Climate Change and Population Migration in Brazil's Northeast: Scenarios for 2025-2050

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This paper investigates scenarios of climate change impacts on migration in Brazil's Northeast Region between 2025 and 2050. The Northeast is the second most populated (28% of the country's population) and the poorest region, with an extensive semi-dry area. An integrated economic-demographic-climate model combining Population Projection Models, a Computational General Equilibrium Model, and the projected climate changes in Brazil (IPCC's regional A2 and B2 scenarios) creates state- and municipal-level population migration scenarios based on the impacts of climate change on the primary economic sector of the economy and their articulations with the other economic sectors. In addition, the paper discusses how the effects of climate change may create future scenarios of increased vulnerability of some groups living in urban areas (particularly migrants) – can be factored-in to Brazilian public policy and planning, helping to promote prompt and strong action in terms of creation or adaptation of institutional settings at different scales.

KEYWORDS: Climate Change, Migration, Brazilian Northeast, Agriculture Sector, Adaptation, Vulnerability

INTRODUCTION

The debate about the effects of climate change on population dynamics – particularly morbidity, mortality and migration – has usually focused on the impacts of catastrophic events, such as floods and hurricanes. There are scanty evidences in the literature on the impacts of climate change on population dynamics – particularly population redistribution through migration – as a consequence of economic reorganization. In fact, projecting scenarios of population redistribution as a consequence of climate change is a difficult task, not only due to uncertainties in future climate scenarios (particularly in regional climate models) but also in terms of constructing future economic and demographic scenarios. While it is usual for natural sciences to construct scenarios for periods of many decades in the future, social sciences (and particularly economics and demography) have usually dealt with scenarios of shorter periods. There is, in fact, a mismatch in terms of temporal scales, in quantitative exercises of constructing scenarios in natural and social sciences, which creates a challenge for the agenda of investigation on the human dimensions of global changes.

The main objective of this paper is methodological: to examine scenarios of impacts of climate change on migration for Brazil's Northeast Region up to 2050. We use an integrated economic-demographic-climate model which combines Population Projection Models, a Computational General Equilibrium Model, and the projected climate changes in

Brazil, in order to create state- and municipal-level population and economic scenarios which define the structural conditions from which migration decisions are made. The purpose is to investigate the long-term relation (up to 45 years of projection) between climate change, economic dynamics, and population distribution through migration in the Brazilian Northeast region – the poorest in the country, mostly semi-arid, and which will probably be most affected by climate change due to the high socioeconomic vulnerability of its population. While recognizing that the quantification of Net Migration (NM) and Net Migration Rates (NMR) for the Northeast region until 2050 is subject to a high degree of uncertainty due to the reasons mentioned above, the overall *trend* shown in this paper may have important implications regarding better planning and adequate policy measures in response to likely climate changes, especially concerning the most vulnerable population sub-groups.

Besides this introduction, the paper is organized in five sections. The next section discusses theoretical perspectives on migration determinants and how they can inform future scenarios in which population redistribution driven by migration may become an important factor in the evaluation of population vulnerability. The following section provides a description of the conceptual framework, data and methods used in the paper, particularly of the integrated economic-demographic-climate model. The fourth section presents a brief description of the area under study in the Brazilian Northeast region. The last two sections bring, respectively, the results of migration scenarios up to 2050 and the overall conclusions in the paper, with particular emphasis on the effects of migration on population vulnerability and the implications for planning and policy.

CLIMATE CHANGE, MIGRATION AND POPULATION VULNERABILITY

The lack of a hegemonic theoretical approach on the determinants of migration reflects at least in part the fragmentation and disciplinary biases associated to distinct theoretical perspectives (Barbieri, 2006). There is, however, a certain degree of consensus among different perspectives regarding the dominant effects of economic factors such as income and employment (both in absolute terms or relative terms, such as measures of relative deprivation) since the first theoretical developments by Ravenstein (1889) and Lee (1966). In this sense, the conceptual framework and the methodology in this paper consider measures of income and employment affected by climate change as the main drivers of migration in future scenarios.

Previous studies in Brazil show that the one of the main determinants of migration are income differences between regions, even when controlling by factors such as distance, education, employment and urbanization (Sahota, 1968; Ferreira, 1996). Ramos and Araújo (1999) also suggest that besides regional income disparities, the differences in employment opportunities between origin and destination is a key determinant of population migration. Golgher (2001) and Golgher and Araújo (2004) show that regions with lower income levels and worse social indicators present the highest emigration rates, and that internal migrants in Brazil usually have higher educational levels, but lower *per capita* household income. Therefore, evidence suggests that income and employment differences between regions have played an important role in explaining migration patterns, and these variables will be also assumed as key determinants of migration in the future, particularly when affected by climate change.

Macro and micro economic models (including Human Capital Models) provide an important theoretical basis for explaining income differences as a key driver of population mobility. In the macro perspective, the models assume that migration results from differences in labor supply and labor demand between regions, with labor moving from areas with excess supply (and thus lower wages) to areas of less supply. Labor migration is thus seen as a mechanism which engenders equilibrium in labor markets and convergence in income levels and in the capital-labor ratio between regions (Lewis, 1954; Ranis and Fei, 1961; Massey, 1993).

The micro perspective, in turn, considers migration as an individual investment aiming at better wages, better labor market conditions and higher welfare. An individual will migrate if the expected returns are higher than the costs involved in the migration process. The key factors affecting the expected costs and benefits of migration (both in the origin and destination) in a given period of time are the overall economic conditions (labor markets, unemployment rates, wage levels, etc), the social context (criminality, access to health services and education, etc), and amenities (urban amenities, environmental characteristics such as pollution, temperature, etc). Furthermore, other types of institutional intervention, such as cash-transfer programs in the poorest areas, may be an important element driving population migration or population retention.

In sum, the microeconomic perspective can be considered as an analytical framework in which migration decisions are driven mostly by expected wage rates in the present and in the future, assuming that individuals are aware of (or have perfect information about) income differentials between different places and that they have the goal of maximizing utility or satisfaction when deciding to remain in the same place or to migrate (Sjaastad, 1962; Todaro, 1969).

In particular, Human Capital Models have used the microeconomic perspective to explain migration decisions as a function of individual attributes such as age, gender and educational levels (Sjaastad, 1962; Becker, 1964; Vanderkamp, 1971; Levy and Wadycki, 1974; Mincer, 1978; DeJong *et al.*, 1981 Da Vanzo, 1981; Massey, 1990; Milne, 1991). Todaro (1969) and Harris and Todaro (1970) modify some of the assumptions in the microeconomic perspective by assuming that migration from rural to urban areas is driven not only by wage differentials, but also by the expected location in the labor market. In this sense, migration may occur even in a situation of unemployment in the destination (if the migrant expects to be part of the labor market in the future). The tolerance for unemployment in the Harris-Todaro model is also motivated by the existence of social security programs which assures a given income level when the individual is out of the labor market. Ramos and Araújo (1999) tested the Harris-Todaro model in the Brazilian case between 1992 and 1996 and found that expected income (not necessarily actual income levels) is the key factor explaining internal migration in the country.

Understanding the determinants of migration, and how they may be affected by future climate scenarios, is a key requirement for better planning and policies aiming to alleviate the production or reproduction of situations of poverty and vulnerability, particularly in places of destination of migrants. Such planning and policy initiatives should give special attention to measures aiming at population adaptation to climate change, which are particularly relevant in situations of high socioeconomic vulnerability. In this sense, it is important to define in which degree migration may be a mechanism engendering further vulnerability or else a mechanism of adaptation. The *IPCC Third Assessment Report* defines vulnerability to climate change as "*the degree to which a system is susceptible to,* *or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation and to which a system is exposed, its sensitivity, and its adaptive capacity".*

While assuming the diversity of definitions and conceptualizations of the term "vulnerability" across disciplines, and that there is not necessarily a correct definition (Fussel, 2007), we use this concept to qualify a population degree of exposure and "resilience" to the adverse effects of climate change on their livelihoods –particularly the impacts on the generation of income and employment. This vulnerability is contingent on a diversity of factors, especially socioeconomic, political and institutional, which makes a given population susceptible to an external impact such as increasing temperatures and periods of droughts. The intensity of vulnerability in a population will depend on the adaptive capacity and the adaptation mechanisms available.

In particular, migrants to urban areas in developing countries may be one of the potentially most vulnerable populations in future scenarios of climate change. IIED (2007) suggests that in a context of increasing urbanization driven by migration in most of the developing world, the scale of risk to climate change will be affected by infrastructure and housing quality, by the population ability to cope with changes (proxy of factors such as education, culture, solidarity) and by the quality of institutional responses (e.g., aid and medical care, urban planning).

Although some examples in the literature have highlighted the importance of migration as a factor that affects vulnerability (increasing or decreasing it), and as an important mechanism of adaptation to climate change, there are few examples in the literature which discuss these linkages and control for the effects on migration of other social and economic processes besides climate change (McLeman & Smit, 2006).

CONCEPTUAL FRAMEWORK, DATA AND METHODS

Modeling the Linkages Population – Economics – Climate Change

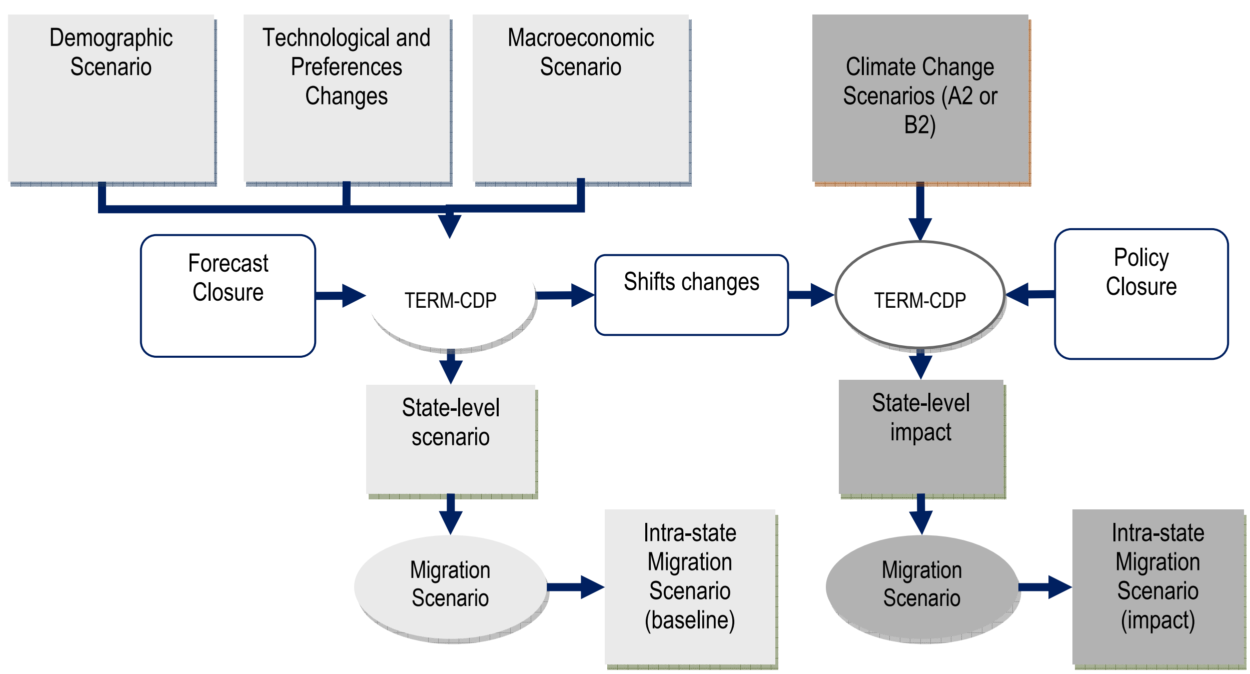
This paper proposes a model to investigate the impacts of climate change in human migration until 2050 by integrating demographic, economic and climate models. The main hypothesis in this integrated model is that the impact of climate changes on the economic performance of the agricultural sector (as measured by income and employment level) may motivate human migration. This hypothesis emphasizes, as discussed before, an economic perspective on human migration, and do not consider the operation of other adaptation mechanisms.

Figure 1 depicts the integrated model and its constituent parts. A central part in the model is the computable general equilibrium model - TERM-CDP, which generates economic scenarios (income, employment, gross product, level of consumption of families) without climate impacts (left-side TERM-CDP box) and with climate impacts (right-side box). In the left-side box, the main inputs to generate the economic scenarios at the state level are demographic scenarios (specifically population projections given fertility, mortality and migration predicted trends using the *components method*), technological and preference changes, and the macroeconomic scenarios predicted up to 2050. Then, the outputs of the TERM-CDP model are used in a mathematical model of Migration Rate (see subsection below) to re-estimate the migration component in the demographic model, allowing a higher sensibility of population estimates to economic scenarios impacted by climate changes (right side box in Figure 1). Finally, a desegregation method is used to generate estimates at the municipality (intra-state) level.

Then, these functions are submitted to the impacts of climate changes, in the A2 and B2 scenarios, in order to generate new economic and migration scenarios. The closure boxes represent different model assumptions in the simulation (e.g. fixed regional labor supply or fixed regional wage; capital mobility or endogenous rate of return, fixed or endogenous trade balance, fixed or endogenous government consumption). The policy closure is implemented to produce "shift changes" that replicate the economic and demographic scenario under the forecast closure. Operating the simulations in this way, we can estimate climate change impacts on the economic and demographic scenario.

Given this overall description of the components of the integrated model, the next subsections describe in more details aspects of each component of the model, especially their assumptions, data and methodologies.

Figure 1 - Integrated model of economic, demographic and climate scenarios



Estimation of Net Migration and Net Migration Rates[1]

The next step is to estimate the Net Migration (NM) and the Net Migration Rate (NMR) based on the parameters of the integrated model[2]. These estimates are then

[1] The estimation of Net Migration and Migration Rate in this paper considers only a closed population, that is, it does not consider the impact of international migration.

compared to the NM and NMR from the baseline demographic model, and the difference between them provides the net effect of climate change on population migration.

The population estimates generated by the integrated model refer to the active population in the economy (that is, individuals between 15 and 64 years of age). Given the interest in estimating migration measures for the whole population, including those below 15 and above 64 (supposedly the group most vulnerable to changes in temperature), it was developed a demographic technique which allows estimating migration measures from the economic and demographic parameters in the integrated model. The Net Migration related to the A2 scenario is estimated using the following equations:

$$NM_{total}^{t,IDECA2} = NM_{0-14}^{t,IDECA2} + NM_{15-64}^{t,IDECA2} + NM_{64+}^{t,IDECA2} = \left(\delta_{total}^{t,A2} \times POP_{15+}^{t,D}\right) + \left[\frac{POP_{0-14}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,A2} \times POP_{15+}^{t,D}\right)\right] + \left[\frac{POP_{65+}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,A2} \times POP_{15+}^{t,D}\right)\right] \quad \text{(Eq. 1)}$$

and, for the B2 scenario,

$$NM_{total}^{t,IDECB2} = \left(\delta_{total}^{t,B2} \times POP_{15+}^{t,D}\right) + \left[\frac{POP_{0-14}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,B2} \times POP_{15+}^{t,D}\right)\right] + \left[\frac{POP_{65+}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,B2} \times POP_{15+}^{t,D}\right)\right] \quad \text{(Eq. 2)}$$

where:

$NM_{total}^{t,IDECA2} < 0 =$ net out-migration due to climate change at time t, scenario A2;
$NM_{total}^{t,IDECA2} > 0 =$ net in-migration due to climate change at time t, scenario A2;
$NM_{total}^{t,IDECB2} < 0 =$ net out-migration due to climate change at time t, scenario B2;
$NM_{total}^{t,IDECB2} > 0 =$ net in-migration due to climate change at time t, scenario B2;

$\frac{POP_{15+}^{t,D}}{POP_{total}^{t,D}}$ = ratio of the population over 14 years-old by the total population, time t;
$\frac{POP_{0-14}^{t,D}}{POP_{15-64}^{t,D}}$ = ratio of the population 0-14 years-old by the population 15-64 years-old, time t;
$\frac{POP_{65+}^{t,D}}{POP_{15-64}^{t,D}}$ = ratio of the population at age 65 and over by the population 15-64 years-old, time t;

[2] The "Net Migration" in this paper refers to a residual estimation, contrasting to the usual estimation in the literature as a difference between in-migrants and out-migrants in a population. Conceptually, however, we assume a similar meaning. In the same way, the term "Net Migration" in Equations 5 and 6 do not reflect a typical measure of "Net Migration Rate" in the literature given the peculiarity of the numerator (the NM) in this paper.

$POP_{total}^{t,D}$ = Total population, baseline demographic model, time t;
$POP_{15+}^{t,D}$ = Population at age 15 and over, baseline demographic model, time t;
$NM_{total}^{t,IDECA2}$ = Net migration, integrated model, scenario A2 at time t, resulting from the difference between the population in the integrated model and the population in the baseline demographic model;
$NM_{total}^{t,IDECB2}$ = Net migration, integrated model, scenario B2 at time t, resulting from the difference between the population in the integrated model and the population in the baseline demographic model;
$NM_{0-14}^{t,IDECA2}$ = Net migration, population 0-14 years-old, integrated model, scenario A2 at time t, resulting from the difference between the population in the integrated model and the population in the baseline demographic model;
$NM_{15-64}^{t,IDECA2}$ = Net migration, population 15-64 years-old, integrated model, scenario A2 at time t, resulting from the difference between the population in the integrated model and the population in the baseline demographic model;
$NM_{65+}^{t,IDECA2}$ = Net migration, population at age 65 and over, integrated model, scenario A2 at time t, resulting from the difference between the population in the integrated model and the population in the baseline demographic model;
$\delta_{total}^{t,A2}$ = net effect of climate change on the variation of employment in the total population, scenario A2, time t;
$\delta_{total}^{t,B2}$ = net effect of climate change on the variation of employment in the total population, scenario B2, time t;

The NM is a 5-year measure of the difference between total in-migrants and out-migrants in a given location between t and t+5. It is also the net impact of climate change on migration, given that the population estimation in the integrated model model isolates, through the parameter δ, the effects of variations in employment affected by climate change in relation to the baseline demographic model. Therefore, in the equations 1 and 2 above, the lack of net impacts of climate change on the employment level (δ=0) generates null net migration, that is, the population projected by the integrated model would be equivalent to the population projected by the baseline demographic model.

The literature review suggests that there is not necessarily a direct relationship between employment variation and migration – for example, a positive variation in employment levels may be followed by the absorption of local unemployed population (and not necessary in-migrants). There are, thus, factors related to the social environment which favors the mobility or immobility of the population. For that reason, the NM is adjusted to include scenarios which consider some "tolerance", at value υ, to the positive or negative variation in the employment level. Thus, the final NM model may be rewritten as:

$$NMv_{total}^{t,IDEA2} = \left\{ \begin{array}{l} \left(\delta_{total}^{t,A2} \times POP_{15+}^{t,D}\right) + \left[\frac{POP_{0-14}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,A2} \times POP_{15+}^{t,D}\right) \right] + \\ \left[\frac{POP_{65+}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,A2} \times POP_{15+}^{t,D}\right) \right] \end{array} \right\} \times (1-\upsilon) \quad \text{(Eq.3)}$$

$$NMv_{total}^{t,IDECB2} = \left\{ \begin{array}{l} \left(\delta_{total}^{t,B2} \times POP_{15+}^{t,D}\right) + \left[\frac{POP_{0-14}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,B2} \times POP_{15+}^{t,D}\right) \right] + \\ \left[\frac{POP_{65+}^{t,D}}{POP_{15-64}^{t,D}} \times \left(\delta_{total}^{t,B2} \times POP_{15+}^{t,D}\right) \right] \end{array} \right\} \times (1-\upsilon) \quad \text{(Eq.4)}$$

The NMR is estimated by the ratio of the NM to the total population in a given year, t. If positive, the NM indicates the proportion of the population at time t which is the result of migration, and if negative, the proportion which would be added to the population at a time t if there was no migration. Thus:

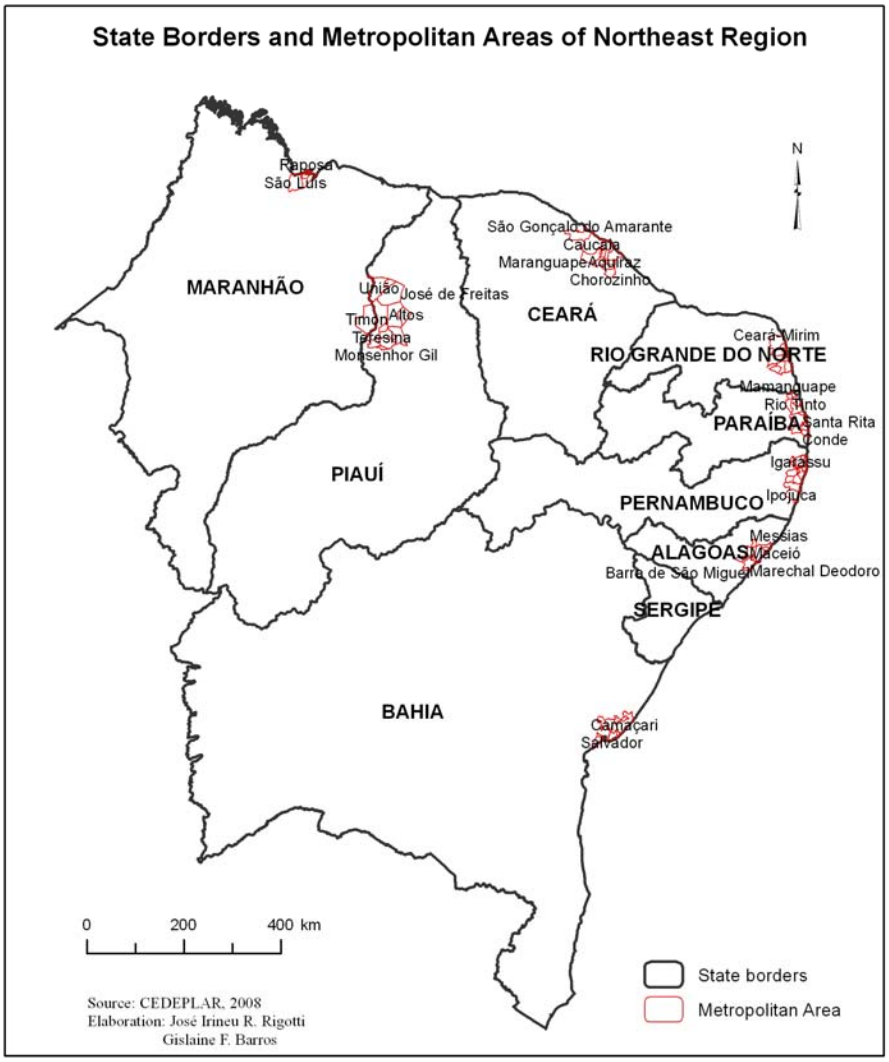
$$NMRv_{total}^{t,IDECA2} = \frac{NMv_{total}^{t,IDECA2}}{POP_{total}^{t,D}} \qquad \text{(Eq.5)}$$

$$NMRv_{total}^{t,IDECB2} = \frac{NMv_{total}^{t,IDECB2}}{POP_{total}^{t,D}} \qquad \text{(Eq.6)}$$

STUDY AREA

The main objective of this paper is to investigate scenarios of impacts of climate change on migration for Brazil’s Northeast Region up to 2050. Among the five Brazilian great regions, the Northeast is the second most populated, with about 49 million individuals in 2000, or 28% of the country’s population. It is also the poorest region in the country, the UN Human Development Index for the region is 0.57 compared to 0.78 for the South, with an extensive semi-dry area and a large population share working in the primary sector – mostly agriculture and cattle ranching. Map 1 shows the study area, with its states and metropolitan areas.

Map 1


State Borders and Metropolitan Areas of Northeast Region
MARANHÃO
PIAUÍ
CEARÁ
RIO GRANDE DO NORTE
PARAÍBA
PERNAMBUCO
ALAGOAS
SERGIPE
BAHIA
Raposa
São Luís
União
José de Freitas
Timon
Altos
Teresina
Monsenhor Gil
São Gonçalo do Amarante
Caucaia
Maranguape
Aquiraz
Chorozinho
Ceará-Mirim
Mamanguape
Rio Tinto
Santa Rita
Conde
Igarassu
Ipojuca
Messias
Maceió
Barra de São Miguel
Marechal Deodoro
Camaçari
Salvador
N
0
200
400 km
State borders
Metropolitan Area
Source: CEDEPLAR, 2008
Elaboration: José Irineu R. Rigotti
Gislaine F. Barros

RESULTS AND DISCUSSION

Baseline Demographic Model

Table 1 and Table 2 show the projected population and their geometric growth rates for Brazil, the Northeast region and its States, from 2000 to 2050. Following the projection for the Northeastern states, the baseline demographic model projects the population for municipalities in the Northeast (not shown in Tables 1 and 2). Overall, the Northeast region and its states show a trend of declining population growth with rates close to zero in 2050. Such declining trend is similar to the one observed in Brazil as a whole, although the study area will still present relatively higher fertility rates (particularly due to an effect of population momentum). The states of Ceará, Rio Grande do Norte, Piauí, Alagoas and Sergipe (and to a lesser extent Pernambuco and Bahia) will show higher population growth in the region.

The population projections and growth rates shown in Tables 1 and 2 consider a trend in net migration rates of -0,29% for every five-year period until 2050. This trend is based on past rates, on future expectations about the role of return migration to the Northeast, and on projected economic performance of the region in comparison to other Brazilian regions[3].

[3] See detailed discussion in CEDEPLAR (2008).

Table 1 – Projected Population for Brazil, Northeast and States in the Northeast – 2000 to 2050

Region / State	Total Population										
	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Brazil	169.566.235	180.965.039	191.758.845	201.532.099	209.961.860	217.349.186	223.642.306	228.806.538	232.789.875	235.602.520	237.360.829
Norheast	47.689.038	51.332.659	54.951.923	58.303.546	61.243.757	63.861.317	66.124.748	68.032.946	69.601.491	70.817.216	71.667.309
Maranhão	5.644.229	6.080.423	6.517.974	6.920.811	7.272.517	7.579.337	7.841.590	8.053.776	8.209.174	8.315.842	8.380.660
Piauí	2.840.776	3.063.236	3.288.069	3.494.505	3.672.218	3.828.311	3.961.717	4.070.511	4.159.801	4.228.131	4.273.430
Ceará	7.419.703	8.069.944	8.723.427	9.353.610	9.932.977	10.473.539	10.966.066	11.401.496	11.776.933	12.103.728	12.377.050
Rio Grande do Norte	2.773.082	2.995.863	3.220.451	3.434.444	3.627.309	3.804.011	3.960.987	4.098.856	4.220.744	4.321.457	4.400.556
Paraíba	3.441.547	3.689.940	3.943.201	4.184.076	4.397.851	4.592.157	4.764.320	4.915.323	5.050.268	5.162.353	5.248.920
Pernambuco	7.910.465	8.453.664	8.985.994	9.473.418	9.896.185	10.270.561	10.587.271	10.854.109	11.075.677	11.242.392	11.351.647
Alagoas	2.819.554	3.038.994	3.243.097	3.422.217	3.574.701	3.705.314	3.813.057	3.894.120	3.945.268	3.972.516	3.978.423
Sergipe	1.781.491	1.937.695	2.088.939	2.228.500	2.353.115	2.465.440	2.563.912	2.646.099	2.713.587	2.767.284	2.805.947
Bahia	13.058.191	14.002.900	14.940.771	15.791.965	16.516.883	17.142.646	17.665.828	18.098.655	18.450.038	18.703.514	18.850.676

Source: IBGE (2000), CEDEPLAR (2007)

Table 2 – Annual Geometric Population Growth Rate for Brazil, Northeast and States in the Northeast – 2000 to 2050

Region / State	Annual Geometric Growth Rate									
	2000/05	2005/10	2010/15	2015/20	2020/25	2025/30	2030/35	2035/40	2040/45	2045/50
Brazil	1,30	1,16	0,99	0,82	0,69	0,57	0,46	0,35	0,24	0,15
Northeast	1,47	1,36	1,18	0,98	0,84	0,70	0,57	0,46	0,35	0,24
Maranhão	1,49	1,39	1,20	0,99	0,83	0,68	0,53	0,38	0,26	0,16
Piauí	1,51	1,42	1,22	0,99	0,83	0,69	0,54	0,43	0,33	0,21
Ceará	1,68	1,56	1,40	1,20	1,06	0,92	0,78	0,65	0,55	0,45
Rio Grande do Norte	1,55	1,45	1,29	1,09	0,95	0,81	0,68	0,59	0,47	0,36
Paraíba	1,39	1,33	1,19	1,00	0,86	0,74	0,62	0,54	0,44	0,33
Pernambuco	1,33	1,22	1,06	0,87	0,74	0,61	0,50	0,40	0,30	0,19
Alagoas	1,50	1,30	1,08	0,87	0,72	0,57	0,42	0,26	0,14	0,03
Sergipe	1,68	1,50	1,29	1,09	0,93	0,78	0,63	0,50	0,39	0,28
Bahia	1,40	1,30	1,11	0,90	0,74	0,60	0,48	0,38	0,27	0,16

Source: IBGE (2000), CEDEPLAR (2007)

Population and migration estimates: the integrated model

Table 3 summarizes the results of the projected migration for the A2 and B2 scenarios. In both scenarios, the effects of climate change on migration in the Northeast during 2025-2030 can be described as marginal (0,03% in the A2 scenario and -0,01% in the B2 scenario). This represents a volume of migration induced by climate change of, respectively, 17.752 individuals in-migrating to the Northeast, and 6.026 out-migrating from the Northeast. While the direction of these results is contrary to our expectations, the low values indicate a potential null impact of the A2 and B2 scenarios in 2025-2030.

Table 3 – Net Migration (NM), Net Migration Rate (NMR) and Total Population by Scenario (Baseline, A2 and B2) – Brazilian Northeast Region, 2025-2030, 2035-2040 and 2045-2050.

Scenario	Net Migration			Net Migration Rate (%)			Total Population / Projected		
	2025-2030	2035-2040	2045-2050	2025-2030	2035-2040	2045-2050	2025-2030	2035-2040	2045-2050
Baseline	-192513	-203925	-208781	-0,29	-0,29	-0,29	65339961	68559267	70349764
A2	17752	-246777	-236065	0,03	-0,36	-0,34	65357713	68312491	70113699
B2	-6026	-13565	-20603	-0,01	-0,02	-0,03	65333935	68545703	70329161

Following the trend estimated for 2025-2030, the scenario B2 is associated with only marginal impacts on migration also for the years 2035-2040 and 2045-2050, with NMRs of -0,02% and -0,03%, respectively. It can be suggested that the impact of the B2 scenario on the agricultural sector is not strong enough to drive significant population migration.

On the other hand, the A2 scenario not only presents stronger impacts on the agricultural sector when compared to the B2 scenario, but it is also the one which presents the most distinctive impacts on Brazil as a whole. According to the results for 2025-2030, by affecting more intensely the agricultural sector in the South and Southeast regions (these results are not presented here), the A2 scenario might reduce the trend of out-migration from the Northeast. For example, the B2 scenario is less severe in Minas Gerais and Espírito Santo (two states in the Southeast which border the southernmost states of the Northeast region) than in the A2 scenario.

Overall, the A2 scenario engenders much more significant impacts on migration in the Northeast in 2035-2040 and 2045-2050. The projected migration is even higher than the one projected by the baseline demographic model. The integrated model suggests a NMR of -0.36% in the period 2035-2040, which represents the out-migration of 246.777 individuals, and -0.34% and 236.065 individuals in 2045-2050, respectively. The net migration is 21% higher than the baseline demographic model in 2035-2040 (-0.29%), and 13% higher in 2045-2050. Also, it is 18 times the net migration projected by the B2 scenario in 2035-2040, and 11 times in 2045-2050.

Table 4 shows the projected A2 and B2 scenarios of NM and NMR for 2025-2030, 2035-2040 and 2045-2050, for Metropolitan Areas (MAs) and clusters of municipalities according to size. As suggested by the overall trend in Table 3, the results are marginal in both scenarios in 2025-2030 except for significant and negative NMRs for the MAs of São Luís, João Pessoa (A2 and B2), Teresina and Salvador (B2). In the following years for the B2 scenario, the NMRs are also marginal except for the MAs of São Luís, João Pessoa, Salvador, and Teresina.

The A2 scenario shows consistently negative and significant NMs and NMRs in 2035-2040 and 2045-205 (except for the MA of Aracaju). The higher NM occurs in the MAs of Recife and João Pessoa. The MA of São Luís, probably due to its proximity to the Amazon (which will probably gain population in the future A2 scenario) also shows high negative NMR, both in the A2 and in the B2 scenarios as discussed above. The MA of Salvador and Teresina will also have significant loss of population through out-migration.

The municipalities over 150,000 inhabitants will probably experience significant NMs and NMRs in the A2 scenario in the three periods of analysis, with higher intensity in 2035-2040 and 2045-2050 (with NMRs above the Northeast average in the period of analysis). On the other hand, municipalities between 70,000 and 150,000 inhabitants in the A2 scenario, and municipalities between 25,000 and 70,000 inhabitants in the A2 and B2 scenarios, will have small positive NMRs in 2025-2030. However, the trend is the same as in the larger municipalities, with negative NMRs in the last two periods of analysis. Finally, the municipalities with less than 25,000 inhabitants also show a trend of negative NMRs in the last two periods, scenario A2.

Table 4 – Net Migration (NM) and Net Migration Rate (NMR) for Metropolitan Areas (MAs) and Municipalities According to Size in the Brazilian Northeast Region – Scenarios A2 and B2, Years 2025-2030, 2035-2040 and 2045-2050

Metropolitam Areas (Mas) and Municipalities	**2025-2030**				**2035-2040**				**2045-2050**			
	A2		**B2**		**A2**		**B2**		**A2**		**B2**	
	NM	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**	**NM**	**NMR (%)**
MA of São Luís	-1167	-0,06	-5169	-0,26	-9529	-0,42	-5958	-0,27	-5492	-0,23	-6849	-0,28
MA of Fortaleza	547	0,01	-131	0,00	-9462	-0,21	-343	-0,01	-7576	-0,16	-697	-0,01
MA of Natal	541	0,02	366	0,02	-5782	-0,22	526	0,02	-7262	-0,24	715	0,02
MA of João Pessoa	-1387	-0,08	-1445	-0,08	-13728	-0,68	-1780	-0,09	-16948	-0,75	-2223	-0,10
MA of Recife	123	0,00	8	0,00	-47518	-0,99	61	0,00	-53005	-1,10	131	0,00
MA of Maceió	436	0,02	74	0,00	-2236	-0,11	77	0,00	-2388	-0,11	81	0,00
MA of Aracajú	495	0,04	237	0,02	-406	-0,03	447	0,03	54	0,00	732	0,04
MA of Salvador	-1286	-0,03	-4021	-0,08	-12321	-0,24	-4877	-0,10	-10561	-0,21	-5869	-0,12
Teresina	-422	-0,04	-1246	-0,12	-5824	-0,59	-1236	-0,13	-4731	-0,58	-1120	-0,14
More than 250.000 inhab.*	-101	-0,01	-838	-0,04	-8355	-0,44	-869	-0,05	-7448	-0,40	-894	-0,05
Between 150.000 and 250.000 inhab.**	320	0,01	-883	-0,04	-17061	-0,67	-826	-0,03	-19862	-0,77	-788	-0,03
Between 70,000 and 150,000 inhab.***	3038	0,07	-647	-0,01	-10987	-0,22	-21	0,00	-7239	-0,13	-1435	-0,03
Between 25.000 and 70.000 inhab.***	7490	0,05	7490	0,05	-49907	-0,34	1124	0,01	-45612	-0,32	-2364	-0,02
Less than 25.000 inhab.***	9124	0,05	178	0,00	-53661	-0,29	110	0,00	-47995	-0,25	-22	0,00
Total - Norteast Region	*17752*	*0,03*	*-6026*	*-0,01*	*-246777*	*-0,36*	*-13565*	*-0,02*	*-236065*	*-0,34*	*-20603*	*-0,03*

* Except the state capitals and the municipalities in the MAs. Include the municipalities of Campina Grande, Caruarú, Feira de Santana and Vitória da Conquista.
** Except the state capitals and the municipalities in the MAs. Include the municipalities of Imperatriz, Juazeiro, Sobral, Petrolina, Arapiraca, Ilhéus, Itabuna and Juazeiro.
*** Except the state capitals and the municipalities in the MAs

Population redistribution as a consequence of migration induced by climate change: an analysis by municipalities

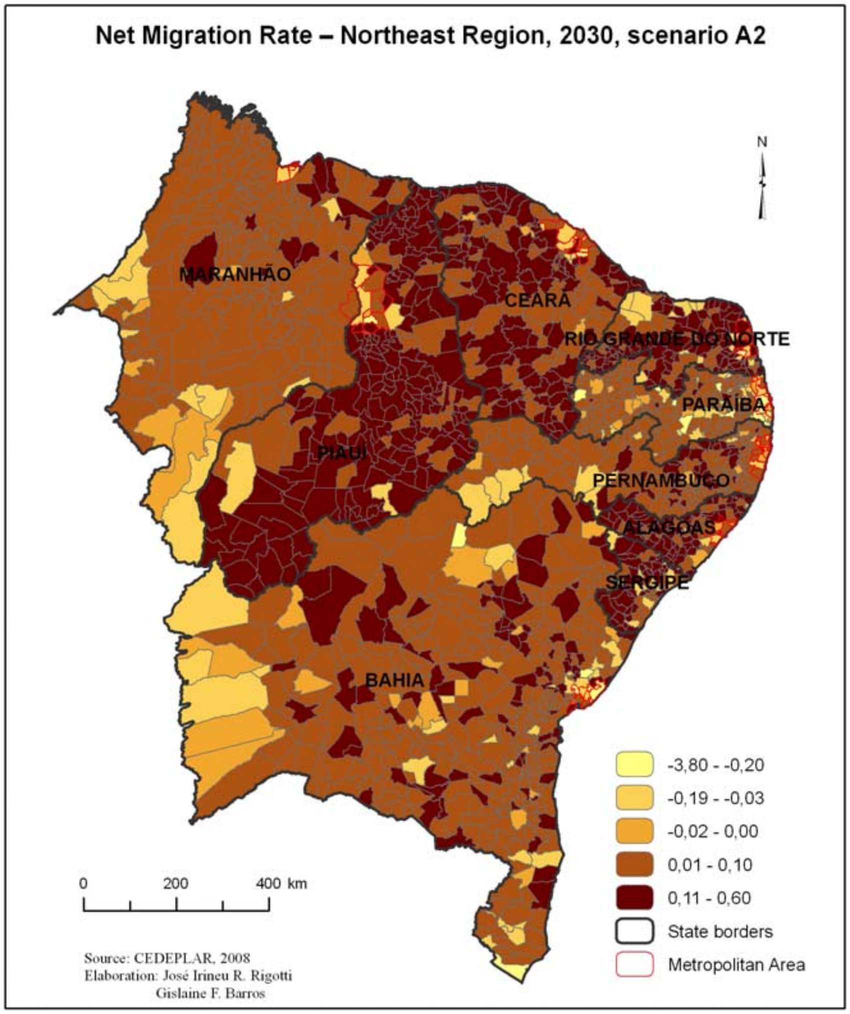
This section focuses on the impacts of the A2 scenario on population migration in the Brazilian Northeast Region at the local level. As mentioned before, this scenario presents much stronger impacts on migration as compared to the B2 scenario. Maps 2 and 3 show, respectively, the NMR for 2025-2030 and 2045-2050, in the A2 scenario.

Regarding the period 2025-2030, the maps show that most of the municipalities present very low positive net migration (below 650 migrants). Given the strong linkages in the integrated model between migration and performance of the agricultural sector, it can be seen that the highest negative impacts of the A2 scenario occur in areas with a strong agricultural sector. In this sense, clusters of municipalities with negative net migration are found in Western Bahia and Southern Maranhão – the most recent agricultural frontiers in the Northeast Region – as well as in areas along the São Francisco River (central Bahia), plus Southwest Pernambuco and Western Maranhão. Overall, and as expected, the NMRs follow the signal of the NMs.

Regarding the period 2045-2050, the integrated model shows a predominant trend of out-migration from the Northeast, with the exception of (and at low positive NMRs) the Southern part of the region, east and center west Bahia and some municipalities in Maranhão, Ceará, Rio Grande do Norte and Sergipe. The highest negative NMRs occur in most of the central part of the Northeast region (the core of the semi-arid area in the study area, particularly Pernambuco and Paraíba), and in the states of Ceará, Piauí and Maranhão. These results are particularly strong for the state of Piauí, the poorest in the Northeast and characterized by the predominance of smaller municipalities. This is also mostly explained by the weight of the agricultural sector in the state (10.3% of the GIP, against 8.4% for the Northeast region).

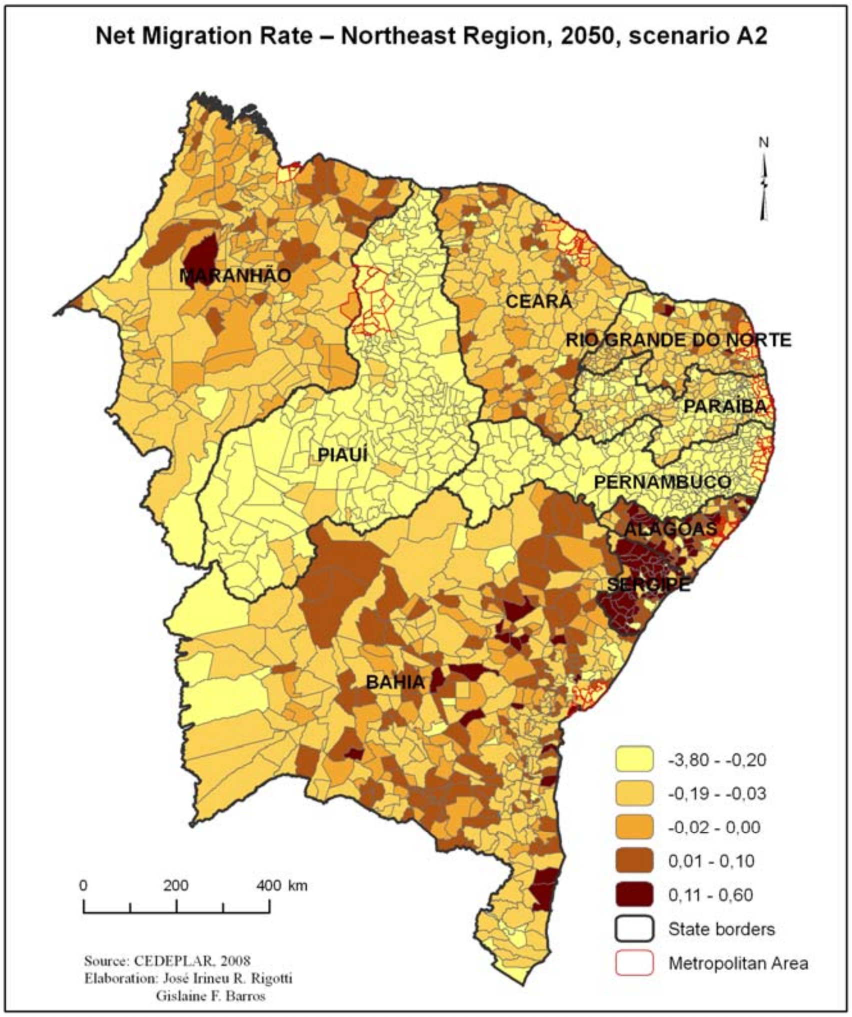
Finally, and corroborating the discussion on Table 4 above, the municipalities within the MAs show negative NM and NMRs in 2045-2050, except for some cases in the MAs of Maceió and Aracajú.

Map 2



Net Migration Rate – Northeast Region, 2030, scenario A2
N
MARANHÃO
CEARÁ
RIO GRANDE DO NORTE
PARAÍBA
PIAUÍ
PERNAMBUCO
ALAGOAS
SERGIPE
BAHIA
-3,80 - -0,20
-0,19 - -0,03
-0,02 - 0,00
0,01 - 0,10
0,11 - 0,60
State borders
Metropolitan Area
0
200
400 km
Source: CEDEPLAR, 2008
Elaboration: José Irineu R. Rigotti
Gislaine F. Barros

Map 3



Net Migration Rate – Northeast Region, 2050, scenario A2
N
MARANHÃO
CEARÁ
RIO GRANDE DO NORTE
PARAÍBA
PIAUÍ
PERNAMBUCO
ALAGOAS
SERGIPE
BAHIA
-3,80 - -0,20
-0,19 - -0,03
-0,02 - 0,00
0,01 - 0,10
0,11 - 0,60
State borders
Metropolitan Area
0
200
400 km
Source: CEDEPLAR, 2008
Elaboration: José Irineu R. Rigotti
Gislaine F. Barros

CONCLUSIONS AND POLICY IMPLICATIONS

This paper investigates the long-term relationship between climate change and population migration. The main hypothesis is that climate changes motivate population migration in some circumstances, particularly when adaptation mechanisms fail, by affecting production and productivity in various economic sectors (agriculture, in particular).

It can be suggested from the results that population may adapt to changes in the environment, being the individual ability to move across space a key mechanism of adaptation. Based on the A2 and B2 scenarios for the Brazilian Northeast Region until 2050, this paper aims to delineate the main mechanisms through which climate changes may impact population redistribution and consequently socioeconomic vulnerability. In this sense, it is much more important to understand how potential *trends* may qualify the construction of future socioeconomic and demographic scenarios, than to *quantify* population migration, even recognizing the importance of the quantitative estimations (especially within a range, such as A2 and B2 scenarios) for policy and planning actions regarding adaptation.

Regarding the latter issue, the identification of vulnerable populations should be a key target for the elaboration of policies and planning focused on adaptation. This argument is based on two assumptions: a) the allocation of human activities is related to climate changes, and b) the identification of most vulnerable groups in important in determining the magnitude of the impact and the adaptive capacity to climate changes. In this vein, the identification of groups of migrants may be an important aspect in the detection of specific vulnerabilities among population groups.

The economic impacts estimated in the integrated model resulting from climate change, particularly in the agricultural sector, redefine the territory by creating employment and income conditions which affect not only the redistribution of economic activities, but also of the entire population (active or not in the labor market). This, in turn, may generate the production of new vulnerabilities or reproduction of existing vulnerabilities across the territory. In this sense, the impacts on the agricultural sector in the Brazilian Northeast play a role in redefining the territory in its economic and demographic dimensions, being this effect stronger in regions characterized by tighter links between agriculture and other economic sectors.

Thus, failures in adaptation mechanisms may bring about higher population vulnerability, especially when associated to migrant populations of lower socioeconomic status. On the other hand, the "migration response" cannot be considered only as a mechanism of adaptation of the poorest or less favored in any social or economic dimension. It may also be a mechanism available for those with sufficient resources or types of capital (social, financial) to move out of an area of risk, which may not be an option for the poorest in some circumstances. For example, in the case of Hurricane Mitch in Central America in the 1990s, the most vulnerable portion of the population was the less able to change residence from risk areas before or even after the disaster (in the last case, with rampant morbidity) (Martine and Guzmán, 2002).

Finally, it must be mentioned that the modeling approach in this paper is far from comprehensive in terms of the identification and understanding of the linkages between factors affecting future scenarios of population redistribution and vulnerability. In the construction of future scenarios, many factors should be taken into account, related to the adaptive capacity and potential population vulnerability. Such factors include demographic and economic aspects, land use, water supply, energy production, and the role of institutions, among others. On the other hand, it can be claimed as strength of this paper the identification and understanding of the key linkages between critical demographic and economic determinants of population redistribution and vulnerability, and how they are affected by climate change.

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