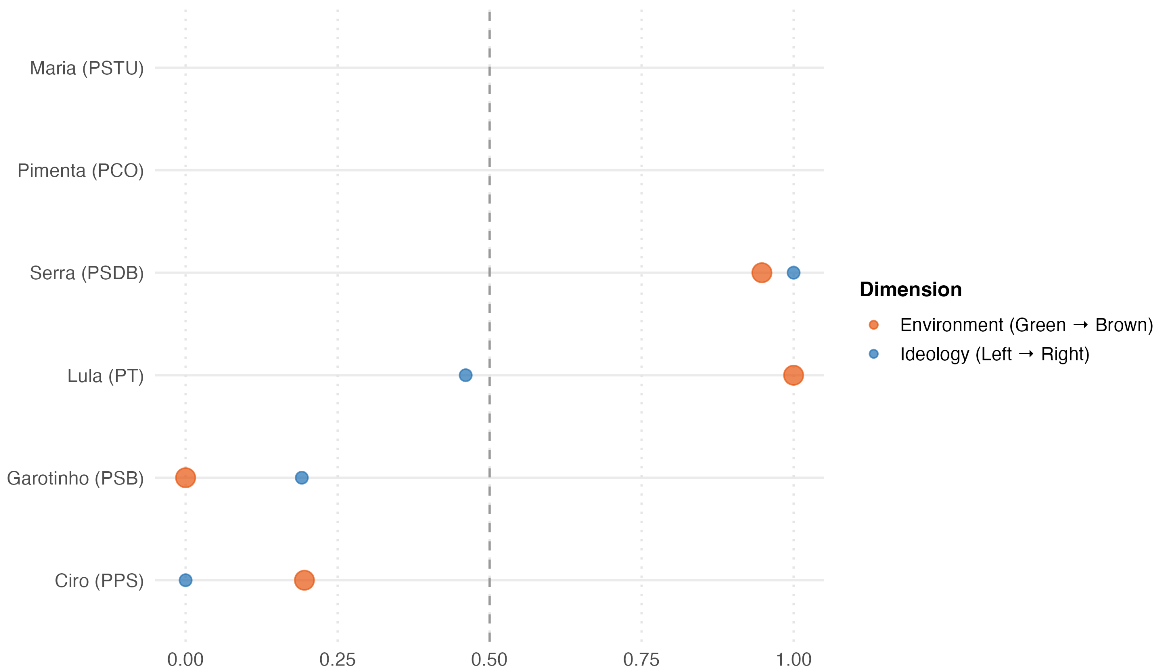


Figure A4: Party positions in the 2006 election

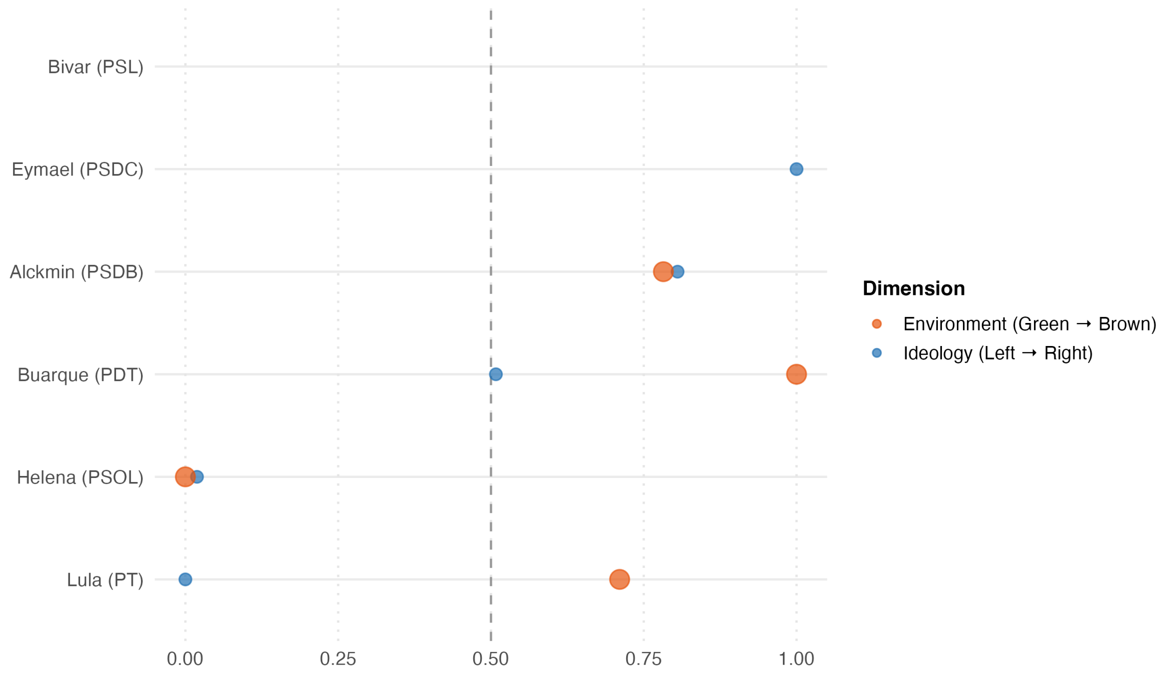


Figure A5: Party positions in the 2010 election

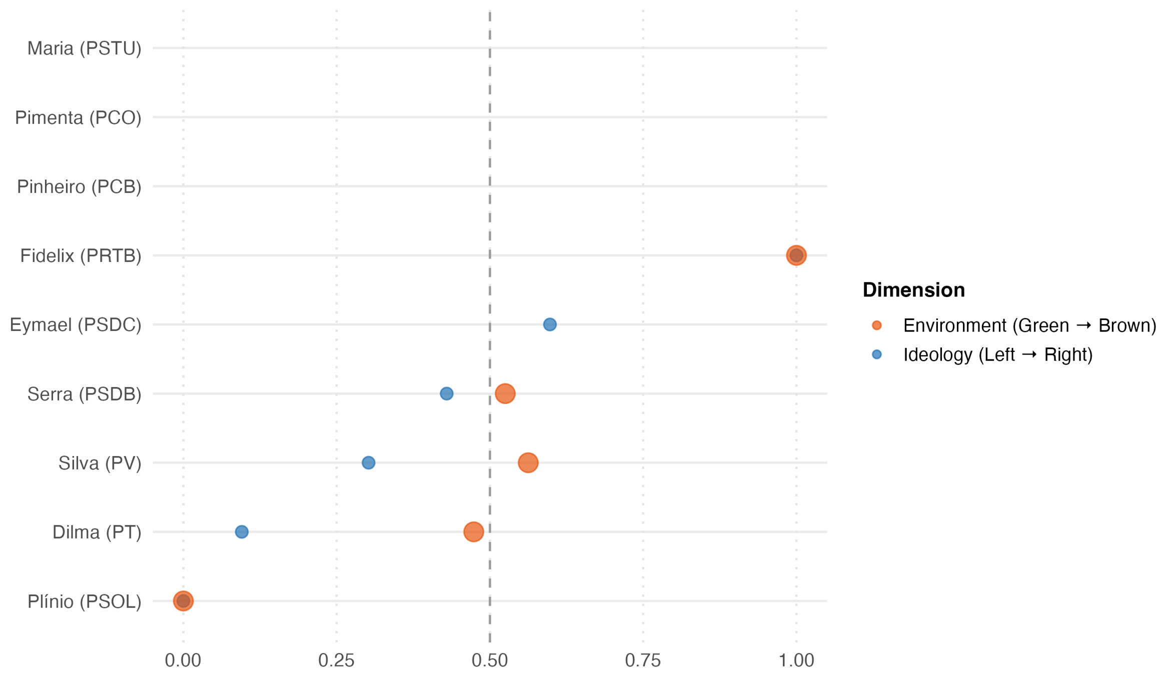


Figure A6: Party positions in the 2014 election

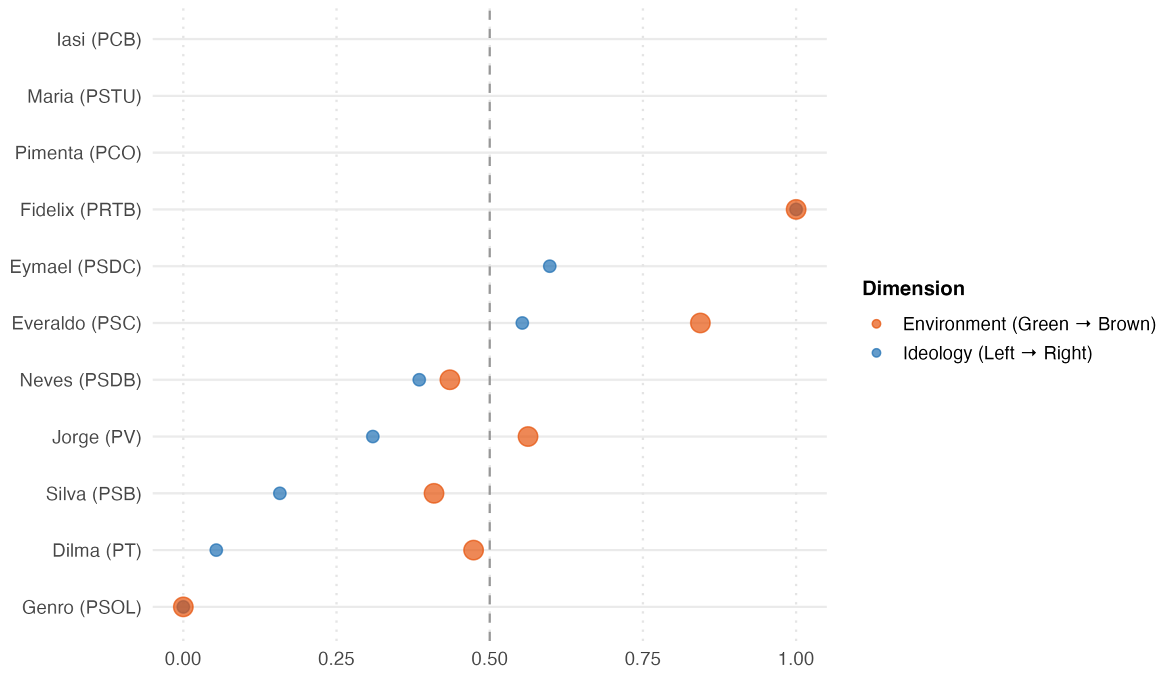


Figure A7: Party positions in the 2018 election

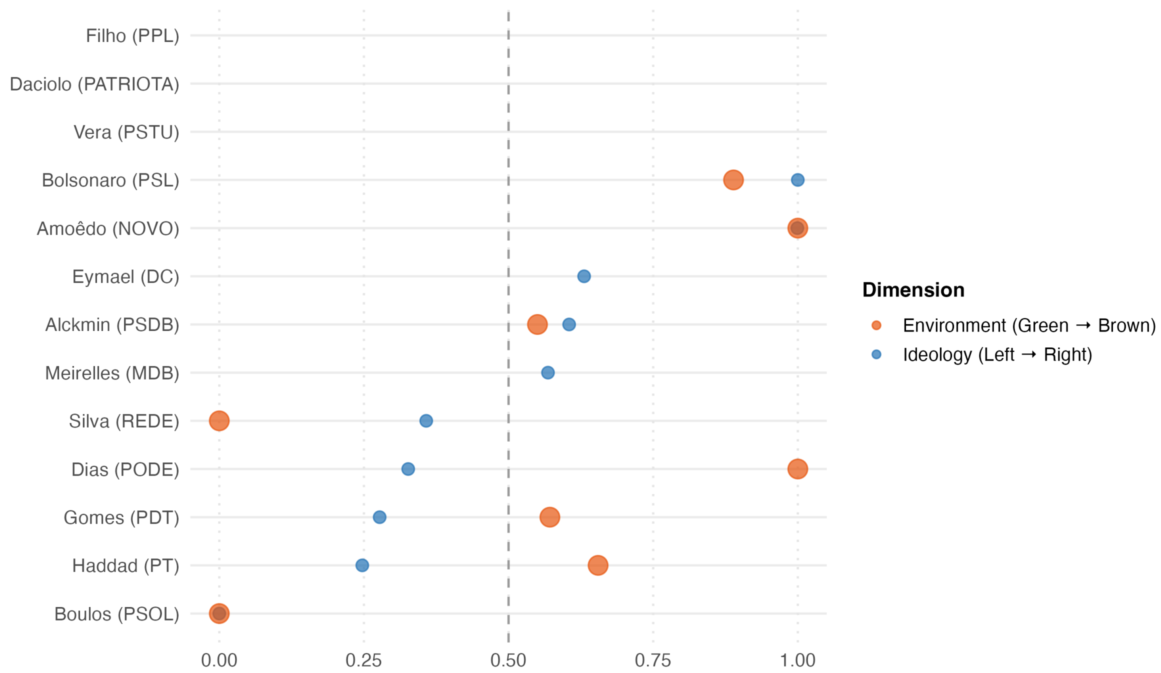
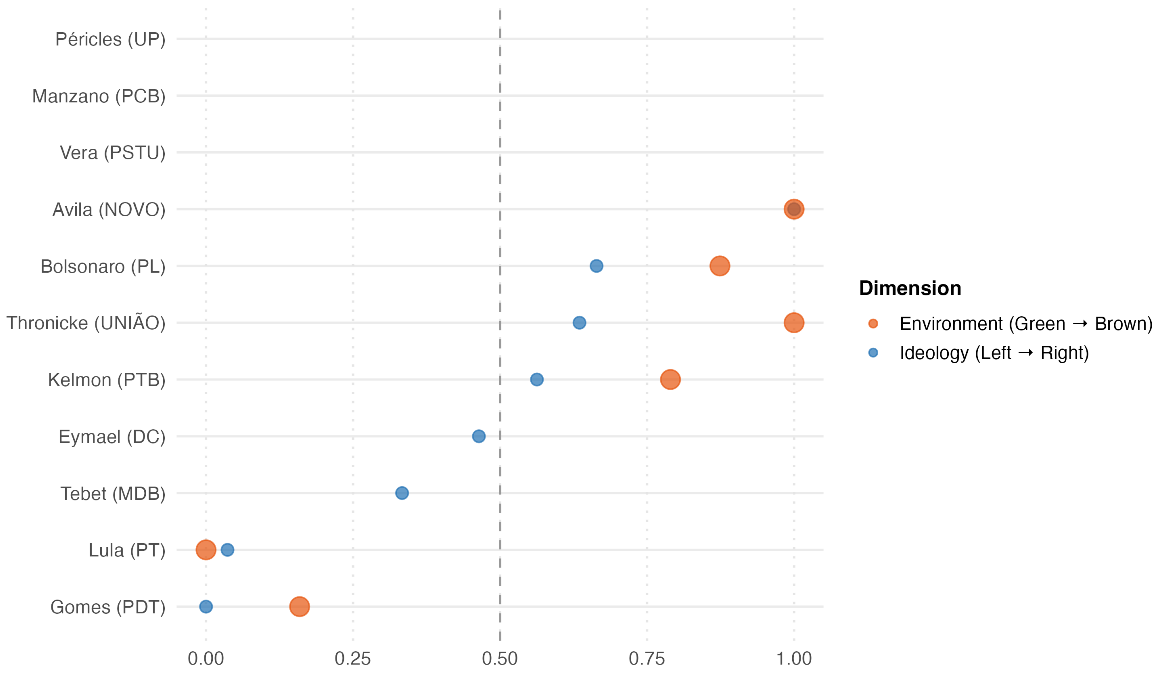


Figure A8: Party positions in the 2022 election



Importantly, these placements are consistent with qualitative accounts of Brazilian party politics. Candidates from the PT and PSOL (e.g., Lula, Dilma, Genro, Boulos) appear on the left and toward the green side of the spectrum, in line with their long-standing emphasis on social policies and environmental protection. Green parties such as PV and REDE (e.g., Marina Silva and other environmentalist figures) are systematically located among the greenest options, even when they occupy more moderate positions on the left–right scale. By contrast, conservative and evangelical parties (e.g., PSC, PSL/PL, Patriota) and Bolsonaro-led candidacies occupy right-wing and brown positions, reflecting their programmatic focus on deregulation, agribusiness interests, and weaker environmental protections. Overall, the BLS-based scores recover patterns that closely match well-known ideological and environmental cleavages in contemporary Brazilian politics.

B Additional details on crop classifications, growing seasons, and SPEI

This appendix provides additional technical detail on the construction of (i) the main crop, (ii) State-level growing seasons, and (iii) SPEI-based drought exposure measures. These steps underlie the treatment variables used throughout the empirical analysis.

B.1 Identification of main crops (2002–2022)

Annual harvested-area data come from the *Pesquisa Agrícola Municipal* (PAM) (IBGE, 2024), which reports, for each municipality and year, the total harvested area for a wide range of crops. To assign a single "main crop" to each municipality, I follow a simple and transparent majority rule: within each municipality–year, I compute each crop's share of total harvested area and define the yearly main crop as the crop with the largest share. The municipality's main crop over 2002–2022 is then defined as the crop that most frequently appears as the yearly main crop. This procedure reduces the influence of short-run fluctuations or one-off extreme values in a single year, which is important given that changes in crop composition over time may themselves reflect farmers' adaptation to drought conditions (e.g., switching away from water-intensive crops) and thus to the treatment variable.

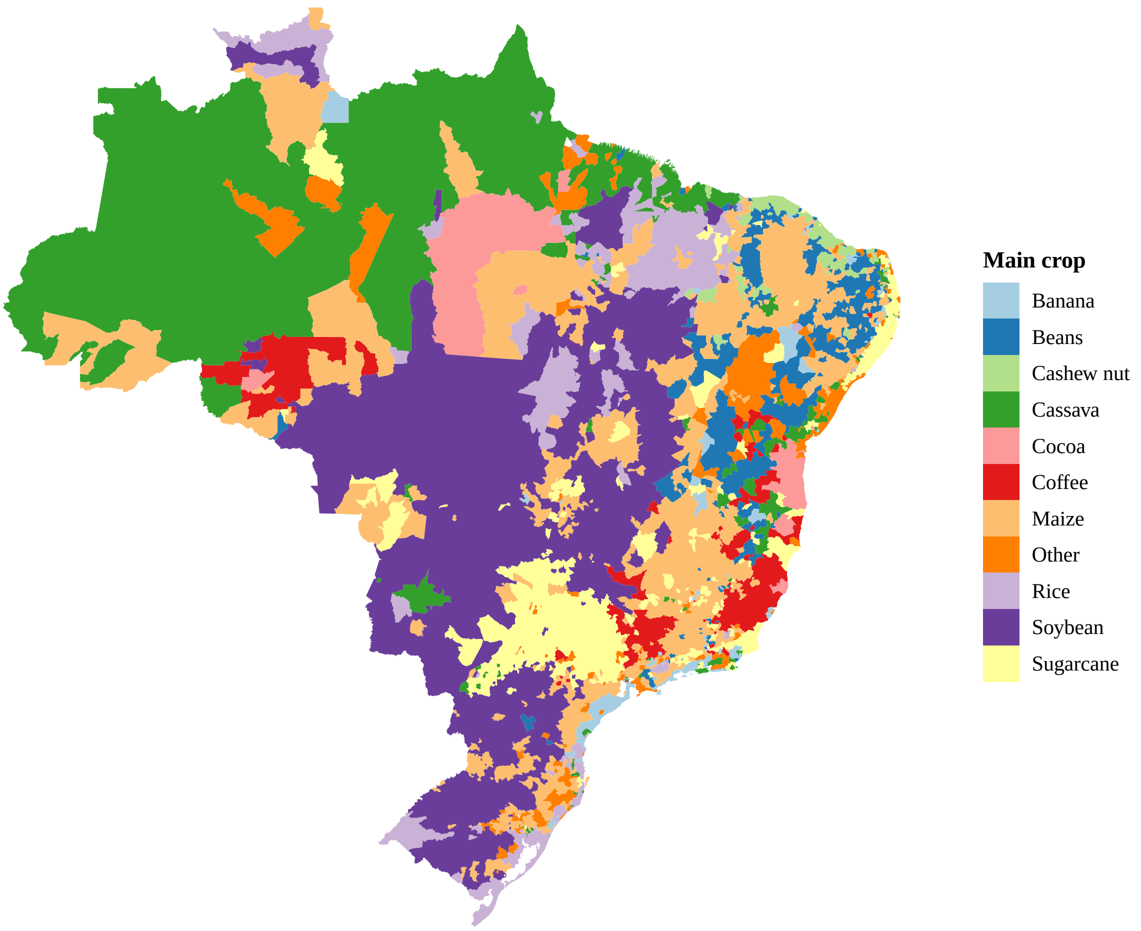


Figure A9: Main crop per municipality, 2002–2022

Several major crops in Brazil are produced in multiple *safras*, that is, distinct within-year production cycles (e.g., first/summer crop, second crop, and, in some regions, a third crop). For municipalities whose main crop is maize (*milho*) or beans (*feijão*)—the two main multi-safra crops in the sample—I use state-level historical series from CONAB's *Séries Históricas de Área Plantada e Produção* (CONAB, 2024) to determine which safra accounts for the largest share of cultivated area in each state. I then assign this dominant safra to all municipalities within the corresponding state. This step is essential, as correctly identifying the relevant safra allows me to match each main crop to its appropriate growing season, which can differ substantially across safras. This is particularly important given that a large number of municipalities in the sample have maize or beans as their main crop.

Figure A9 shows the spatial distribution of the top 10 main crops across Brazilian municipalities between 2002 and 2022. The pattern is highly consistent with qualitative knowledge of Brazilian agriculture. Soybean and maize dominate large contiguous areas of the Center-West and parts of the South, while sugarcane is concentrated in São Paulo and neighboring states, as well as in parts of the Northeast. Rice is mainly located in the southern states, especially Rio Grande do Sul, whereas cassava and banana are more prevalent in the North and in the humid areas of the Northeast. Coffee is concentrated in Minas Gerais and Espírito Santo, cocoa in southern Bahia, and cashew nut in the semi-arid Northeast. Remaining crops account for only a small fraction of municipalities (around 6%) and are grouped under the "Other" category. Overall, the map confirms that the main-crop classification used in the analysis aligns closely with well-known regional production structures.

B.2 Assignment of growing seasons across states

Growing seasons are assigned at the crop–state level by combining information from two complementary sources: (i) CONAB's *Calendário de Plantio e Colheita de Grãos no Brasil* (CONAB, 2022), which provides detailed planting and harvesting months for numerous crops[13] ; and (ii) the MIRCA-OS dataset (Kebede et al., 2025), which reports crop-specific phenological calendars (planting and maturity months) at the state level based on satellite-derived irrigated and rainfed crop distributions.[14] Given Brazil's continental size and marked heterogeneity in climate and biomes, having planting and harvesting calendars at least at the state level is crucial to avoid imposing unrealistic national growing seasons and to capture meaningful spatial variation in drought exposure. For each crop–state combination, the main growing season is therefore defined on a monthly basis, with the first month corresponding to the earliest planting month and the last month to the latest harvesting month reported in the underlying calendar.

In total, approximately 65% of Brazilian municipalities have a main crop whose growing season can be credibly assigned using either CONAB or MIRCA. For the remaining municipali-

[13] The CONAB calendar includes planting and harvesting schedules for the following crops and, when relevant, for their within-year production cycles (*safras*): algodão (cotton), amendoim (peanut; 1st and 2nd safra), arroz (rice), feijão (beans; 1st, 2nd, and 3rd safra), girassol (sunflower), mamona (castor bean), milho (maize; 1st, 2nd, and 3rd safra), soja (soybean), sorgo (sorghum), aveia (oat), canola, centeio (rye), cevada (barley), trigo (wheat), and triticale. Only a subset of these appears as main crops in the empirical sample.

[14] MIRCA-OS provides planting and maturity months for the following crops relevant to this study but not covered by CONAB's calendar: sugar cane (*cana-de-açúcar*), cassava (*mandioca*), coffee (*café*), cocoa (*cacau*), oil palm (*dendê*), and potatoes (*batata-inglesa*). In constructing the growing seasons, I rely on the calendars for *rainfed* systems only. This choice reflects the fact that Brazilian agriculture remains predominantly rainfed over the period studied and ensures that the resulting drought exposure measures capture agriculturally meaningful variation in water availability rather than irrigation-driven buffering. Because MIRCA uses global land-use and phenology models informed by remote-sensing data, crops that grow continuously throughout the year (e.g., sugar cane, coffee, and oil palm) mechanically receive a growing season spanning all twelve months. In practice, MIRCA provides precise seasonal information for a limited number of crops—notably cassava, potatoes, and some fruits and vegetables—while important perennial crops such as sugar cane or coffee do not have a reliable, well-defined growing cycle in monthly terms.

ties—primarily those whose main crop is perennial and lacks a well-defined seasonal cycle[15]—the growing season is conservatively set to the full calendar year. To the best of my knowledge, no publicly available dataset offers more detailed or reliable crop calendars at the national level that would allow for a finer assignment of growing seasons across all Brazilian municipalities.

This unified crop–state growing-season calendar forms the basis for computing municipality-level drought exposure, the construction of which is described in the following section.

B.3 SPEI computation and construction of drought exposure variables

This section provides additional detail on the computation of the SPEI and on the construction of municipality-level drought exposure variables. The approach closely follows the original methodology of Vicente-Serrano, Beguería, and López-Moreno (2010) with adaptations to the TerraClimate dataset, which provides global gridded climate information—including monthly meteorological variables such as precipitation and PET—at a spatial resolution of 4 km since 1958. For each month and year between 1958 and 2022, I extract precipitation and PET for all grid cells intersecting Brazilian territory.

Step 1: Climatic water balance For each municipality and month, I compute the climatic water balance

$$D_{m,t} = P_{m,t} - \mathrm{PET}_{m,t},$$

where $P_{m,t}$ denotes total monthly precipitation and $\mathrm{PET}_{m,t}$ is potential evapotranspiration. Both variables are taken directly from TerraClimate, which provides physically based PET estimates derived from the FAO-56 Penman–Monteith equation (Allen et al., 1998).

Step 2: Temporal aggregation (four-month water balance) The water balance series is aggregated over a four-month scale (SPEI-4). This aggregation captures short- to medium-term moisture anomalies relevant for crop development, water stress, and yield fluctuations. Earlier studies similarly emphasize that a 3–4 month window captures the seasonal water balance affecting agricultural productivity (Beguería et al., 2014; Harari and Ferrara, 2018).

Formally, the accumulated water balance is

$$D^{(4)}_{m,t} = \sum_{k=0}^{3} w_k \, D_{m,t-k},$$

where w_k are Gaussian kernel weights that give gradually less importance to past months, as in the original SPEI formulation.

[15]For a small set of annual horticultural crops that appear as main crops in a very limited number of municipalities (e.g. sweet potato, onion, tomato, melon, and watermelon), I use MIRCA-OS's "other annual crops" categories to define an aggregate "Others annual" growing season at the state level, based on the subcategory with the largest growing area.

Step 3: Standardization to obtain SPEI The aggregated series $D^{(4)}_{m,t}$ is then standardized by fitting a three-parameter log-logistic distribution using L-moments. The cumulative probability distribution

$$F(x) = \left[1 + \left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1}$$

is transformed into a standard normal variate, yielding the SPEI:

$$\text{SPEI}_{m,t} = \Phi^{-1}(F(D^{(4)}_{m,t})).$$

By construction, the SPEI has mean zero and unit variance over the baseline climatology. In this paper, the standardization uses the full 1958–2023 TerraClimate record—as recommended by Vicente-Serrano, Beguería, and López-Moreno (2010) to maximize the stability of the fitted distribution.

Step 4: Alignment with municipal growing seasons To capture agriculturally relevant drought exposure, monthly SPEI-4 values are aligned with crop-specific growing seasons described in Appendix B.2. For each municipality–election pair, I identify the most recent growing season fully completed before the election date[16] and compute the average SPEI-4 across all months in that season:

$$\text{SPEI}^{GS}_{m,e} = \frac{1}{T_{m,e}} \sum_{t \in GS_{m,e}} \text{SPEI4}_{m,t},$$

where $GS_{m,e}$ denotes the set of months belonging to the growing season relevant for municipality m before election e, $T_{m,e}$ its number of months, and $\text{SPEI4}_{m,t}$ the corresponding monthly SPEI-4 values.

Step 5: Municipalities without crop-specific calendars As explained in Appendix B.2, approximately 35% of municipalities have a main crop (typically perennial) for which no reliable growing-season calendar is available in either CONAB or MIRCA-OS. For these municipalities, the growing season is conservatively defined as the full calendar year, and the drought measure becomes the mean SPEI-4 over the twelve months preceding the election.

Resulting treatment variables The main treatment variable is the average SPEI-4 during the last completed growing season preceding each election. Lower values indicate drier-than-average conditions, with more negative values corresponding to more severe drought. In some specifications, I also use the average SPEI-4 *outside* the growing season as a complementary regressor. In these cases, the out-of-season period is defined as the set of months in the year preceding the election that do not belong to the growing season, and municipalities whose growing season spans the entire calendar year are excluded from the sample for this specification.

In an additional exercise, I introduce lagged versions of the treatment to capture the per-

[16]The first round of Brazilian presidential elections is always held on the first Sunday of October. In the period covered by this study, first-round election dates are: 6 October 2002, 1 October 2006, 3 October 2010, 5 October 2014, 7 October 2018, and 2 October 2022.

sistence of drought effects. For each election, I compute the average SPEI-4 not only over the growing season that ends just before the election year, but also over the three growing seasons that immediately precede it in time (i.e. the growing seasons in years $t-1$, $t-2$, and $t-3$ relative to the election year). These lagged growing-season averages are then included as separate regressors in the specification.