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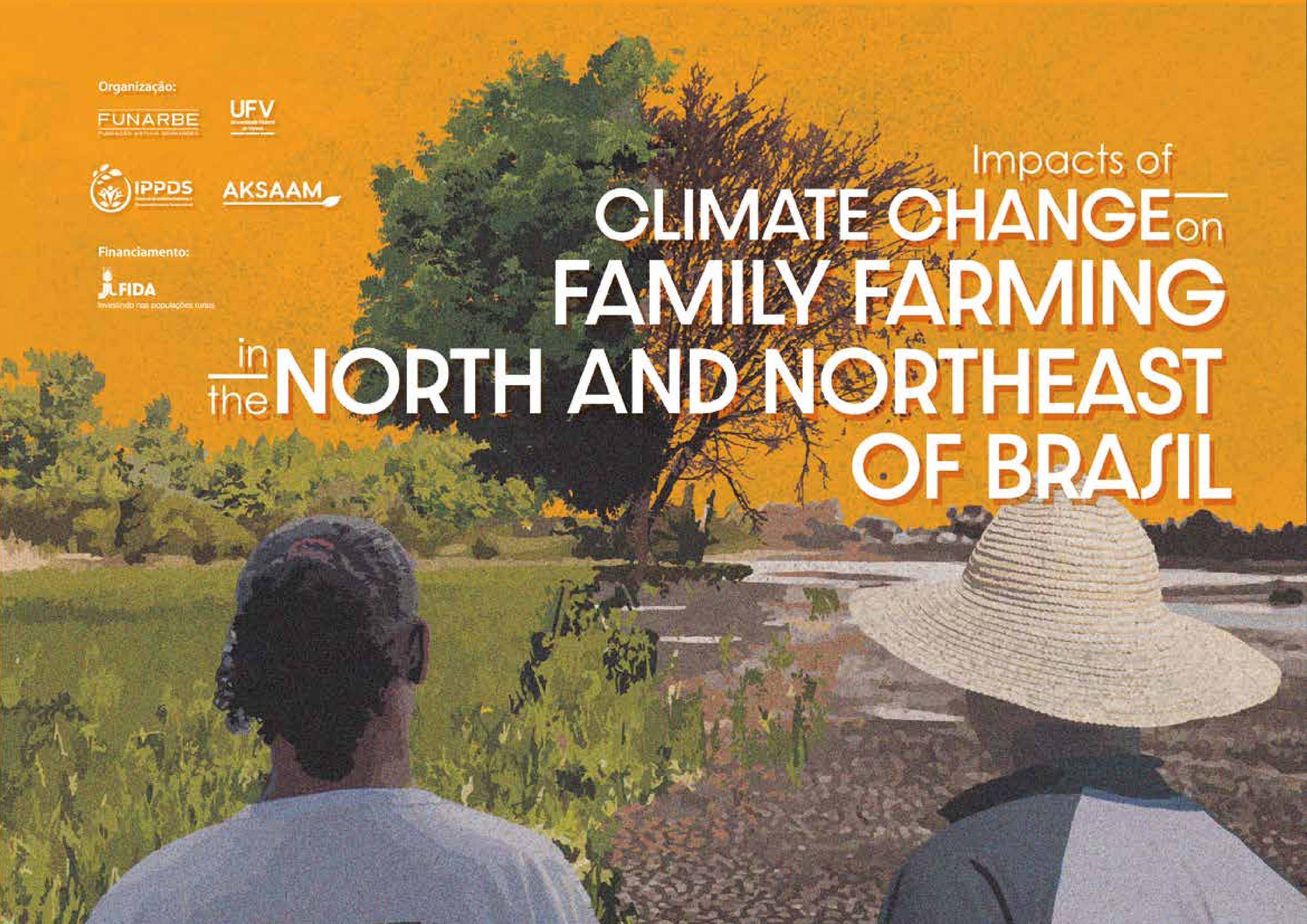
Impacts of CLIMATE CHANGE on FAMILY FARMING in the NORTH AND NORTHEAST OF BRASIL



IMPACTS OF CLIMATE CHANGE ON FAMILY FARMING IN THE NORTH AND NORTHEAST OF BRAZIL

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IMPACTS OF CLIMATE CHANGE ON FAMILY FARMING IN THE NORTH AND NORTHEAST OF BRAZIL

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SUMMARY

INTRODUCTION

Climate change represents one of the greatest challenges that rulers, policymakers, and civil society in general face in the 21st century. According to the sixth evaluation report - AR6 - by the Intergovernmental Panel on Climate Change (IPCC-AR6, 2021, p. v), the recent changes in the climate system, particularly the heating of the atmosphere, were caused unequivocally by "human activities", and are "unprecedented over centuries to thousands of years". The conclusions of the IPCC-AR6 (2021, p. v; 8) indicate that "**each of the last four decades [1980 to 2020] has been successively warmer than any decade that preceded it since 1850**" and that extreme climate events, such as heatwaves, storms droughts, and tropical cyclones "have become more frequent and more intense across most land regions since the 1950s".

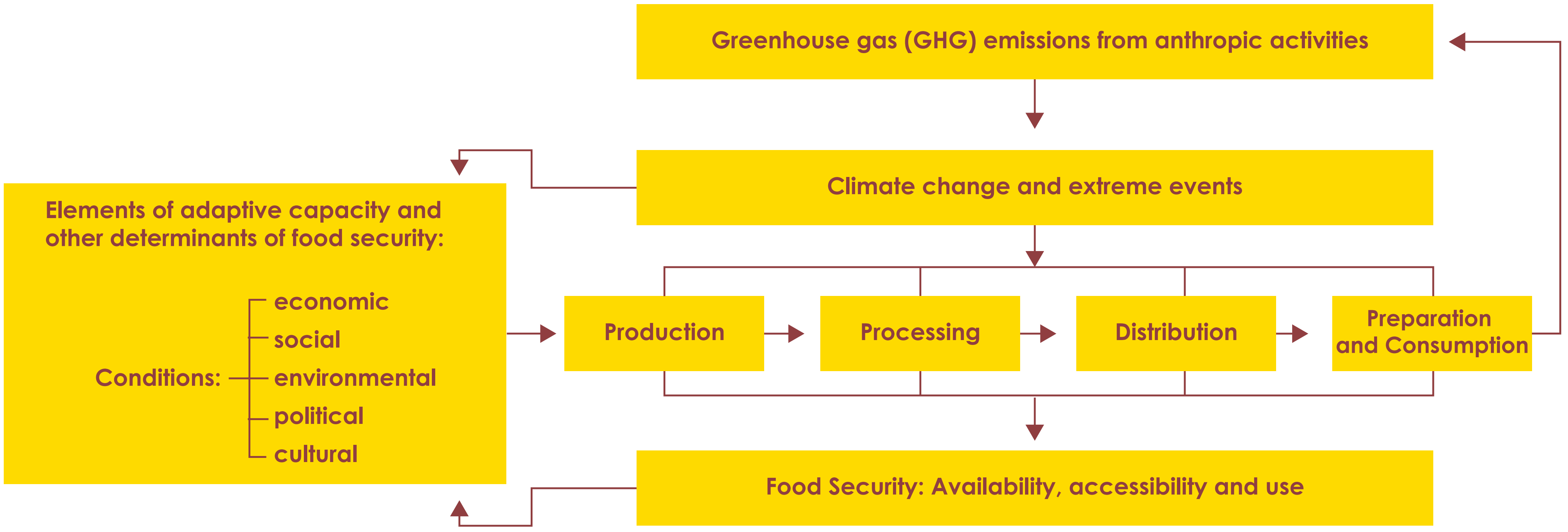
All regions of the planet have been (and will continue to be) affected by climate change. However, the risks and impacts differ significantly in terms of place and sector. Semiarid regions and those located in middle and low latitudes tend to be more exposed to the effects of climate change, such as heat extremes and periods with abnormal soil moisture deficit (combination of very low or scarce rainfall and excess evapotranspiration). This last impact, called "**agricultural and ecological drought**", will become more common in various global regions, including South America, affecting food production and ecosystem functions in general (IPCC-AR6, 2021). In Brazil, the North and Northeast regions are expected to be even more exposed to the effects of climate change.

The **agricultural sector is one of those that undergo the greatest negative impacts** resulting from climate change. The main conclusion from research is that elements such as droughts, higher rainfall variability, increased average temperatures, heat extremes, as well as the high atmospheric concentrations of carbon dioxide, **have already been causing harvest losses and reduced agricultural productivity**, which tend to intensify in future climate change scenarios (Jägermeyr et al., 2021; Müller et al., 2021). Such losses make it difficult to overcome other major global challenges, especially poverty and income inequality, food insecurity, and hunger.

Thus, it can be said that there is a nexus between these themes, as shown in Figure 1 (Charles, Kalikoski and Macnaughton, 2019; Schnitter and Berry, 2019). Agricultural losses reduce the economic activity of regions that rely the most on the primary sector, **increasing unemployment rates**; with lower food production, their prices and those of other products in the production chain rise, which **impairs the consumption**, the nutritional quality of the diet, and the health of the population. As stated by Mbow et al. (2019, p. 439), throughout the 21st century, there can be up to.

> **“183 million additional people at risk of hunger across the SPPs compared to a no climate change scenario”**
> **(MBOW et al., 2019, p. 439).**

Figure 1. Nexus between climate change, agriculture, and food (in)security



Source: Adapted from Schnitter and Berry (2019).

This nexus has another dimension, which is associated with greenhouse gas (GHG) emissions of the Agriculture, Forestry and Other Land Use (AFOLU) sector. According to data from the "Climate Change and Land" report, published by IPCC (2019), AFOLU activities generated about 23% of the global anthropogenic GHG emissions from 2007 to 2016. Moreover, if the reduction in expected agricultural productivity is compensated for the expansion of planted areas and, consequently, increased deforestation, GHG emissions will increase even further. As mentioned by Leite-Filho et al. (2021, p. 5), "deforestation does not only result in CO2 emissions and irreversible loss of (...) biodiversity, it also imposes massive productivity losses (...) on agribusiness". It means that negative impacts on agriculture, economy, and food security can be intensified.

Some particularities, such as the level of exposure to climate change (place-dependent), the importance of the agricultural sector for the national income generation, as well as socioeconomic, political, cultural, and institutional factors of the populations, can aggravate the nexus "climate change - agriculture - poverty - food (in)security/hunger". According to Roy et al. (2018, p. 447), climate change "would disproportionately affect disadvantaged and vulnerable populations through food insecurity, higher food prices, income losses, lost livelihood opportunities, adverse health impacts and population displacements". Charles, Kalikoski and Macnaughton (2019, p. 6) explain that impacts are more intense in rural areas in which small poor farmers are based on agricultural activities. Since they have less access to assets (land and capital, for example), they "have greater difficulty anticipating, coping with, adapting to and transforming their livelihoods – or way of life".

Smallholders and family farmers form "groups with high dependence on natural resources for livelihoods, income, food and well-being". These groups of farmers have low adaptive capacity and, consequently, few risk management options, as production and consumption decisions are closely related (Charles, Kalikoski and Macnaughton, 2019, p. 7). Such particularities tend to intensify situations of poverty and food insecurity resulting from the impacts of climate change in these groups.

Smallholders *versus* family farmers

The literature on climate change consulted for doing this study does not have a homogeneous definition of the terms "Smallholder" and "Family Farmer". Some authors use the terms as synonyms, while others distinguish the two groups (for example, small farmers are considered only those who use at most two hectares of land to perform their activities). There are also those who consider small farmers as a subgroup of family farmers, given the great heterogeneity of the latter (Lowder, Skoet and Raney, 2016). Most definitions agree that family farmers are those who rely on family labour for the management and operation of agricultural activities and property in general, which comes from their main source of income and support (Graeub et al., 2016). In Brazil, the "Family Unit of Agrarian Production" is defined as one that has an area of up to four fiscal modules and which obtains most of the income from the activities developed in the establishment itself, using, above all, family labour for production and management (Law N°. 11.326/2006, amended by Decree N°. 9.064/2017). Based on the legal definition, Gori Maia and Schons (2020, p. 185) describe that family farming includes "the rural households that carry out agricultural and extraction activities (forest products and fishing, for example) for subsistence and/or cash income; (...) this group does not only comprise small landholders settled by the government but also indigenous peoples, quilombolas (...), caboclos (...), seringueiros (rubber gatherers), and riverine families". It is, therefore, a very heterogeneous group. Data from the 2017 Agricultural Census (the Brazilian Institute of Geography and Statistics - IBGE, 2019) allow stating, for instance, that most small Brazilian farmers - with an area of up to two hectares - are family farmers (77.8%), even though not even all family farming establishments are necessarily small (the properties of this group have an average of 20.8 hectares). As it is not part of the scope of this study to identify the elements that differentiate the groups "smallholder" and "family farmer", it is noteworthy that the focus here is farmers "inherently vulnerable to climate change", that is, those who are more sensitive because: (i) their survival is directly linked to agricultural practice; (ii) their property is located in areas more exposed to climate risks; and (iii) they have lower adaptive capacity due to worse socioeconomic and institutional conditions.

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*De acordo com o Decreto N°. 9.064/2017, módulo fiscal se refere a uma "unidade de medida agrária para classificação fundiária do imóvel, expressa em hectares, a qual poderá variar conforme o município, calculada pelo Instituto Nacional de Colonização e Reforma Agrária - Incra".

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Although several characteristics that account for the greatest vulnerability to climate change in family farming have been listed, it should be noted that this group also has important resilience factors, such as:

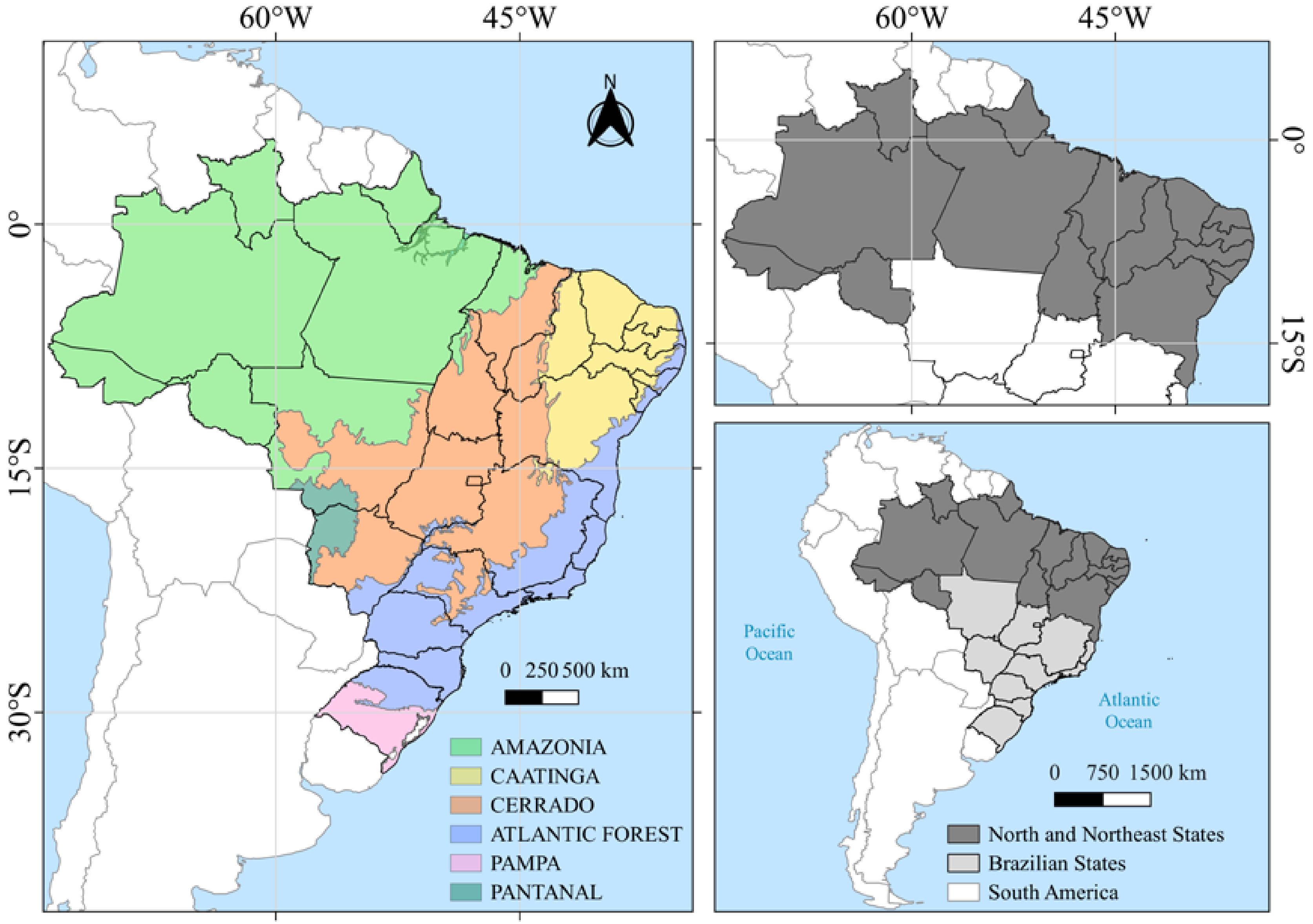
- Efficient use of family labour for producing food and raw materials for use in their own property (Morton, 2007);
- Traditional knowledge of indigenous peoples and of communities such as *quilombolas*, riverine people, rubber tappers, fundo e de fecho de pasto, among others. Such knowledge, typical of their daily activities and perfected over centuries, enables more subsistence means and makes it easier for them to face risks and crises (Morton, 2007);
- Adoption of more diverse agricultural production systems with greater conservation of natural resources, once these factors contribute to reducing food risks and to the variability of family income (Pereira and De Castro, 2022).
- Use of "creole" seeds, which have been naturally selected throughout generations and hold desirable traits, such as greater tolerance to climate stresses and higher productivity; as well as of some animal species, like chickens and goats, which are more resistant and adapted to the conditions of the semiarid (Da Cunha, 2022).
- Contribution to reducing deforestation and to the regeneration of native vegetation, protecting biodiversity, to which their quality of life is directly and indirectly associated. Specifically in the Amazon, between 2012 and 2017, indigenous lands and *quilombola* territories were the ones that most contributed to the regeneration of native vegetation (Alves-Pinto et al., 2022).

Given what was exposed, the present study has two main goals: (i) discuss the main conclusions of the literature on climate change in the North and Northeast of Brazil and its impacts on family farming; and (ii) present coping recommendations, that is, coexistence and adaptation, as well as ways for the sustainable development of family-based agricultural activities. The latest scenarios of global climate change presented on IPCC-AR6 (2021) will be taken into consideration in order to aid the understanding of risks projected for these two Brazilian regions. The analyses presented here expand and complement the study "Climate change and its impacts on family farming in the North and Northeast of Brazil" by Machado Filho et al. (2016), whose conclusions were based on the previous IPCC report, IPCC-AR5 (2013).

Figure 2 shows the regions analysed in this study and highlights the biomes that are located in each of them. The North is characterized by the presence of the Amazon rainforest, with exuberant and diverse vegetation and one of the richest biodiversity areas on the planet. In the Northeast, the caatinga is the main biome there, whose vegetation is adapted to the conditions of aridity and water scarcity; there is also the presence of transitional vegetations to the Cerrado, the Atlantic Forest, as well as the coastal and mangrove ecosystems.

Apart from this introduction, the study has four sections, which present: the historical pattern and future scenarios of the variables rainfall and temperature in the North and Northeast regions; the main impacts of climate change on family farming based on specialized literature; discussions on alternatives to increase resilience and mitigate climate change in family farming; and final considerations.

Figure 2. North and Northeast regions and biomes in the Brazilian territory



Source: prepared by the authors based on data from the Brazilian Institute of Geography and Statistics – IBGE.

CLIMATE CHANGE SNENARIOS IN THE NORTH AND NORTHEAST REGIONS

1

Climate change is a global phenomenon unequivocally influenced by human activities. Despite the fact that countries around the world have already been affected, manifestations are regionally distinct (IPCC-AR6, 2021). This way, obtaining climate information on a local scale is crucial for adaptation and mitigation policies to be properly made, especially in Brazil, given its continental dimensions. According to IPCC-AR6 (2021, p. 1366), “regional reanalyses represent the distributions of precipitation, (…) temperature, and (…) the frequency of extremes, better than global reanalyses”. Hence, in this section, data on historical patterns and future climate variables to the North and Northeast are presented to better understand regional risks. The information is spatialized, which allows local policymakers more detailed climate trends, and thus think of strategies to minimize the predicted adverse effects (Da Silva et al., 2019).

Figures 3 to 8 show past behaviour (from 1986 to 2014) and future simulations in three periods (2016-2045, 2046-2075, and 2076-2100) of the minimum and maximum temperature variables, as well as the average accumulated rainfall for the four seasons of the year in the North and Northeast regions of Brazil. The data presented in the figures, organized especially for this study by the Applied Climatology Research Group (CLIMAP) of the Federal University of Viçosa (UFV)[1], are part of the same set of information on which the conclusions of the Working Group 1 (*The Physical Science Basis*) of IPCC-AR6 (2021) were based.

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[1] Information on CLIMAP/UFV can be obtained from https://climap.ufv.br/.

Future simulations result from estimates of General Circulation Models (GCMs), provided by the *Coupled Model Intercomparison Project Phase 6* – CMIP6[2]. CMIP6 has a large set of GCMs made up by different research groups, which perform simulations of climate variables for all regions of the planet. For the present study, the four GCMs that had the best performance at simulating the historical conditions of temperature and rainfall of the Brazilian regions according to the results de Firpo et al. (2022) – ACCESS-ESM1-5; CMCC-CM2-SR5; MIROC6; and MRI-ESM2-0 – were selected. Model data were obtained at a spatial resolution of 0.25° x 0.25°, which is equivalent to pixels of approximately 28 km^2. The data presented in figures 3-8 represent the average of the four models used. This choice was made seeking a better sense of the observed trajectory of climate variables in the past, in addition to their projected future evolution (Papalexiou et al., 2020; Avila-Diaz et al., 2023), so that outliers are avoided and the internal variability of each GCM is mitigated.

Two climate change scenarios were chosen: Shared Socioeconomic Pathways (SSP2-4.5 and SSP5-8.5). As stated by Da Cunha (2022, p. 26), climate scenarios are the result of "different GHG emissions trajectories built on assumptions about population growth, lifestyles, use of fossil fuels (...), changes in land use, technological and socioeconomic development, and so forth". Ballarin et al. (2023) point out that SSP2-4.5 presupposes an intermediate level of GHG emissions ("halfway"), whereas SSP5-8.5 is considered a pessimistic trajectory ("fossil fuel-powered development"). Most research revised in the third section of the present study also uses the intermediate and pessimistic scenarios yet based on the IPCC-AR5 (2013) estimates.

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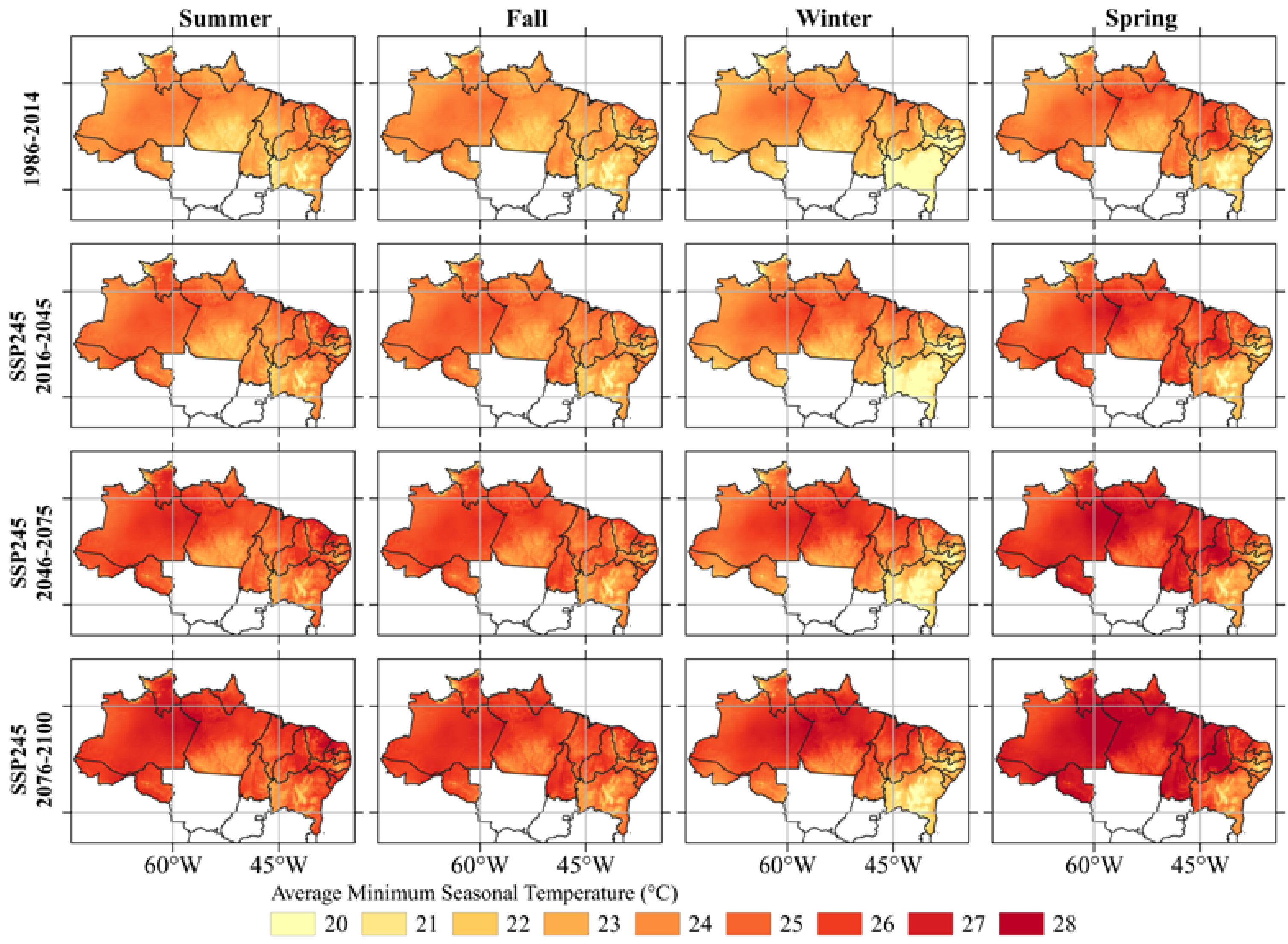
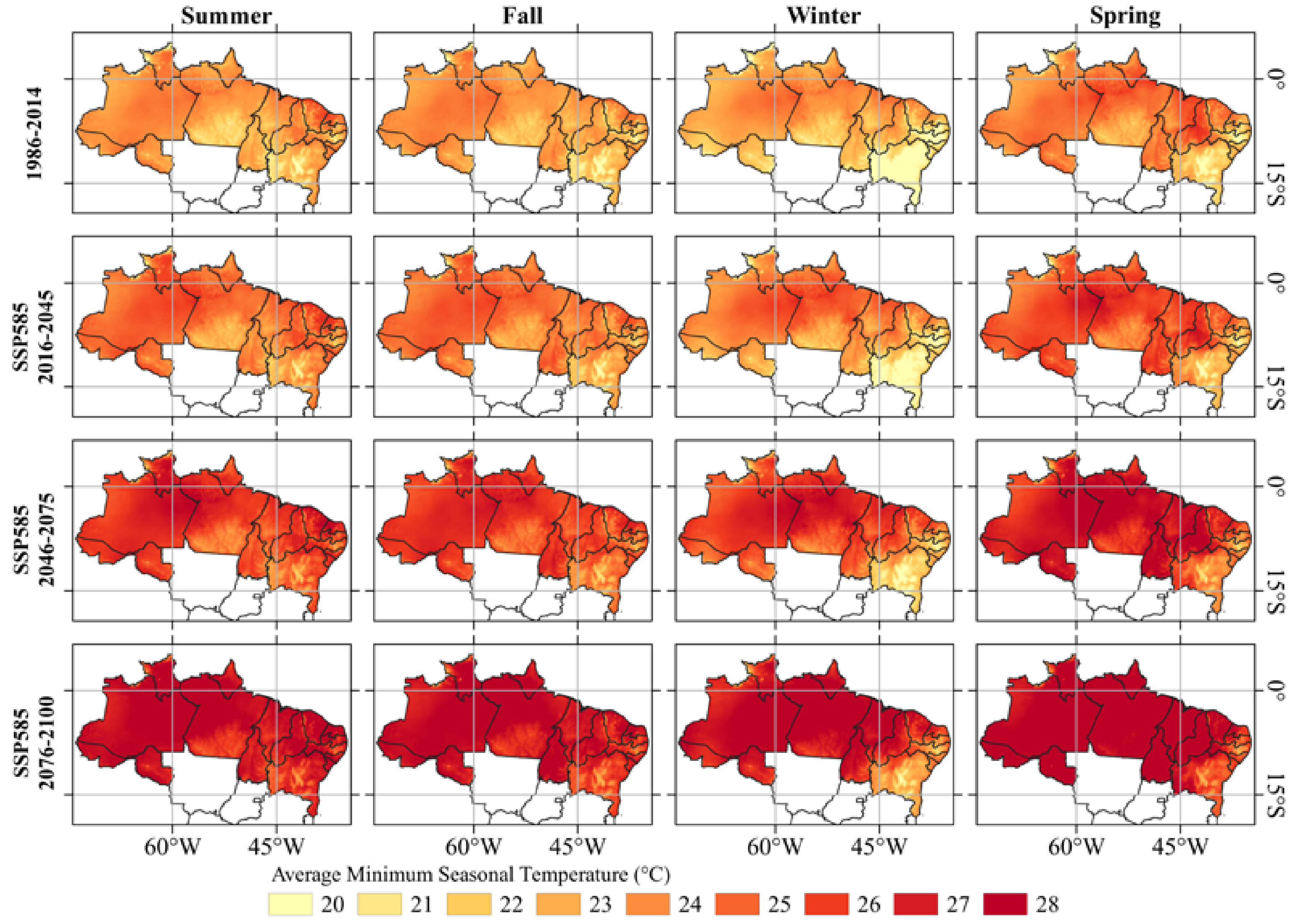
[2] NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6, 2021).

Figure 3. Average minimum seasonal temperature (°C), historical pattern and future "intermediate" scenario (SSP2-4.5)



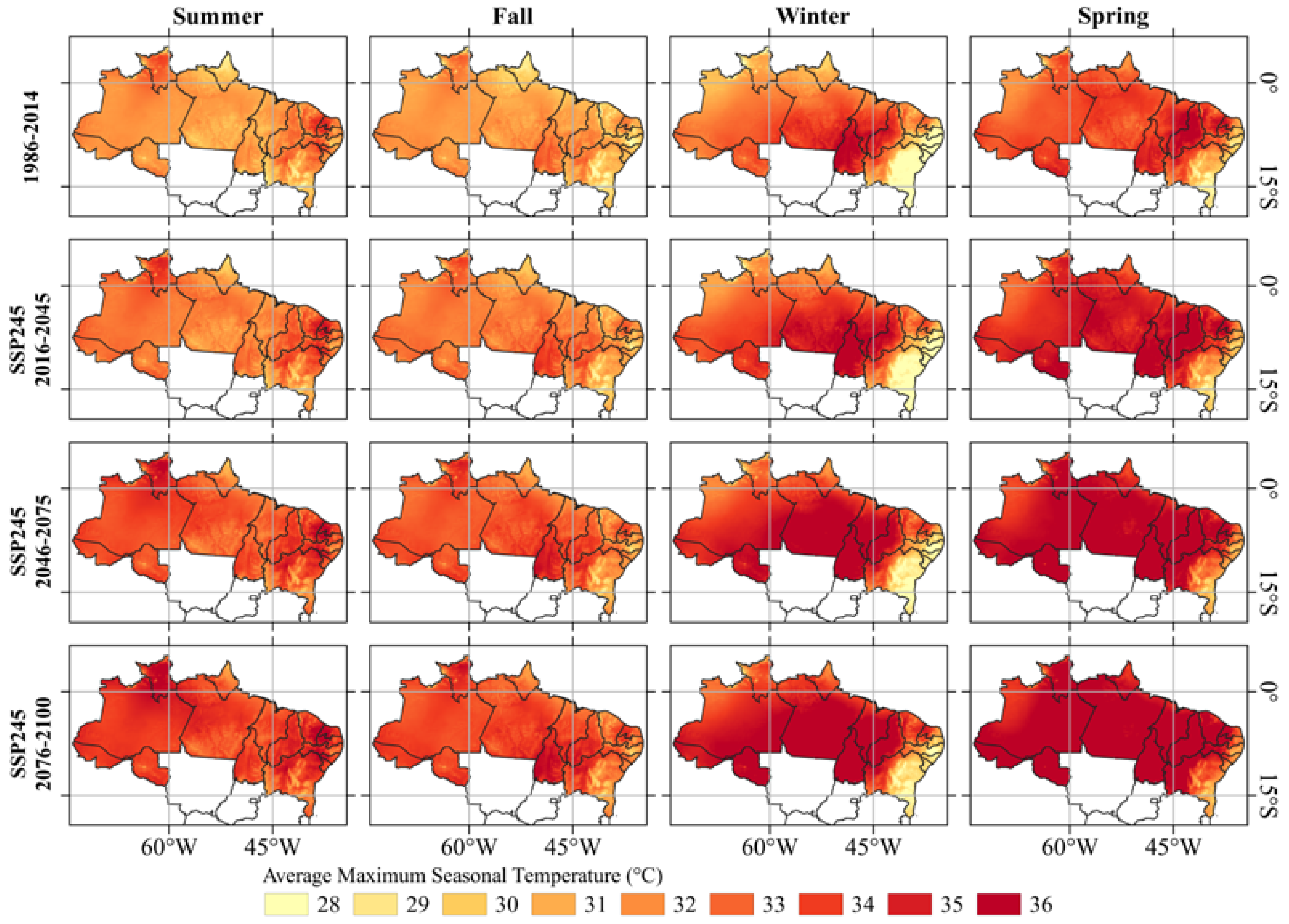
Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

Figure 4. Average minimum seasonal temperature (°C), historical pattern and future “pessimistic” scenario (SSP5-8.5)



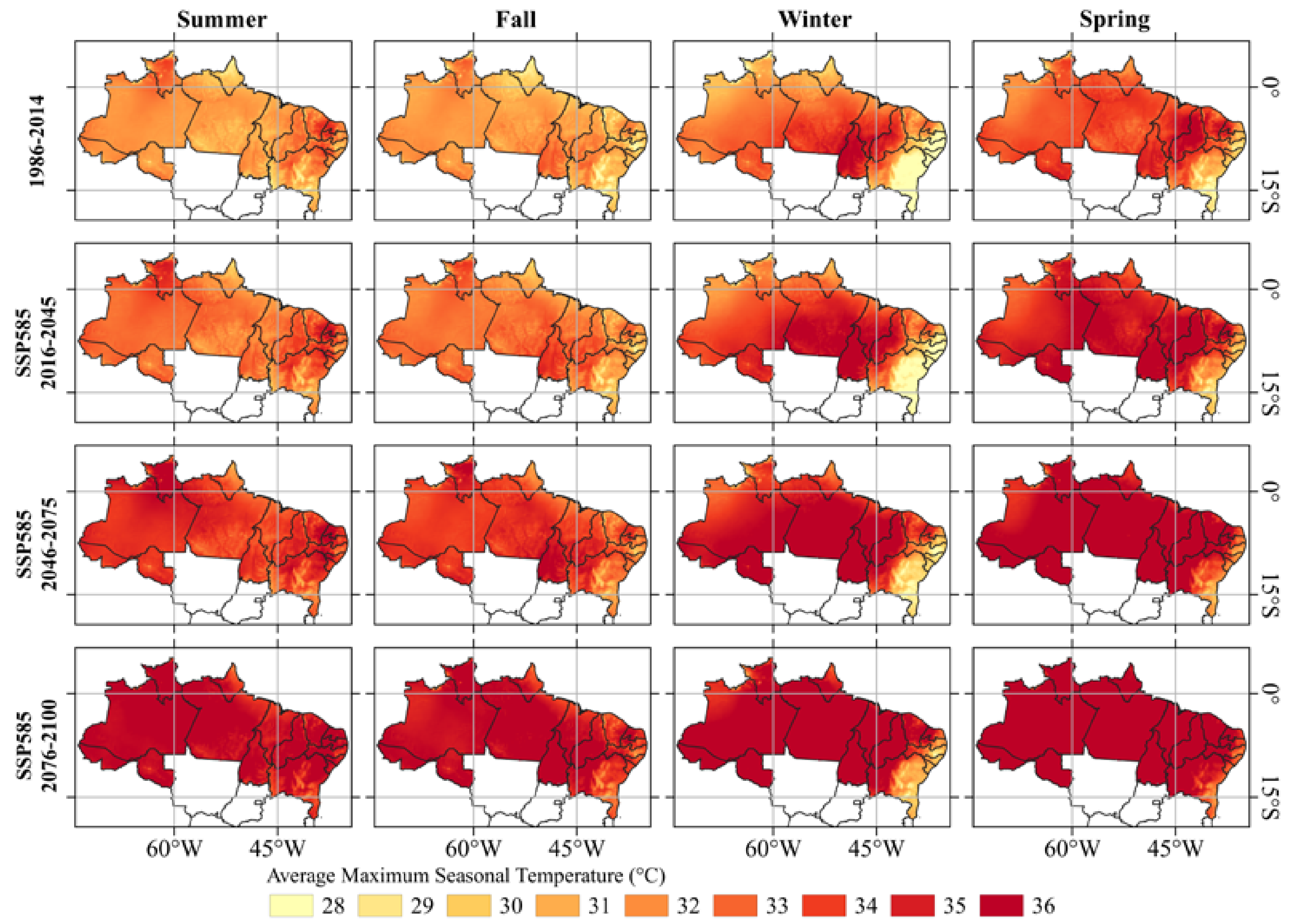
Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

Figure 5. Average maximum seasonal temperature (°C), historical pattern and future “intermediate” scenario (SSP2-4.5)



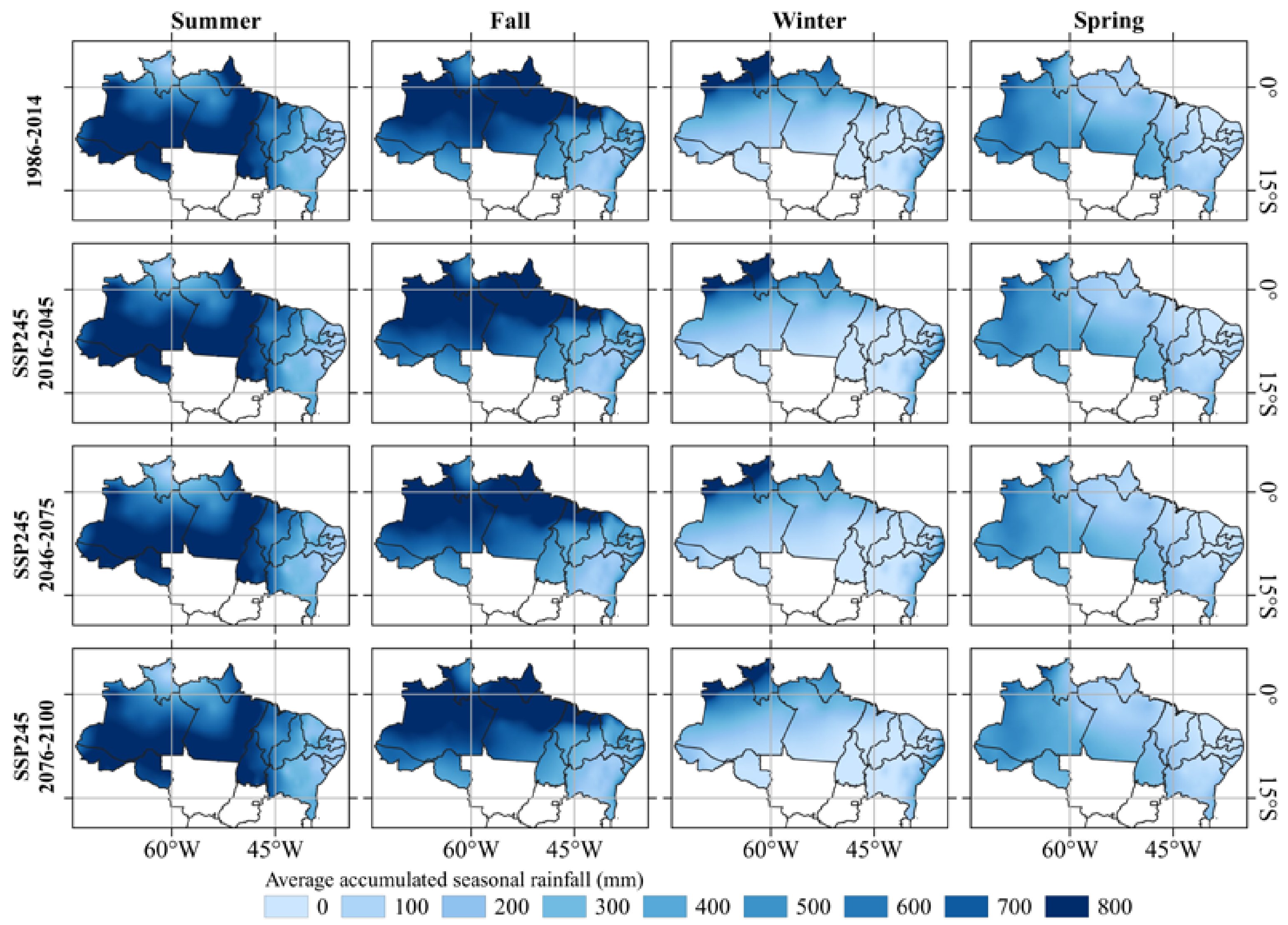
Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

Figure 6. Average maximum seasonal temperature (°C), historical pattern and future “pessimistic” scenario (SSP5-8.5)



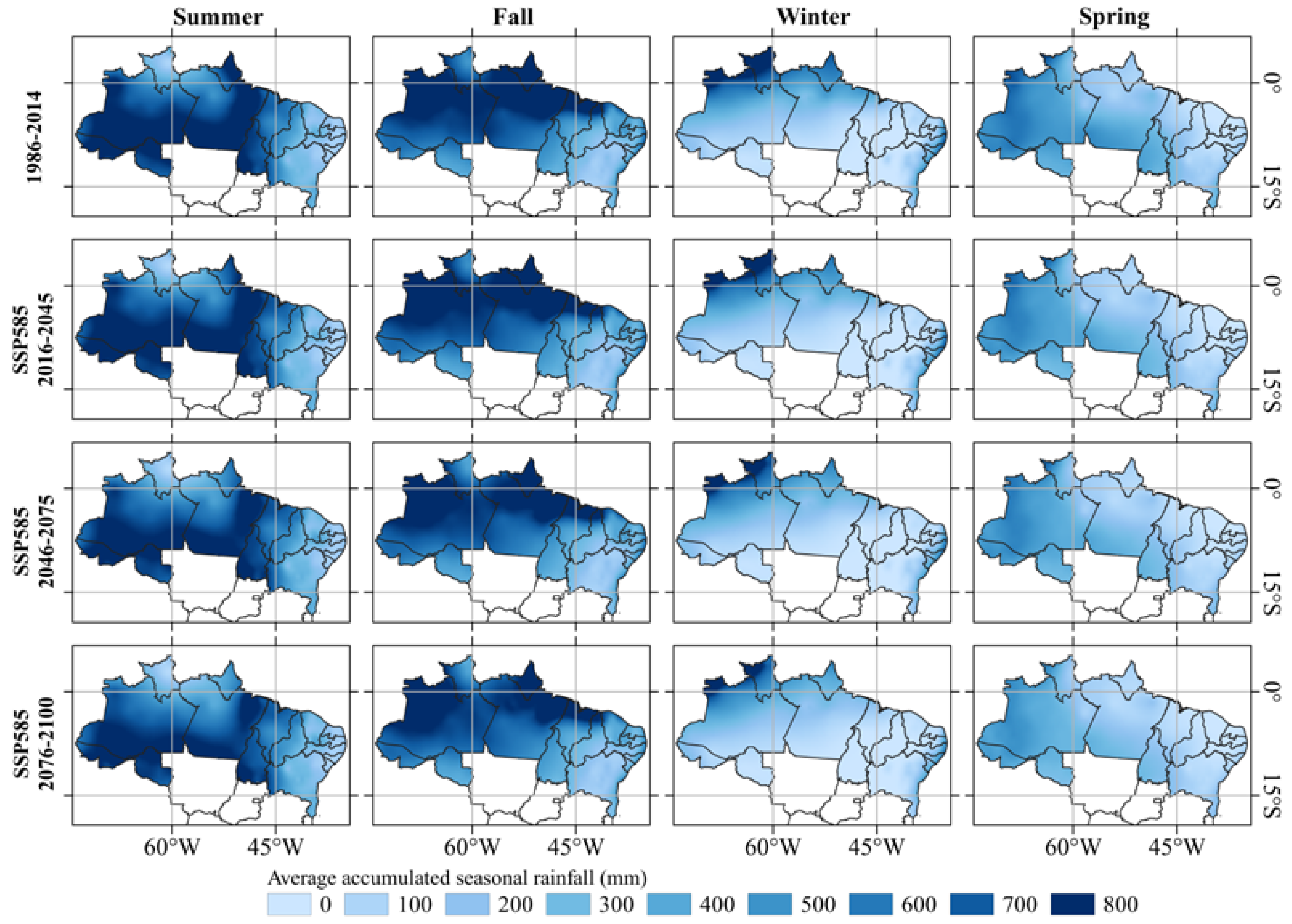
Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

Figure 7. Average accumulated seasonal rainfall (mm), historical pattern, and future “intermediate” scenario (SSP2-4.5)



Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

Figure 8. Average accumulated seasonal rainfall (mm), historical pattern, and future "pessimistic" scenario (SSP5-8.5)



Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

Despite being regions with distinct climate characteristics, future scenarios on the IPCC-AR6 (2021) indicate that the north and northeast will undergo some similar impacts as results of climate change. In general, the analysis of figures 3 to 8 demonstrate that both regions will have a rise at the temperature extremes (minimum and maximum) and reduction in rainfall volume. The effects are also expected to be more intense from the second half of the 21st century and in the "pessimistic" scenario (SSP5-8.5). It should be noted that these effects have great spatial variability. Regarding the Northeast, for example, coastal areas are less impacted; as for the semiarid region, the largest heat extremes are expected and, mainly, much smaller rain volumes. Cortez et al. (2022) also revealed great spatial variability of extreme rainfall patterns in the regions studied here. According to the authors, extreme rainfall is expected to increase (50 to 80 mm.day-1) on the northeastern coast and in the central and northwestern Amazon regions, and it is expected to reduce in the Semiarid.

Figure 9 presents the maximum temperature behaviour (annual average) in the two climate change scenarios taken into consideration in this study (maps of Figures 3 to 6). In both regions, the heating trend is very expressive[3]. Regarding the present, in the North region, the models predict that the maximum temperature will increase ranging from 0.95°C to 2.66°C until 2050 and from 2.04°C to 4.67°C until 2100; in the Northeast region, such values may vary from 0.92°C to 2.74°C until 2050 and from 1.98°C to 4.51°C until 2100 ("intermediate" scenarios - SSP2-4.5 and "pessimistic" scenarios - SSP5-8.5, respectively).

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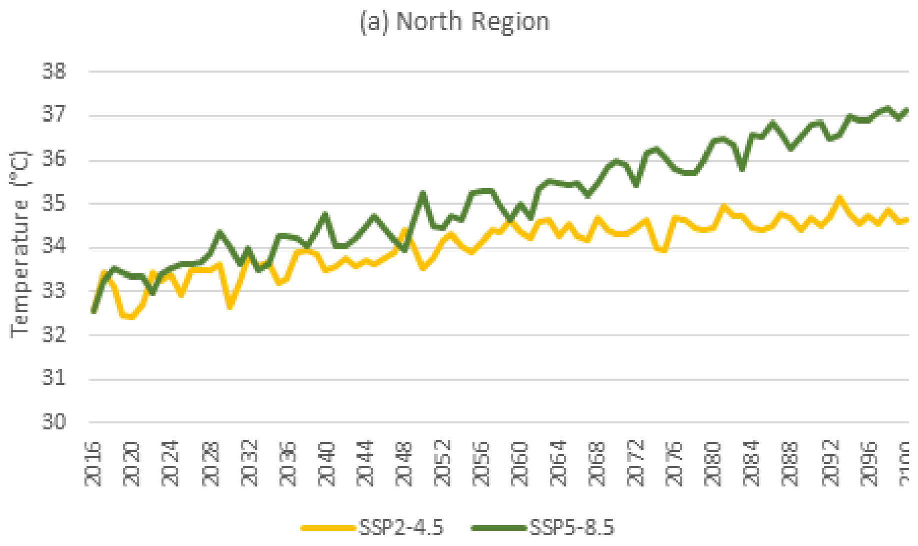
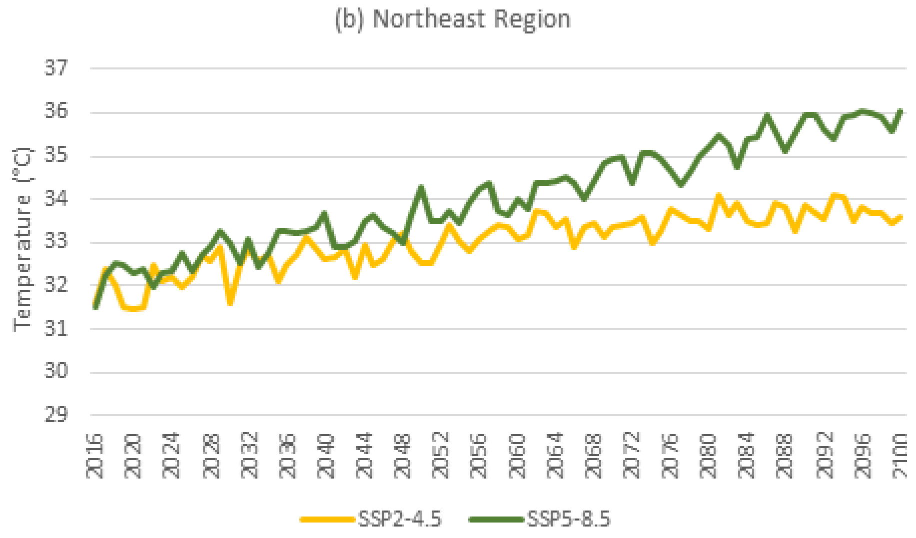
[3] The trend is similar for the minimum temperature, whose results are not shown here..

Figure 9. Average maximum annual temperature (°C), future scenarios


(a) North Region


(b) Northeast Region

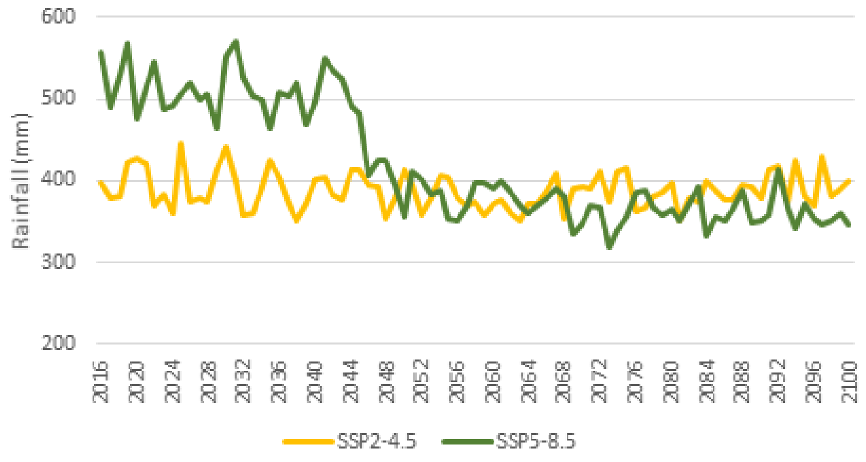
Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

Figure 10 shows the annual evolution of future accumulated rainfall estimates presented in the maps of Figures 7 and 8. The trend of reduction in rainfall is clearer in the Northern region, with a significant increase in variability (the standard deviation exceeds 22.02 in the "intermediate" scenario - SSP2-4.5 to 72.30 in the "pessimist" scenario - SSP5-8.5). In the Northeast, both scenarios also reveal great rainfall variability, yet with no major differences between them (standard deviation of 53.01 and 50.12, respectively). It is important to pinpoint that, unlike temperature, there is greater uncertainty concerning rainfall projections, that is, less agreement between models and scenarios (IPCC-AR6, 2021).

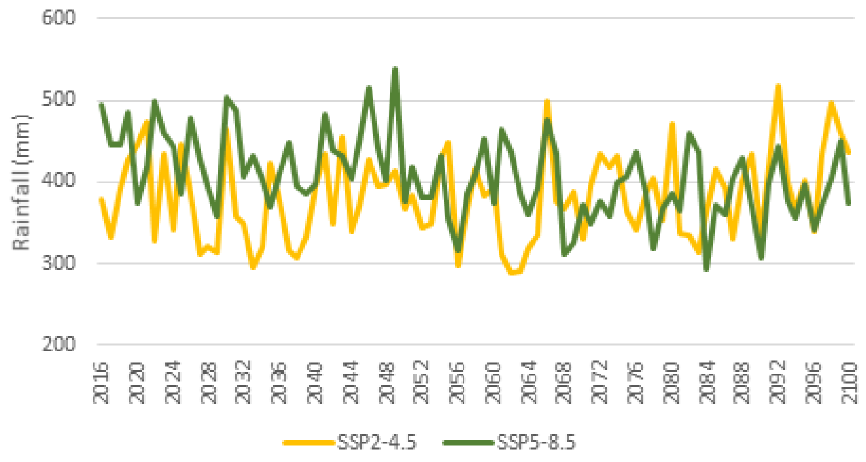
The results reported in this study are similar to those obtained by Ballarin et al. (2023), which analysed the 19 GCM data available at CMIP6. Among these authors' conclusions on the Amazon and Caatinga biomes – the main regions of those studied here – these ones stand out: (i) increase in the maximum and minimum temperatures higher than the average temperature rise projections; the percentage increase in the maximum temperature projected is slightly higher in the Amazon than in other biomes; and (ii) reduction of average rainfall in all seasons but maintaining the seasonal cycles typical of each biome. For the Atlantic Forest biome, Ballarin et al. (2023) demonstrated that a large increase in the average rainfall is expected from April to July and as well as a reduction between August and September. There are also projections of increased temperature, especially for the minimum temperature (up to 35% rise, compared to the present, in the "pessimistic" scenario - SSP5-8.5).

Figure 10. Average annual accumulated rainfall (mm), future scenarios

(a) North Region



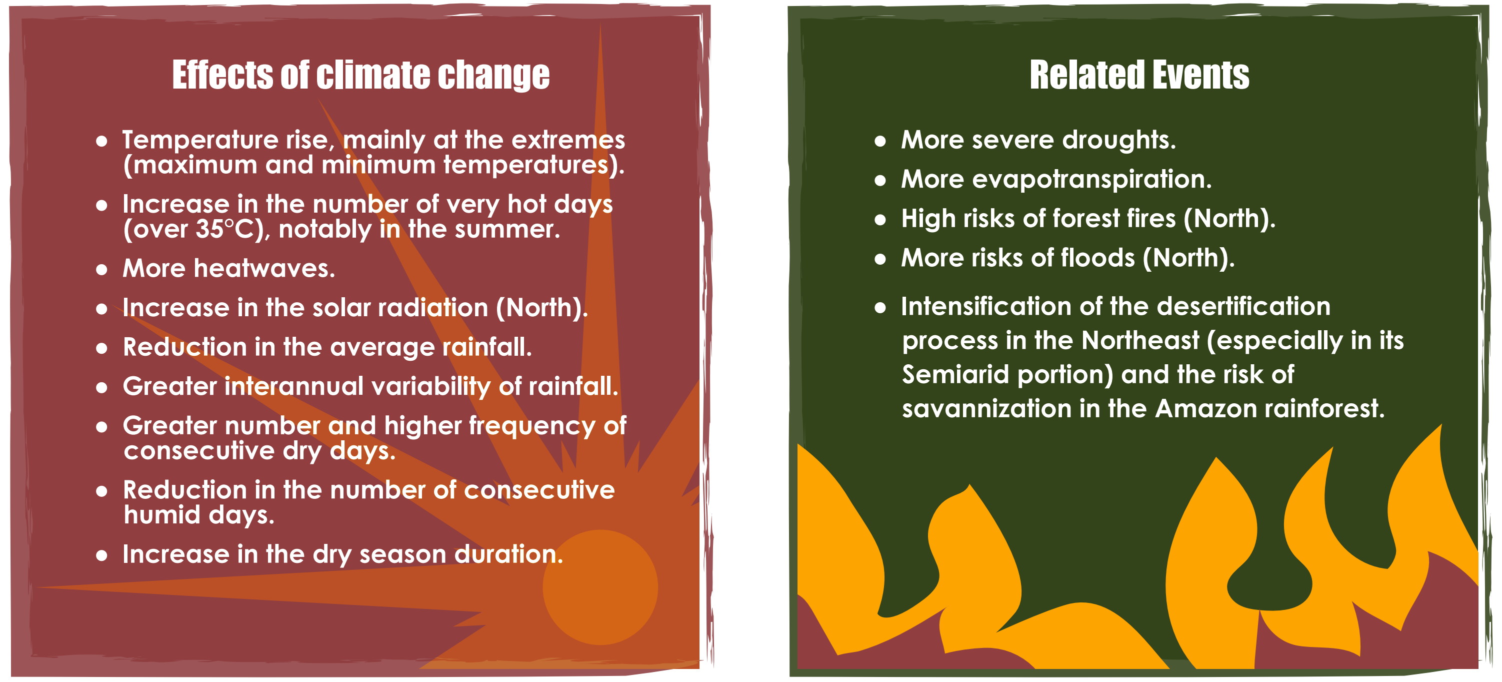
(b) Northeast Region



Source: Prepared by the authors from the NEX-GDDP-CMIP6 dataset (2021).

The main climate change effects on the North and Northeast reported in the literature are summarized in Table 1. Most of the events listed have already been reported in both regions and tend to intensify throughout the 21st century, markedly in the "pessimistic" scenario - SSP5-8.5.

Chart 1. Main expected effects of climate change on the North and Northeast regions reported in the literature



Effects of climate change

- Temperature rise, mainly at the extremes (maximum and minimum temperatures).
- Increase in the number of very hot days (over 35°C), notably in the summer.
- More heatwaves.
- Increase in the solar radiation (North).
- Reduction in the average rainfall.
- Greater interannual variability of rainfall.
- Greater number and higher frequency of consecutive dry days.
- Reduction in the number of consecutive humid days.
- Increase in the dry season duration.

Related Events

- More severe droughts.
- More evapotranspiration.
- High risks of forest fires (North).
- More risks of floods (North).
- Intensification of the desertification process in the Northeast (especially in its Semiarid portion) and the risk of savannization in the Amazon rainforest.

Source: Da Silva et al. (2018); Marengo et al. (2020); Avila-Diaz et al. (2020); Alves de Oliveira et al. (2021); IPCC-AR6 (2021).

The impacts of climate change presented in Table 1 can cause several negative shocks to the population, including reduced water and food security, as well as several health problems. As a general consequence, the socioeconomic and human development is compromised, which worsens the regional living conditions. In the next section, some of these consequences will be discussed upon the projections of loss in the production of family farming.

2

IMPACTS OF CLIMATE CHANGE ON FAMILY FARMING IN THE NORTH AND NORTHEAST REGIONS

The impacts of climate change on agriculture, especially the reduction or stagnation of productivity and the viability decline of some culture varieties, have been well documented in the literature (MBOW et al., 2019; IPCC-AR6, 2022). However, most studies do not take into account the activities of smallholders or family farming (Mbow et al., 2019). In 2016, when publishing the report "Climate change and its impacts on family farming in the north and northeast of Brazil", Machado Filho et al. (2016, p. 64) emphasised that the working group on vulnerability of IPCC-AR5 (2014), which is "the most comprehensive review on the subject", cited little research done on this important group of farmers.

Reality has not changed much since then; as the latest report of the IPCC-AR6 (2022, p. 1762) identified, "the impacts of climate change on vulnerable groups remain understudied", and the focus of research continues the main commodities globally marketed (soybean, corn, rice, and wheat). As for the Northern region, it is even more difficult because most climate change research is interested in the ecological and economic effects of deforestation, with little attention to family farming.

There is wide and growing literature on the impacts of climate change on the Brazilian agriculture. Although there are major differences in modelling and, consequently, uncertainties about the magnitude of effects, the studies agree that the Brazilian agriculture will be affected negatively. The crops most analysed in Brazil are also the main commodities of the country's export agenda, particularly soybeans and corn, and there is virtually no differentiation between types of farmers. Even though the focus of these studies is not family farming, they are important to demonstrate that

> **"climate change is likely to increase regional disparities across Brazilian states and municipalities because the most affected areas are those that already show lower productivity"**
> **(ASSUNÇÃO and CHEIN, 2016, p. 598).**

A study by Nazareth, Cunha and Gurgel (2020), for instance, reveals how Brazilian regions can be affected differently, widening existing socioeconomic disparities. From agricultural productivity shocks as a result of climate change, the authors simulated the trajectory of regional Gross Domestic Product (GDP) up to 2050 (Figure 11). The results confirm the North and the Northeast will have great impacts, while the South may even benefit.

Figure 11. GDP percentage variation of Brazilian regions as a result of declining agricultural productivity in climate change scenarios, 2025-2050

Source: prepared by the authors based on the results of Nazareth, Cunha, and Gurgel (2020).

Santos, Oliveira and Ferreira-Filho (2022, p. 19) have complementary conclusions, that is, they corroborate that "the losses will be greater for those regions whose economies are more dependent on agriculture in the composition of their production value". The authors also concluded that poor workers and the low-income groups more dependent on agriculture in general will have consumer losses and, consequently, more expressive well-being losses, mainly in the Northeast and the Midwest. Dealing specifically with the Legal Amazon, Tanure et al. (2020) demonstrated that the states Mato Grosso, Tocantins, Pará and Maranhão could have the largest GDP declines resulting from agricultural losses caused by climate change by 2050.

Considering the concept of vulnerability as a "predisposition of individuals or systems from being adversely affected" by climate change, Santos et al. (2023, p. 3) concluded that farmers in the North and the Northeast are the most vulnerable in the country. The authors identified that there is a positive correlation between the municipal percentage of family farmers and the degree of vulnerability. The IPCC-AR6 (2022, p. 2422) clarifies that it takes place because "climate risks are (...) strongly related to (...) multi-dimensional inequalities, often (...) related to geographic location, as well as economic, political and socio-cultural aspects". It is a viewpoint of "contextual vulnerability" (Iwama et al., 2016), in other words, the effects of exposure to climatic risks on family farmers in the North and the Northeast are deepened due to their low adaptive capacity.

The studies of Tanure, Domingues and Magalhães (2023, 2024) have a very detailed overview of the impacts of climate change on family farming in Brazil, as well as in the North and Northeast regions. Unlike most research that approaches Brazil, whose aim is only the major commodity exports, not drawing a distinction between producer types, the authors took a large set of agricultural activities into consideration, which represents the diversity of national production, and differentiated them between family farming and large-scale agriculture.

The model developed by the authors contains (i) agricultural production (disaggregated in rice, wheat and cereals, maize, cotton, sugarcane, soybeans, cassava, tobacco, tomato, potato, onion, peanut, pineapple, banana, beans, cashew nut, grape, orange, coffee beans, and other permanent and temporary cultures); (ii) livestock, (iii) forestry, and (iv) agrarian extractivism. Climate change was represented by two IPCC-AR5 (2013) scenarios - RCP 4.5 ("intermediate") and RCP 8.5 ("pessimistic") - with productivity shock and macroeconomic impact simulations for the period from 2021 to 2050.

Among the main conclusions of Tanure, Domingues and Magalhães (2023, 2024) for Brazil as a whole, these are highlighted:

Farmers with lower productivity are more vulnerable to climate change;

Changes in the historical pattern of the variables temperature and rainfall cause greater productivity losses in family farming than in large-scale agriculture. For example, the 1°C increase at the average temperature of the seasons spring and summer leads to a reduction of about 3.1% and 2.3% in average agricultural productivity, respectively;

Crops with the greatest accumulated losses by 2050 would be cassava, coffee beans, and banana in family farming, and maize, cotton, and orange in large-scale agriculture;

Expected losses for agriculture would have an equally negative and cumulative impact on the rest of the economy, triggering a reduction in family consumption, investments, exports, imports and, thus, in the national GDP

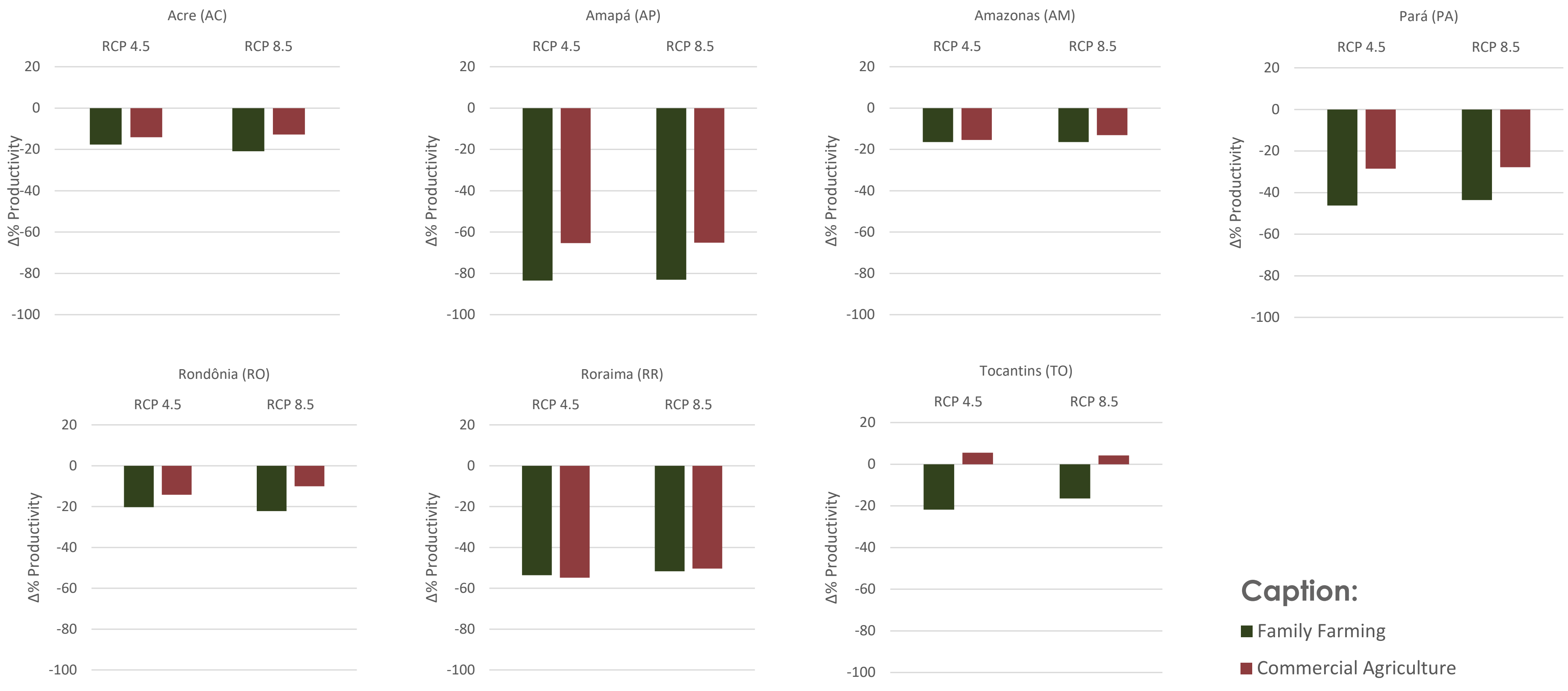
Regarding particularly the regions North and Northeast, Tanure, Domingues and Magalhães (2024) conclude that:

Some important cultures for family farmers will have great productivity losses (cassava, beans, banana, and maize, for example) – "intermediate" scenario - RCP 4.5 and "pessimistic" scenario - RCP 8.5;

The negative impacts on productivity are greater in family farming than in large-scale agriculture (Figures 12 and 13). Importantly, in the most affected states (Amapá, Roraima and Pará in the North, and Sergipe, Alagoas, Bahia and Pernambuco in the Northeast), the crops for which steep falls were estimated at productivity levels (cassava, beans, maize, coffee beans, and cotton) are more relevant in local agricultural production – "intermediate" scenario - RCP 4.5 and "pessimistic" scenario - RCP 8.5;

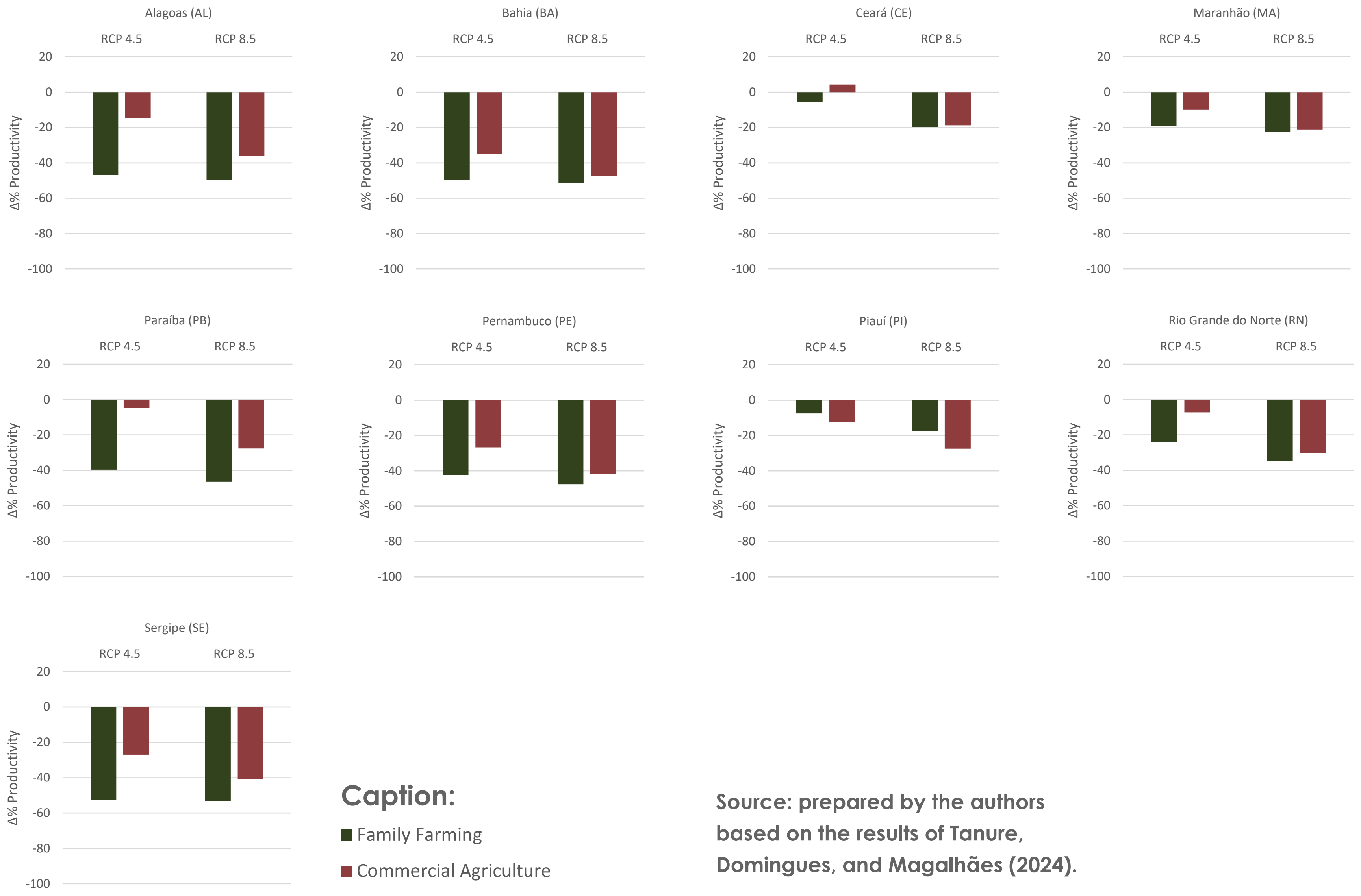
Losses in terms of sectoral economic activity are approximately four times greater in family farming than in large-scale agriculture – "intermediate" scenario - RCP 4.5.

Figure 12. Impacts of climate change on family farming and commercial agriculture productivity in the Northern states



Source: prepared by the authors based on the results of Tanure, Domingues, and Magalhães (2024).

Figure 13. Impacts of climate change on family farming and commercial agriculture productivity in the Northeastern states

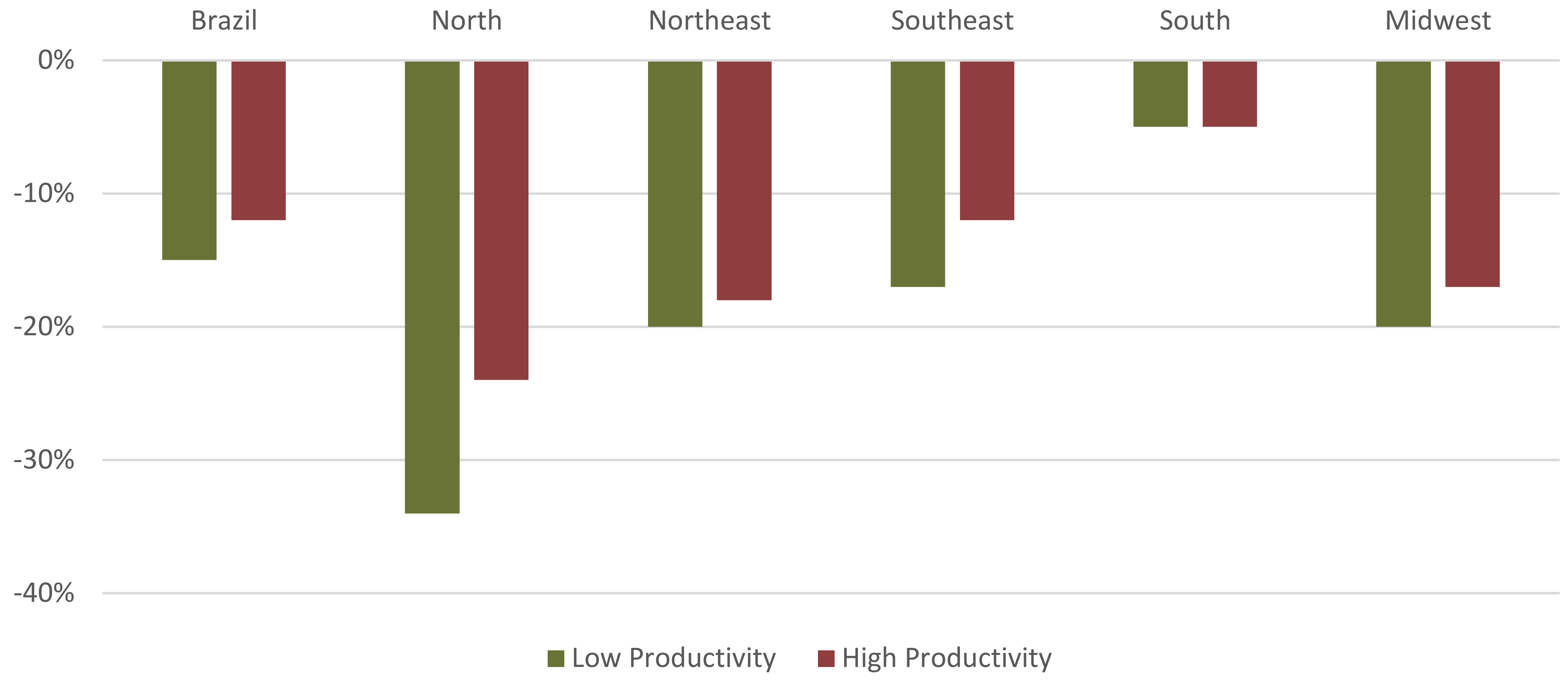


Source: prepared by the authors based on the results of Tanure, Domingues, and Magalhães (2024).

DePaula (2018) studied the effect of changes in the historical pattern of temperature and rainfall (1960-1990 and 1996-2006) on the Brazilian commercial agriculture (including family farming establishments), with disaggregated analyses for different categories of land values and productivity levels (with no separation by crops). The results indicate that an increase of 1°C at average temperature causes losses of up to 20% to national agriculture. Such effect is quite different between the regions, and the North and the Northeast are more impaired than the national average. One of the most important conclusions of the author shows that the lower the levels of agricultural productivity, the more significant are the negative effects of climate change (Figure 14). This result is comparable to that one found by Tanure, Domingues and Magalhães (2023, 2024). As mentioned by DePaula (2018, p. 33),

> **“A 1°C increase in warming reduces land values by 5% for the most productive farmers in the South and by 34% for the least productive farmers in the North”.**
>
> **(DEPAULA, 2018, p. 33).**

Figure 14. Impacts of increased average temperature on the Brazilian agriculture and large regions



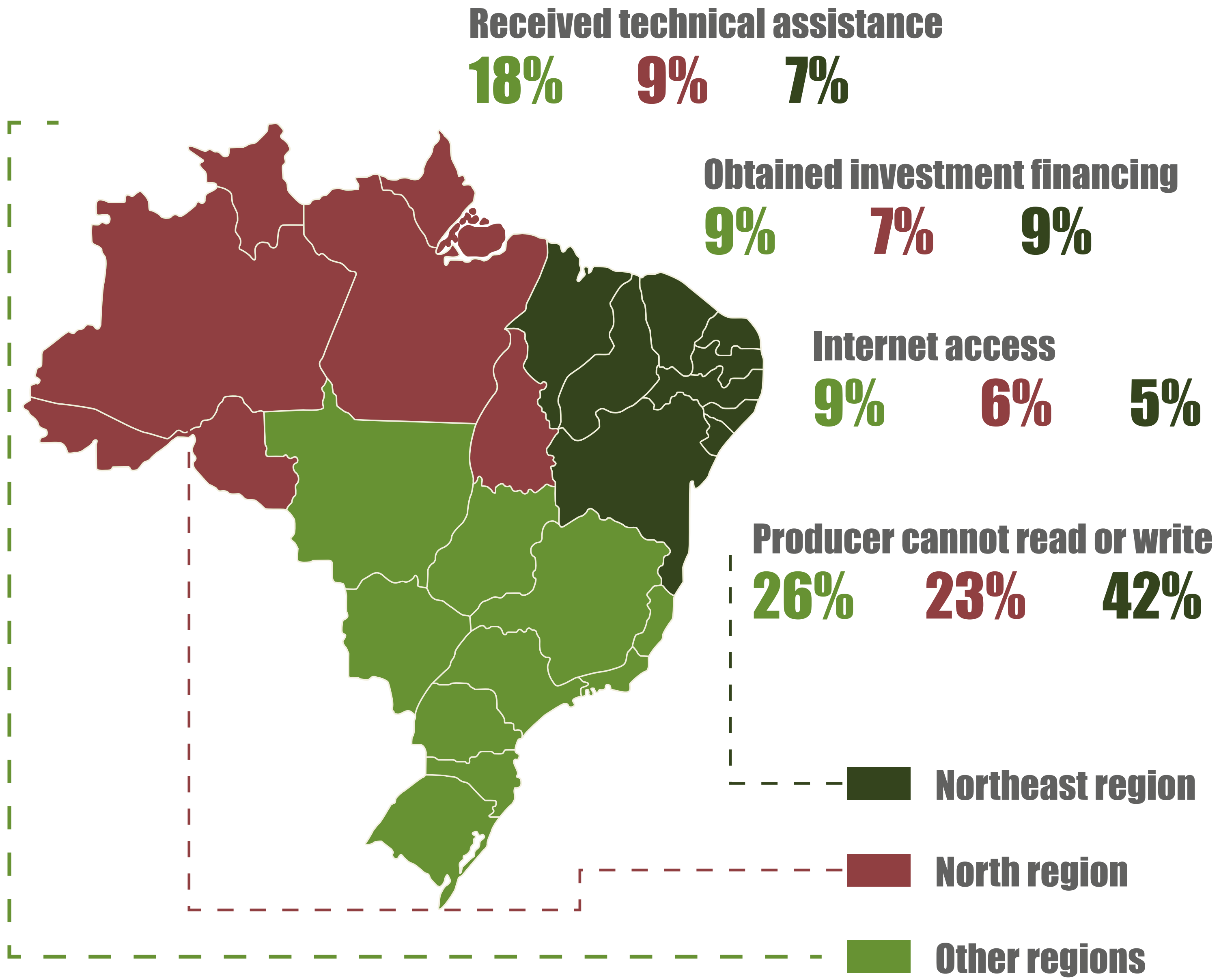
Source: prepared by the authors based on the results of de DePaula (2018).

The direct consequence of the results of Deale (2018) is increasing the inequality between the less and more productive producers, especially in the North and Northeast. In Brazil as a whole, and particularly in these regions, the productivity of family farming is lower than that of large-scale agriculture in various crops. This fact leads to a "technological gap" between the two types of producers (Pereira and De Castro, 2022); ergo, it intensifies the family sector barriers and makes regions a vulnerability "hotspot" to climate change (Gori Maia et al., 2018).

The lower productivity of family farming is related, among other factors, to the difficulty that the sector faces to invest in **agricultural technological innovations** and use it more heavily (Pereira e De Castro, 2022). As stated by Buainain, Cavalcante and Consoline (2021, p. 9; 10), "in recent decades, the main element of productivity dynamics and reproduction of inequality was the capacity for technological absorption, i.e., for innovation in general". They also emphasise that "the difficulties and obstacles faced by family farmers lie on the *conditions for innovation*" (our italics).

Among the main barriers to adopting technological innovations, the low access of family farming to the following are highlighted: (i) technical assistance and rural extension services; (ii) agricultural credit for investment in new technologies; and (iii) climate information. Some representative variables of these three categories are presented in Table 1, which allows comparing the average values of Brazil with those of the North and Northeast regions.

Figure 15 - Representative variables of barriers to the adoption of technological innovations by family farming



Source: Prepared by the authors based on the data obtained from the Agricultural Census 2017(IBGE, 2019).

According to the IPCC (2022, p. 1737), “Climate information services has an important role in climate-change adaptation and there is a recognised gap between climate science and farmers”.

Table 1 data shows there are still countless barriers to access to climate information that could reduce the vulnerability of the North and Northeast family farmers. Jones (2022) explains that in Brazil there is a lot of information on climate change which, if known in advance by citizens, could avoid or reduce losses. However, it is necessary that the difficulties of access to this knowledge are overcome by working with the affected communities, mainly the most remote ones, providing them with relevant climate information for smallholders and family farmers to make their decisions (IPCC, 2022).

Still concerning information, Zabaniotou et al. (2020) mention that “the perception of changes by local communities is important for risk analysis and subsequent social decision making”, which could minimize losses. This way, in addition to making that academic knowledge on climate change reach communities, it is crucial to understand traditional knowledge and the farmer’s perception of risks. Local knowledge represents a very rich source of information, which can make the basis of scientific evidence even more complete.

Impacts of climate change on important agricultural activities for family farming/food security

In general, literature indicates that some important activities for food security of family farmers in the North and Northeast (cassava, maize, beans, and extensive livestock) will be greatly affected by climate change. Some of the main studies and results are shown below:

- Tanure et al. (2020) identified that all mesoregions forming the Legal Amazon states will have a reduction in cassava production by 2050 (Maranhão, Tocantins, Pará and Mato Grosso will be the most affected). They also estimated the possibility of great future losses in maize production, with the largest reductions in Pará, Maranhão, and Tocantins.

- The results of Vale et al. (2020) indicate that in Rio Grande do Norte state the higher the rainfall deficits, the more impaired the productivity of maize, beans, and cassava.

- Martins, Tomasella and Dias (2019) estimated great reductions in productivity for maize produced in the rainfed system in the Northeast. Losses can range from 30% before 2070 in the least pessimistic scenario to 60% between 2071 and 2099 in the most pessimistic scenario. The authors also identified that irrigation could alleviate the losses resulting from water stress, but still temperature extremes would have considerable negative impacts on productivity.

- Martins, Hochrainer-Stigler and Pflug (2017) analysed the risks of maize and bean productivity reduction for different soil types and probabilities of water stress (measured by the annual number of days with rainfall below 1mm from 2005 to 2012) in municipalities of the Northeast region and of the semiarid portion of Minas Gerais. The results reveal that productivity losses can range from 75% to 92% for maize and 69% to 88% for beans. According to the authors, the resulting productivity for both crops after the expected losses “are insufficient to feed the families who depend on this production for their subsistence” (Martins, Hochrainer-Stigler and Pflug, 2017, p. 11). The states with the highest risks of loss would be Ceará, Piauí, Pernambuco, and Paraíba. Negative effects tend to intensify according to future projections of dry days by IPCC-AR5 (2013).

- Assad et al. (2016) estimated that increases in temperature and water scarcity and the dry spell intensification of foreseen by the IPCC-AR5 (2013) scenarios may lead to large reductions in low-risk maize and bean crop areas throughout the Northeast region .

- Gori Maia et al. (2018) figured that temperature increases and drought episodes from 1974 to 2014 reduced the productivity of livestock (milk and meat of cattle, sheep and goats) of family farmers of the Brazilian semiarid. The historical reduction of rainfall had more negative effects on family milk livestock, and the poorer the farmer, the worse the impact. As reported by the authors, the region's family livestock is more vulnerable, as it has fewer financial conditions to protect itself by investing, e.g. in “the replacement of natural pasture by other forages (silage) as needed in more extreme climate conditions” (Gori Maia et al., 2018, p. 747).

* Assad e colaboradores (2016) também fizeram estimativas para as demais regiões brasileiras e para outras culturas além de milho e feijão (soja, trigo e arroz).

The research reviewed so far is quite enlightening on the impacts of climate change on family farming in the North and Northeast regions. Nevertheless, it is believed that it is essential to review studies that have analysed this issue in other areas. The following studies to be taken into consideration are specific ones on the Amazon biome and on the Brazilian semiarid region. As populations are not uniformly vulnerable to climate change (Thomas, et al. 2019), disaggregated and local-specific analyses can provide more elements to consider about coping strategies and increased resilience of regional family farming.

The Amazon Biome

Extreme events, such as very high temperatures, floods, droughts, and periods of too low-level water, have become more frequent and intense in the Amazon in recent decades, causing various types of losses to the fauna, flora, population, and local infrastructure (Brondizio and Moran, 2008; Osuna, Börner and Cunha, 2014; Marengo and Espinoza, 2016, Almudi and Sinclair, 2022). According to Vasconcelos et al. (2022, p. 1), "climate changes expose workers to extreme environmental conditions, which in response have been modifying their ways of life, such as working in agriculture and fishing, and their social activities, such as leisure". Some of the major problems faced by family farming reported in the literature include increased fire risks, crop losses and lower productivity; reduction of the time window available for planting and the consequent need to harvest prior to maturation period, and also fishing difficulties and fish mortality (Ávila et al. 2021; Vasconcelos et al., 2022).

As Almudi and Sinclair (2022, p. 4) explain, in the communities where they live in the Amazon biome, the "livelihoods involve various combinations of small-scale family-based crop and animal husbandry, fisheries, and the extraction of timber and non–timber forest products". Therefore, the main source of livelihood is crucial for the vulnerability of families, that is, farmers and cattle-ranchers are more harmed by floods, while fishermen suffer more from droughts. The place of housing also determines the negative impact; for instance, "riverine communities (...) are highly vulnerable (...), as seasonal hydroclimatic cycles govern their daily lives, integrate their way of life with the environment, and determine the organization of social and agricultural calendars" (Vasconcelos et al., 2022, p. 1), whereas "households located on lower floodplain areas were the most exposed to extreme floods" (Almudi and Sinclair, 2022, p. 8).

Lapola et al. (2020) reported that the Amazon biome has the largest territorial extension in protected areas (conservation units, mosaics, and ecological corridors) with high rate of vulnerability to climate change. As most of these areas are managed by indigenous communities, it can be said that their quality of life, food security, and traditional knowledge are highly threatened by climate change. According to IPCC-AR6 (2022), in order to face risks such as those identified by Lapola et al. (2020), the original peoples and other traditional communities need to be supported by climate policies that ensure greater adaptive capacity as well as respect the specificities of their ways of life and production.

Along with climate change, other problems faced by Amazonian communities are deforestation and forest degradation (Berenguer et al., 2021)[4]. Besides several ecological impacts, there are multiple socioeconomic effects whose severity is more intensely felt by family farmers and traditional communities in the region. The main ones are highlighted by Lapola et al. (2023): lower availability of flora species, animals for hunting and fish, which contribute to feeding or the production of natural medicines; reduction of the offer of forest resources; and increased exposure to disease vectors.

Food insecurity, malnutrition and other health problems are some of the main direct effects of the worsening of socioeconomic conditions associated with climate change, deforestation, forest degradation, and extreme events in the Amazon biome. There are also cases of conflict and violence, disorganization of collective work, and isolation of communities which directly impacts the access to school by children and to the market by farmers. Moreover, there are impacts in terms of "relational and subjective dimensions of people's lives, which

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[4] Climate change, deforestation, and forest degradation are intrinsically associated phenomena, which have cause and effect relationships. It is not the scope of this study to go further in this discussion, but the interested reader will find a vast literature on the subject. At first, the studies suggested are Berenguer et al. (2021) and Lapola et al. (2023).

make important contributions to human well-being" (Lapola et al., 2023, p. 7). All such adversities in rural areas have the potential to aggravate the socioeconomic conditions of cities due to intra and intercity migratory processes (Lapola et al., 2018; Lapola et al., 2023).

As stated by Pinho et al. (2020, p. 237), climate changes tend to cause "migration flows (...) in the Amazon by 2030 (...). This will bring high social costs, since migrants end up occupying marginal spaces and precarious housing and jobs in bigger cities like Manaus and Boa Vista". Gori Maia and Schons (2020) identified that environmental changes, characterized by the authors as increased deforestation, variations in historical patterns of temperature and rainfall, as well as extreme climate events, have the potential to lead to the displacement of family farmers to both urban and other rural areas. Almudi and Sinclair (2022) point out that while these displacements happen in search of better living conditions or agricultural production, they generally tend to further aggravate the vulnerability of migrant families.

The Semiarid

The Brazilian semiarid has quite peculiar biophysical, demographic and socioeconomic characteristics: it faces recurring episodes of drought, rainfall irregularity, high temperatures, and extreme heat; it is the semiarid region with the highest population density on the planet and the one that faces the most critical conditions of food insecurity in the country; most of the rural population is very poor and dependent on family farming and/or on self-consumption, practised – almost it all – without irrigation and with few technological resources (Martins, Hochrainer-Stigler and Pflug, 2017; Martins, Tomasella and Dias, 2019; Marengo et al., 2022).

Just in the Amazon region, natural resources are directly linked to the quality of life in the rural areas of the Brazilian semiarid. Water (un)availability is preponderant, either for human consumption, basic daily domestic activities, or for agricultural production. Historically, the rural population has been adapting to water scarcity through "traditional rainwater harvesting (RWH) technologies", such as "capturing and storing surface run-off in open dams" and "superficial reservoirs excavated in the drainage basins of small rivers and streams" (Lindoso et al., 2018, p. 1). Family farming, whose production is predominantly rainfed suffers from various difficulties in access to water, including long distances to the resource, restriction on entry into third party properties, and lack of financial conditions to invest in groundwater capture systems (Lindoso et al., 2018; Martins, Tomasella and Dias, 2019; Marengo et al., 2022).

The studies by Lindoso et al. (2014; 2018), Herwehe and Scott (2018), Dobkowitz et al. (2020), Dantas, Silva and Santos (2020) allow to conclude that the difficulty and poor distribution of water access are determinant in accounting for the vulnerability to climate change family farmers face in the semiarid. The recurring drought episodes contribute to the low availability of water in the region. Between 2011 and 2017, the drought that occurred in the Northeast was "more intense in terms of duration, severity, and recurrence for at least the last 30 years" (Cunha et al. 2019b, p. 7). During this period, water insecurity and, consequently, food insecurity also, were intensified in the semiarid. As mentioned by Cunha et al. (2019a), about six million smallholders lost their harvest.

Another problem that increases the vulnerability of semiarid family farming is desertification. It is a complex phenomenon whose causes involve interactions of biophysical, socioeconomic, and demographic variables, and it can be accelerated by projected climate change (Vieira et al., 2021). Angelotti and Giongo (2019, p. 446) clarify that "increased temperature and drought tendency (...) intensify aridity in the semiarid region, which has a direct impact on the desertification process". Depending on the climate scenario considered, areas highly susceptible to desertification may increase between 12.3% (RCP 4.5) and 19.6% until 2045 (RCP 8.5). The combination of expected high risks of drought, increased desertification, and more extreme heat (heat over 4°C, as shown in Figure 8) can compromise agricultural activities, mainly those of family farmers, and disrupt local and regional food markets (Marengo et al., 2020; Pinho et al., 2020).

Since the climate change scenarios in IPCC-AR6 (2021) estimate reduction of average rainfall and increased seasonal and spatial variability, and greater frequency and intensity of droughts, the risks to family farming increase. Such climate changes can lead to crop losses and major productivity reductions from the main crops produced by family farming like maize, beans and cassava (Martins, Hochrainer-Stigler and Pflug, 2017; Martins, Tomasella and Dias (2019); Vale et al., 2020; Marengo et al., 2022; Tanure, Domingues and Magalhães, 2024). The small extensive livestock will be equally affected, as the herds of cattle, goats, and sheep have a high daily demand of water for their survival (Lindoso et al., 2018).

Harvest losses imply less food availability for families, whose subsistence is directly related to agricultural production. Income is reduced correspondingly, triggering other problems, such as difficulties for purchasing seeds and agricultural inputs, and increased debt (Martins, Hochrainer-Stigler and Pflug, 2017). The farmers' food security and health are, consequently, compromised. In general, "in regions with higher concentrations of subsistence farming (...), productivity losses can lead to increased poverty and conflicts over land and mass migration to overpopulated urban centres" (Marengo et al., 2022, p. 2).

Specifically dealing with the possibility of increasing migratory flows, IPCC-AR6 (2022) states that rural-urban migration in poor regions of the semiarid (also in the northern region of the country) is related to hunger and food insecurity as a result of climate change. Delazeri, Da Cunha and Oliveira (2022) as well as Delazeri et al. (2022) describe that in the semiarid, migration is regarded as the "last resort", that is, the population only leaves rural areas towards cities after trying other possibilities to deal with exposure to climate change and extreme events. Still according to these authors, "migration responses to climate change depend on the financial capacity to implement emigration" (Delazeri, Da Cunha and Oliveira, 2022, p. 2169). Thus, farmers who are very poor and very much affected by climate change cannot even pay the costs of migration. By way of explanation, in the semiarid, "the adverse effects of climate change can result in the permanence of the population who are in rural areas in persistent poverty situations" (Delazeri et al., 2022, p. 82).

The most vulnerable groups

Although the Brazilian family farming has the family labour as characteristic in common, it is very diverse and, that is why different levels of vulnerability to climate change are observed. Traditional peoples, such as the indigenous, quilombola and riverine ones, and particularly women in charge of the properties, often have a higher level of vulnerability. Generally, this is explained by their lower adaptive capacity and lack of public policies aimed at these groups. The lack of specific research also often contributes to higher risks, as the less is known, the fewer are the chances of developing adequate options to confront climate change. Traditional communities (indigenous, quilombola, riverine, and other ones who identify themselves as such) "inhabit and use natural territories and resources as a condition for their cultural, social, religious, ancestral, and economic reproduction" (Brasil, 2007). Their survival is directly associated with natural resources. For this reason, various internal and external risks, in association with climate change, threaten these groups. Regarding the quilombola communities, Cherol, Ferreira, and Sales-Costa (2021) reported high rates of food insecurity, mainly in the poorest regions of the North and Northeast. These cases can get worse with agricultural losses as a result of climate change. Vasconcelos et al. (2022, p. 1) argue that climate changes cause changes in hydrochlimatic cycles that "determine the organization of social and agricultural calendars", hindering the daily life of riverine communities. Indigenous peoples, especially those from the Brazilian Amazon, experience difficulties and similar risks, which are intensified by deforestation and forest degradation, fires and legal and illegal economic activities, such as wood extraction, mining, agriculture, and livestock practices (Rorato et al., 2022). Whether or not women come from traditional peoples, besides being the majority of the poor population, they "face social, cultural, economic, and political barriers that limit" their capacity to cope with climate changes (Zabaniotou et al., 2020, p. 8). According to ONU-Mulheres (2022), agriculture is the most important economic activity for women and girls in low-income regions, especially in rural areas. Even though women are the main ones in charge of home food and water security, they have much less access to natural and financial resources. Thus, gender inequality in the field of climate crisis is one of the greatest challenges currently (ONU-Mulheres, 2022).

INCREASED RESILIENCE AND MITIGATION OF CLIMATE CHANGE IN FAMILY FARMING

3

In the previous sections, future climate change scenarios were described with their main impacts on the subsistence means and the quality of life of family farmers in the North and Northeast of Brazil. In short, it can be stated that the greatest vulnerability of this group comes from its low adaptive capacity, which is associated with poverty conditions and lack of access to (or absence of) specific public policies. Therefore, in this section some strategies will be presented which can contribute to increasing the resilience of farmers, making them less sensitive to the expected risks. At the same time, it is possible to develop strategies that promote synergies between the increase in the adaptive capacity of farmers and the mitigation of GHG emissions in their production activities[5].

The actions discussed in this section can jointly contribute to the UN Sustainable Development Goals (SDGs), especially the SDG 2, whose aim is to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture" (ONU-Brasil, 2023). And this leads to synergies with SDG 13, whose goal is "take urgent action to combat climate change and its impacts". Among the goals of SDG 2, there are:

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[5] It is important to emphasize that the presentation will be based on actions appropriate to regional edaphoclimatic conditions and to the cultural practices of farmers.

> “*By 2030, double agricultural productivity and income of smallholders, particularly women, indigenous peoples, family farmers, pastoralists, and fishermen, including safe and equal access to land, other productive resources and inputs, knowledge, financial services, markets, value-added opportunities, and non-agricultural employment prospects; by 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, which help maintain ecosystems, which strengthen the ability to adapt to climate change, extreme climate conditions, droughts, floods and to other disasters, and which progressively improve the quality of the land and the soil (ONU-Brasil, 2013).*

Initially, it is important to deal with the farmers' knowledge and perception of climate change. Although scientific production on the subject almost never reaches the most isolated and affected communities, it should be acknowledged that farmers have their own ways to perceive changes in the regional climate and their risks, so that they seek adaptation alternatives. Studies carried out in Amazonian communities and in the northeastern Semiarid (Funatsu et al., 2019; Magalhães et al., 2021; Ávila et al., 2021; Almudi e Sinclair, 2022; Magalhães et al., 2022; Vasconcelos et al., 2022) conclude that:

Farmers have perceived climate change, and in general, their perceptions are consistent with regional meteorological records;

Experience with previous extreme climate events tends to be important for the perception of future risks;

The farmer's own experience in agricultural activities is crucial for their perception of risk, as in both regions in this study the agricultural calendar is intrinsically linked to the seasonal variability of climate variables, especially rainfall (in the Amazon, also hydrological seasonality);

The perception of climatic risks is decisive for changes in agricultural planning or adopting other adaptation strategies; that is why answers are specific for places, depending on the frequency and severity of the experiences lived and the availability of resources; and

"Climatic unpredictability hinders effective planning of subsistence activities because their local knowledge is no longer fully reliable" (Ávila et al.; 2021, p. 409).

Therefore, it is essential to invest in **climate communication policies** to improve farmers' perception, and thus increase the chances of seeking adaptation alternatives. The **expansion of access to Technical Assistance and Rural Extension Services** (Portuguese Acronym, **ATER**) should be included in such policies, since they are currently used by a very small portion of family farmers. Besides providing information on climate change, ATER can both contribute to the diversification of agricultural activities and **improve not only property management** but also **the adoption of technologies that enable greater productivity** (Buainain, Cavalcante and Consoline, 2021).

The association with cooperatives is another alternative to increase the resilience of family farmers, just as access to ATER services is. Based on literature review and empirical research, Silva and Nunes (2023, p. 20) concluded that the cooperatives provide "improvement of the production conditions (...) of family farming, especially when the challenges of this segment are considered in relation to production organization, value-added products, and marketing". As mentioned by Santos, Silva and Santana (2022, p. 243), "data from the Agricultural Census show that there is direct correlation between associativism, especially the cooperative one, and access to technologies, production organization, credit, and access to marketing". Furthermore, Mariosa et al. (2022) indicate that developing cooperatives and associations of solidarity economy for family farming can generate environmental and socioeconomic benefits, e.g. conservation of natural resources, better market integration, better selling prices for the production, increased family income, and improvement in living conditions and wellbeing.

Access to ATER information and services as well as participation in cooperatives and associations can help disseminate production technologies that act as adaptation strategies (increasing resilience) and contribute to the mitigation of GHG emissions – "low-carbon agriculture" or "climate-smart agriculture". These techniques involve crop diversification, erosion control and restoration of degraded landscapes, reduced use of chemical inputs, waste treatment, reforestation, and so on. One of the technologies that have been successfully used in family farming in the North and Northeast is agroforestry systems (Portuguese acronym, SAFs) (Miccolis et al., 2019a; Miccolis et al., 2019b; Nascimento, Alves and Souza, 2019; Signor et al., 2022).

The SAFs represent a "social inclusion mechanism for low-income smallholders by valuating 'natural' products, associated with the conservation of biodiversity and of environmental services" (Cuadra et al., 2018, p. 39). By combining crop diversification, increased supply of ecosystem services, and improved living conditions of the population, the SAFs can bring greater environmental, social, and economic benefits to the agents involved in the process, thus contributing to sustainable regional development. An additional benefit of SAFs is the likely lower GHG emission, as shown in Box 4.

Climate-smart family farming

As explained by Angelotti and Giongo (2019, p. 446), “family farming plays a very important role in the sustainable development of the North and Northeast by providing food on a local scale, as well as by being responsible for the conservation of natural resources and agrobiodiversity”. This way, family farmers can participate in the fight against climate change using “climate-smart” agricultural practices, that is, those that increase resilience and reduce poverty, while there is less GHG emission. An example of such contribution was shown in the study “Estimation of greenhouse gas emission from goats and sheep herds in the Caatinga Biome, Brazilian semiarid, in scenarios of the International Fund for Agricultural Development - IFAD”, by Henrique, Bonfim and Tonucci (2023). The authors demonstrated that integrated crop-livestock-forestry systems (ICLFS) associated with herd nutritional improvements can reduce livestock GHG emissions in the Caatinga biome. The experiments were conducted on family farmers' properties in the municipalities of Coxixola and Sumé, in the Paraíba semiarid. Different forms of production organization were evaluated, and the scenario of “low technological adherence” (control) corresponded to degraded areas with lower food quality for goats and sheep, with no additional supplementation. The treatments, in turn, were based on an ICLFS already established (“high technological adhesion”) and on properties with areas in transformation process, i.e., with planting of supplementary foods (grasses such as maize and sorghum, and legumes such as leucine, moringa and gliricidia) and pasture formation (“medium technological adhesion”). In these last two scenarios, the animals had extra supplementation, with a mixture of concentrated foods (maize, soy and wheat bran, and mineral salt). The results of this research show that the higher the level of technological adhesion, the lower the GHG emissions of the herd (-23.3% and -7.6% CO2eq emissions in high and medium technological level systems, respectively). Similar results were obtained by Signor et al. (2022), through the analysis of a silvopastoral system developed by Embrapa Semiarid, which is called CBL - Caatinga Buffel Leucena or another Forage Legume. In this system, livestock goats are raised in areas with buffel grass (no fertilizers used) and “grazed Caatinga (...) composed of native vegetation, rich in forage plants, divided into four paddocks (...), which are used under rotational grazing”; such areas were compared to a stretch of preserved Caatinga (Signor et al., 2022, p. 2). According to the authors, “areas under grazing (grazed Caatinga and buffel grass pasture) show lower GHG fluxes, when compared to the native Caatinga, being an important indication of the environmental sustainability of the silvopastoral activities in this biome” (Signor et al., 2022, p. 9). This conclusion is very important because the CBL system has the potential to be implemented in up to 62% of the Brazilian semiarid area.

The SAF development using agroecological techniques leads to sustainable agricultural intensification, that is, it enables increased productivity and resilience to climate shocks, while it maintains ecosystem services. Altieri Funes-Monzote and Petersen (2012, p. 1) explain that “the agroecological development paradigm [is] based on the revitalization of small farms which emphasizes (...) social processes that value community participation and empowerment”. As stated by Mbow et al. (2019), agroecology contributes to increasing the variety of genes, species and ecosystems within farms, while improving local food systems and equitable access to nutritious and diverse diets.

Investment in “climate-smart agriculture” by family farmers, such as SAFs, faces some barriers, including the high cost of implementing techniques when compared to that of conventional production systems they already use (Miccolis et al., 2019b). For this reason, government support through credit policies and training is essential. However, only offering more credit is not enough; it is necessary to ensure that farmers have access to financing, which requires other initiatives, such as:

Land and environmental regularization programs, as access to credit depends on land ownership and compliance with environmental legislation (Santos, Silva and Santana, 2022);

Support and reduction of bureaucracy for the elaboration of projects by qualified agricultural technicians and extension technicians (Herwehe and Scott, 2018);

Affordable conditions for farmers to pay loans by offering low interest rates and/or longer terms, longer period to start payment upon the implementation, and business maturation (Miccolis et al., 2019b);

Support to add value and guarantee access to better market conditions, preferably through short chains, that is, direct negotiation between farmers and consumers, as well as price warranty policies (Santos, Silva and Santana, 2022; Mesquita et al., 2021);

Social/assistance and agricultural insurance policies, especially when extreme climate events occur, which has become more frequent and intense in the recent period (Herwehe and Scott, 2018).

Brazil already has (or has had) several public policies with the characteristics described above. For instance, National Programme for Strengthening Family Agriculture (PRONAF), National Agrarian Reform Programme, Promotion Programme for Production Activities, Minimum Price Guarantee Policy for Sociobiodiversity Products, National School Feeding Programme, Food Acquisition Programme, Federal Acquisition, Harvest Warranty, One Million Cisterns Programme (P1MC), Environmental Conservation Support Programme, Family Support Grant, among others. Nevertheless, most poorer and more vulnerable farmers still do not have access to these policies or do not use their full potential.

In this sense, all these initiatives can be better developed with the support of civil society associations and local agents. Non-state agents close to communities, in which farmers trust, are easier to support project development, reducing informational asymmetries and cultural barriers, as well as offering technical knowledge and training (Bettles et al., 2021). In addition, some international institutions "operate at local level and strongly influence livelihoods and markets of smallholder farmers" (Mbow et al., 2019, p. 474). The IFAD is an example of such institutions, as it develops actions that

> *"help to (...) care for the environment and make family farming more resistant to the effects of climate change. Its programs and projects have as guiding elements: the conservation of biodiversity; sustainable production, as well as production based on the principles of associativism and cooperativism; the inclusion of traditional peoples and communities; the participation of women and young people; food sovereignty; the aggregation of value and commercialization of products; and the easier access to public policies" (Da Cunha, 2022, p. 44).*

Strategies to increase the resilience of family farming

Several initiatives can contribute to improving the living conditions of family farmers, reducing their vulnerability to climate change and strengthening rural development. Some of these strategies are listed below.

- **Payments for environmental services – it aims the conservation of natural resources (avoiding degradation or deforestation), thus maintaining ecosystem services through sustainable fauna and flora management.**
- **Crop diversification – it increases food availability for families in addition to minimizing losses from extreme climate events or market oscillations.**
- **Organic production (including biological control of pests and diseases) – it improves the environmental quality of property and products, as well as providing higher added value (it should be supported by the development of quality seals and/or certifications that are affordable to family farmers).**
- **Productive backyards - it increases family feeding, generates income for women, which facilitates their empowerment, as well as provides species perpetuation and biodiversity conservation.**
- **Rainwater harvesting, efficient use/reuse of water resources – especially in the semiarid region, it allows the decentralization/democratization of access to water, ensuring water security for everyday activities and food production by using irrigation.**
- **Sources of renewable energy – eco-friendly stoves ensure low-cost efficiency and security and contribute to reducing respiratory diseases; biodigesters represent good environmental management practice by using organic waste (idea of "circular economy"), also offering a relatively cheap alternative energy source, with direct positive impacts on families' income.**
- **Genetic improvement, and regional genetic wealth and in situ conservation of plants - it identifies, preserves, and uses agrobiodiversity for income generation.**
- **Creole" seed houses – besides preserving the regional genetic heritage, it enables the exchange of knowledge between traditional peoples and communities (indigenous and *quilombola*, for example).**
- **Medicinal and cosmetic use of native plants – it promotes improvement of the population's health conditions while it preserves and transmits the traditional knowledge; economic gains from associations with the pharmaceutical and cosmetics industry are also possible.**
- **Family agribusiness – it allows the processing of agricultural production, which adds value to products, decreases seasonality, and increases their durability.**
- **Market access under more advantageous conditions – it generates short commerce chains, bringing producers and salespeople closer and ensuring fairer relationships between farmers and the other links to productive chains.**

It is worth mentioning that, apart from SAFs, many other strategies that increase the resilience of family farmers are there or are currently being developed in regional projects coordinated by civil society associations, research institutes, universities, and other national and international institutions (see Box 5). There is not always the explicit objective of adaptation to climate change, although this is an indirect result of the actions. In common to all initiatives is the sustainable use of natural resources and local knowledge searching for "the solution of concrete social demands, both lived and identified by the population" (Gutierrez and Oliveira, 2018, p. 8), which enhances sustainable regional development.

Regardless of the strategy adopted, it is very important to note that the *coexistence* is the keyword in increasing the resilience of family farming in the North and Northeast. *Living* with the forest in the first region and the semiarid in the second one implies developing income generation strategies and improving well-being along with the preservation of natural resources.

It is not a matter of "keeping the forest intact" or "fighting the drought", but of adapting local conditions to the needs of its inhabitants from the sustainability perspective. Therefore, these initiatives should be based on social technologies (STs), which gather scientific and popular knowledge, through participatory methodologies.

According to the Institute of Social Technology (ITS - Brasil, p. 17), the STs refer to "social intervention practices that stand out for their success in improving the living conditions of the population, building participatory solutions closely linked to the local realities where they are applied". Among the main features of the STs, there are "low implementation cost, easy construction and replication, non-discriminatory participation, and social gain for the population" (Da Cunha, 2022, p. 34).

FINAL CONSIDERATIONS

Climate change is already occurring, and it tends to intensify throughout the 21st century. Despite being a global phenomenon, different human groups will be affected by it in very different levels. In this study, two main factors were demonstrated to account for this different vulnerability: the geographical location and socioeconomic conditions. Based on such fact, the literature was reviewed to address family farming in the North and Northeast regions.

The Brazilian law considers the "Family Unit of Agrarian Production" as one that has an area of up to four fiscal modules, so that this group includes small and commercial farmers. However, regardless of size, this study considered farmers who rely on family labour to manage and operate their agricultural activities (agricultural, livestock or extractive ones), which provide their main source of income and livelihood. This group includes rural families who were based by the government, and indigenous, *quilombolas, caboclos*, rubber tappers, and riverine families. Family farmers are valuable for the producing and maintaining sustainable agriculture in rural areas. They generally adopt more diverse production systems with greater conservation of natural resources. Nonetheless, this group can undergo great losses due to climate change, as they are very dependent on the edaphoclimatic conditions for survival (production, food, and income generation) and have low adaptive capacity.

From the analysis of the historical climatic pattern observed in the last 30 years, this study showed that the northern and northeastern regions have been facing rise in the average, maximum and minimum temperature, gradual rainfall reduction and change of their seasonal standard, as well as longer and more frequent heat waves and droughts. The projections in IPCC-AR6 (2021) indicate that these risks tend to get worse in the future, with even greater losses expected in the "pessimistic" scenario (SSP5-8.5). Even though these are common impacts to both regions (which differ only in magnitude), each of them may have other negative effects depending on its specific conditions. In the North, high risks of forest fires, and floods are projected, besides greater probability of savannization of the Amazon rainforest. In the Northeast, there are greater risks of increased desertification, which would further reduce the areas suitable for agriculture.

All such impacts observed, and which tend to intensify, will have direct effects on local agricultural production. Climate change can negatively affect food production in both regions, causing food security impairment and increasing rural poverty. As a consequence, there may be more pressure on natural resources like water, soils, flora and fauna, which affects species distribution and survival, leading to biodiversity loss. This way, local populations who depend on these resources for their survival will have greater loss, and it will weaken the regional economy and the quality of life of the population. All of this can lead to migratory processes, with aggravated vulnerability of migrant families.

Table 2 summarizes the negative impacts of climate change in the North and Northeast regions and their effects on family farming.

Chart 2. Environmental conditions and impacts on family farming as a result of climate change

Environmental conditions

- **Temperature rise and rainfall reduction (gradual variations).**
- **Longer and more frequent heat waves and droughts.**
- **More risks of forest fires and floods (north).**
- **Increased desertification in the semiarid.**
- **Higher risk of savannization of the Amazon rainforest.**

Impacts on family farming

- **Harvest losses and productivity reduction.**
- **Shorter "time window" for planting.**
- **Water and food insecurity.**
- **Increased rural and urban poverty.**
- **Larger migration flows.**
- **Biodiversity losses.**
- **More (infectious and non-infectious) diseases.**

As described in this study, family farmers have lower adaptive capacity. Among the main factors that explain this conclusion, the present study demonstrated that:

- Many family farmers in these regions have low income and depend solely on agricultural production for their subsistence. This situation limits their ability to invest in more advanced technologies and practices to adapt to climate change;
- Family farming has little access to climate predictions or information about more resilient agricultural practices. This makes it harder for farmers to be able to make informed decisions about the best adaptation strategies;

- The North and Northeast regions of Brazil are prone to extreme weather conditions such as droughts, floods, and intense climate events. These conditions may severely affect crops and limit agricultural production, impairing family farmers' income and subsistence; and
- There is also limited access to public policies that could contribute to investing in climate change adaptation practices. This includes financing to invest in more advanced technologies and technical assistance/rural extension to implement more sustainable practices.

In addition, this study demonstrated that some groups tend to be even more harmed, which is the case of traditional women and peoples, such as indigenous, *quilombolas*, and riverine. These groups already face socioeconomic and political inequalities that limit their access to resources and opportunities. Climate change can make this situation even worse, increasing poverty and social exclusion. As for women, there is an aggravating factor, which is gender discrimination. Women often have less access to public policies and resources than men do, making them more vulnerable to climate change. Furthermore, during climate crises, women tend to be more affected because of their role in the family and the community, such as being in charge of family food, and looking after the children, the old, and the sick.

Given this scenario, the pathway to sustainable development becomes much more complex, as poverty reduction and the improvement of the population's living conditions, associated with economic gains and environmental conservation, are threatened by climate change. For this reason, improving the responsiveness of family farmers is an essential prerequisite for reducing the impacts of climate change. Among the main alternatives described in this study, these stand out:

- Adoption of sustainable agricultural techniques and practices, such as agroecology, which aim to increase soil and plant resilience to climate variations and reduce dependence on external inputs;
- Diversification of crops and agroforestry systems, which contribute to biodiversity conservation, and increase the farmers' food security and income;
- Soil management techniques that use organic fertilization, as they are more affordable and less dependent on chemical inputs; also, the integrated management of pests and diseases based on the use of biological agents, which minimizes pesticide use;
- Access to updated climate information and technologies adapted to local conditions, such as efficient irrigation systems and species of plants resistant to environmental stresses;
- Strengthening of cooperation networks and knowledge exchange between family farmers as well as between these and other institutions and organizations operating in the sustainable agriculture field; and
- Promotion of public policies that support and encourage agroecological production, the commercialization of local products, and the organization of farmers in cooperatives and associations.

The adaptation alternatives listed in this study not only increase the resilience of family farming, but also promote positive externalities, that is, they contribute to environmental conservation and reduce GHG emissions. These techniques of "climate-smart agriculture" should be promoted because they respect the production characteristics, the potentialities, and the cultural identity of the different groups that form family farming in the North and Northeast of Brazil.

Fostering family farming in the face of current risks and the expected ones for the future is a matter of climate justice, since this group is disproportionately impaired, whereas its contribution to GHG emissions is lower than large-scale agriculture.

Therefore, vulnerability reduction needs to be widely supported by government agencies through public policies appropriate to regional characteristics. Articulation between the federal, state, and municipal spheres is necessary, so that these policies actually come to the population that depends most on them. Civil society associations and local leaders are greatly important in this process, as they are closer to farmers and know their reality more deeply.

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