Estimating the impacts of climate change on Brazilian regions[1]

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Introduction

The climate changes brought by global warming are a social problem of utmost importance to Brazil. The notion that these are "issues to be addressed by the rich countries" – because they caused these issues and therefore they must solve them – is an inaccurate rendition of the principle of common but differentiated responsibility enshrined in the UN Convention on Climate Change. It is increasingly improbable that its impacts can be avoided simply through mitigation efforts by the richest nations since the annual emissions by some developing countries such as China, India and Brazil are now higher than those of several developed economies (in absolute terms, but not on a per capita basis).

Global warming is an issue that will primarily affect the poorest (and therefore most vulnerable) populations, and there is just very little time to opt for inaction. The economic aspect of this problem is discussed in this study.

The two latest reports by the IPCC (2001 and 2007) and many other recent scientific papers state that climate change is an unequivocal fact and is primarily caused by man. A number of scientific and climate modelling breakthroughs have taken place since 2001 that have made it possible to adjust estimates on an ongoing basis. IPCC's Fourth Assessment Report (AR4, 2007) provides an extreme variation between 1.1°C and 6.4°C (4°C on average) by the end of the 21st century, using the 1990 average as a reference. In addition to temperature increases, changes are expected in rainfall patterns, although these projections are more difficult and remain extremely uncertain.

Because there is increasing agreement today that the increase in greenhouse gas (GHG) concentrations is mainly due to man's actions, the rich world is mostly liable for the problem to start with, which is further compounded by the fact that these very GHG emissions have stoked economic growth in the rich world. It is therefore fair that the developing nations, too, have the opportunity to make use of per capita emissions at the same levels as the developed

[1] This paper emphasizes the economic aspects of the multidisciplinary study "The Economy of Climate Change in Brazil", which was supportes by the British Embassy to Brazil, Fapesp – Fundação de Amparo à Pesquisa do Estado de São Paulo, and CNPq – Conselho Nacional de Pesquisas. That study was coordinated by Jacques Marcovitch (FEA/USP), Sergio Margulis (World Bank) and Carolina Burle Schmidt Dubeux (COPPE/UFRJ). The principal authors of the related parts of the original study are Alexandre Szklo (COPPE/UFRJ), Eduardo Assad (EMBRAPA), Eneas Salati (FBDS), Hilton Pinto (UNICAMP), José Feres (IPEA), José Marengo (CCST/INPE), and Roberto Schaeffer (COPPE/UFRJ). For more information, visit www.economiadoclima.org.br.

world. The challenge is precisely resolving this 'unfair' equation: ensuring that developing countries have the equitable right to growth without increasing GHG concentrations in the atmosphere.

Hence, it is critical and urgent that all countries seek a consensus that is not only technically and politically feasible, but also equitable. However, economic studies that support the decision-making process at domestic and international levels are necessary. Therefore, this is the primary objective of this study.

The purpose of this study is to conduct an economic assessment of the impacts of climate change in Brazil. Considering the various scenarios for this phenomenon, Brazil's main economic and social vulnerabilities are identified. A fundamental issue discussed here is the extent to which global warming has an influence on the Country's development agenda, given that Brazil has large areas covered by forests and the agriculture sector contributes a significant share to the GDP and exports.

Integrated Economic Assessment

The regional climate models point to a risk of "savannisation" of a sizeable portion of the Amazon, more intense and frequent droughts in the North East region, heavy rainfalls and floods in coastal and urban areas in the South East and South regions, and significant reductions in the hydropower generation potential in the North, Mid-West and North East regions. This is, however, just a part of the problem. Countless uncertainties are involved in the modelling of the impacts of climate change, especially when the 20-50 year planning timeframe is extrapolated.

Economic assessment of climate changes and the policies to address them depend on information that is not yet available. The uncertainty associated to the science of climate and climate projections has a substantial influence on economic analyses and the policy-making process. This uncertainly, however, should not be a reason for inaction; rather, it should be the opposite: it simply increases the cost of inaction.

The great methodological challenge in this study is to establish a link between future climate projections and business sectors and several environmental and socio-economic features at local and regional levels. Additionally, a level of aggregation or disaggregation of analyses that makes this study relevant and a faithful reflection of the 'local' reality at a minimum must be established, and it must also be feasible from the perspective of information and data handling. This is a critical issue in a study that involves a myriad of industries with very diverging natures. Hence, this study attempts to reconcile the macroeconomic perspective (which supposedly integrates sector-specific analyses in an aggregate fashion) with an industry – or microeconomic – perspective. Sector-specific studies seek to include climate variables and analyse their economic effects on the individual sectors, while at national level a macroeconomic model brings together cross-sector analyses and climate variables.

From the economic point of view, analysing the implications of global warming in any given country involves two major issues. The first issue refers to the difficulty in valuing economic losses. Using agriculture as an example, based on a specific climate change scenario in a given region, it is necessary to uncover the implications of these changes on agricultural production in this region. Based on these, it is possible to design adaptation measures – such as irrigation and development of adapted varieties – or even more extreme strategies, such as crop rotation or discontinuation of farming and introduction of livestock. The difficulty obviously lies in establishing the relationship between a specific climate change and its effect on agricultural production – a task that involves a combination of agricultural science, economics, and evaluation of requirements such as local and external markets, competitiveness, current production systems, etc.

Climate Scenarios in Brazil

The task of building future climate scenarios in Brazil was performed by the National Institute for Space Research (INPE) in 2007. The analyses of economic impacts discussed in the next few sections are based on these climate projections, which reflect high and low global greenhouse gas emission scenarios – A2-BR and B2-BR, respectively –, which in turn are based on global projections by the IPCC (2007).

Climate models. This study used HadRM3P from the Hadley Centre's regional climate modelling system3 PRECIS (Providing Regional Climates for Impact Studies), which has a horizontal resolution of 50 km with nineteen vertical levels (30 km up the stratosphere from the surface) and four ground levels. For future climate scenario downscaling, a global climate model was used – HadAM3P –, which was chosen because it was the only one that provided the required frequency in 2007 (outputs once every six hours) and because it was a satisfactory representation of the present climate.

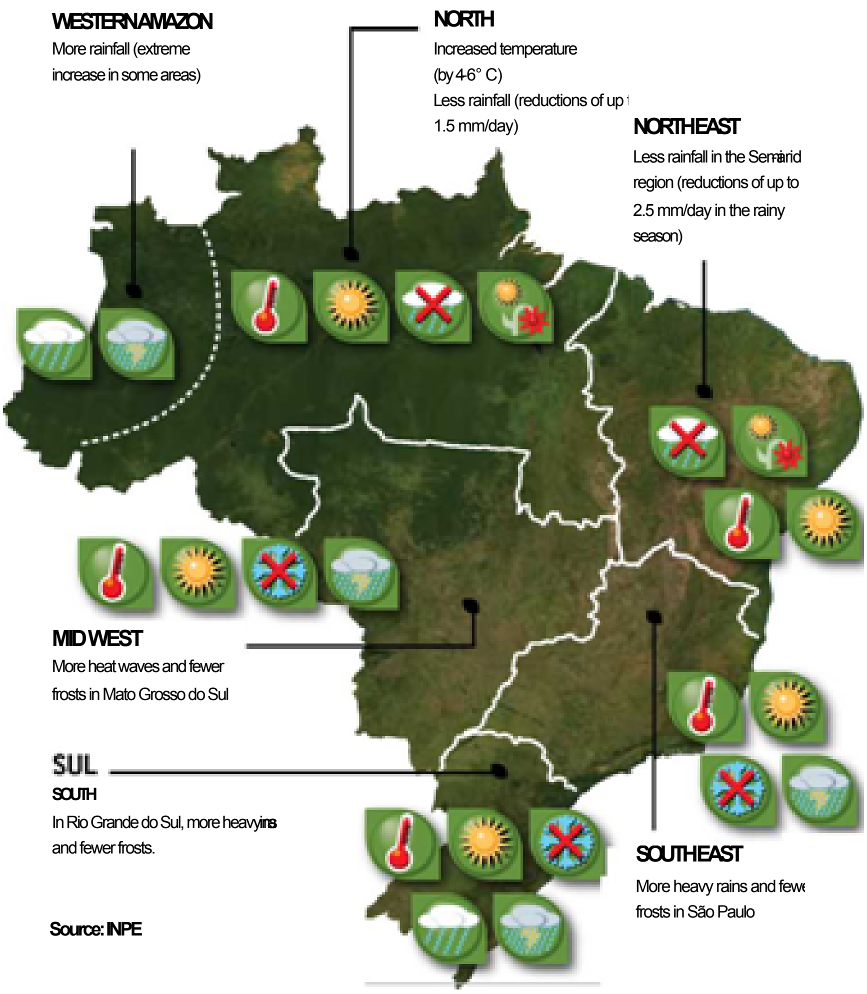
Integrations of the regional model were initially conducted in order to obtain the model's climatology for the current climate (1961-1990) and then future climate projections (2071-2100) for the A2-BR climate scenario (high greenhouse gas emissions, or GHG) and the B2-BR scenario (low GHG emissions). To obtain the values for periods 2010-2040 and 2041-70, a grid-based, point-to-point simple linear regression was used considering the current climate and future projections for the regional model HadRM3P as a dependent variable, and for the global model HadCM3 as an independent variable.

Climate variables. Out of the nearly 300 climate variables generated through the regional model HadRM3P, the following (main) variables were used by the various work groups participating in this study, for whom the following future values were available on a daily basis: temperature (average, maximum and minimum) of air close to the surface; rainfall levels; radiation flows (solar and long-wave, from the Earth surface); components of the energy balance (liquid radiation, sensible and latent heat); wind velocity close to the surface; and atmospheric humidity (relative and specific humidity).

Future rainfall and temperature projections. The Amazon and the North East region are notably considered to be the most vulnerable areas. Average warming can reach 5°C in 2100 under the A2-BR scenario, and 3°C according to the B2-BR scenario, although in the Amazon progressive warming can reach 7-8°C or 4-6°C in 2100, respectively. Rainfalls are likely to decrease during the 21st century, the most substantial reductions taking place in the North East region (2-2,5 mm/day) and the Amazon (1-1,5 mm/day). For Brazil as a whole, the projections show increased temperatures and bouts of heat, as well as less frequent frosts due to an increase in the minimum temperature, especially in the states situated in the South East, South and Mid-West regions (Figure 1).

The level of uncertainty is still significant. It is important to enhance and create new tools to look at the impacts in Brazil in detail, thus providing a scientific basis for the decision-making process on vulnerable regions and critical environmental conservation processes. Analyses that include responses by ecosystems to global climate forcings and to the dynamic flow of changes caused by human settlements are necessary, and also that point to the factors that cause the most relevant impacts.

Figure 1. CHANGES IN BRAZIL: Climate projections by region in 2100



Sectoral Impacts

The key question that runs through the subsections in this section is: "Given the climate change projections, what should we expect in terms of economic, social and environmental impacts?" From this question derive the sector-specific analyses and models that link temperature and rainfall variations to specific changes in the various economic sectors (sometimes called 'dose-response' relations). Topics covered include: water resources; agricultural production; land use patterns; and the energy sector.

Water Resources. Methods were established to calculate potential evapotranspiration and the water balance for the Brazilian territory. The water balance was calculated in a spatialised and geo-referenced fashion, according to a geographical information system with a space resolution of 0.5^o x 0.5^o (latitude/longitude) (50 km x 50 km, or 2,500 km2), based on monthly long-term climate averages. Selection of the best method for each hydrographic region was based on a comparison of the water balance results and estimated long-term runoff, rainfall levels and evapotranspiration as measured by the ANA. The actual evapotranspiration/rainfall ratio was used to compare the modelled water balance and the actual water balance for the various regions. To simulate the water balance for the current climate, data were used from the CRU05 database, which is considered a climate standard for the period 1961-1990. Two methods to calculate potential evapotranspiration (PET) were tested: Thornthwaite and Camargo. Estimates were adapted to drier and more humid climates by using maximum and minimum temperature data (Camargo et al. 1999).

The results are alarming for some river basins, especially in the North East region. In the Eastern parts of the North East and the East Atlantic basins, a sudden reduction in flows is estimated by 2100 for both scenarios, and the resulting values are close to zero. For the São Francisco river basin, a decrease in flows is expected for the period 2011-2040, and a minor increase is likely for the period 2041-2100. For the basins in the South Atlantic and Uruguay, the result is a minor trend towards increased flows by 2100. Flows for the South East Atlantic basin show a trend of minor decrease by 2100 under scenario B2-BR, and remain virtually unchanged under scenario A2-BR.

In view of the various uncertainties involved and the variable plus/minus sign from climate models (increase/decrease in regional rainfall levels), further comparisons were drawn between the potential effects of global climate changes in water surpluses, which are calculated through the Thornthwaite-Mather method for eight hydrographic regions in Brazil. The results reveal the discrepancies in the projections of various global climate models and their implications in terms of water surpluses. It is particularly important to highlight the least dramatic projections of declines in the North East region – for example, the average provided by all other models for the River Parnaíba anticipates a 56-percent surplus by 2100, differently from the 14-percent surplus predicted by the Hadley Centre model, which is used here (scenario B2-BR). The figures for the Western Atlantic North East are 86% and 59%. In the case of the Paraguay and Paraná river basins, projections have opposite directions: a 40-percent surplus instead of 147% (Paraguay river basin) and 47% instead of 110% (Paraná river basin; both under scenario A2-BR by 2100).

With regard to the variability in underground water supply, the study revealed that, considering only rainfall variations for scenarios A2-BR and B2-BR, the runoff for the Amazon, South Atlantic, South East Atlantic, Uruguay, Paraná, and Paraguay river basins should be maintained or even expanded. All other river basins should run into a deficit.

Table 1. RIVER BASINS: Comparison of results from the average provided by 15 alternative climate models and HadRM3P with relation to runoff surpluses during the period 1961-1990

RIVER BASINS	1961 to 1990	Averages of Models 2° x 2°lat/ton						HadRm3P 50 km x 50 km					
		Scenario B2-BR			Scenario A2-BR			Scenario B2-BR			Scenario A2-BR		
		2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
River Tocantins	100%	83%	77%	73%	84%	73%	63%	72%	67%	54%	73%	55%	47%
River Amazonas	100%	88%	82%	80%	89%	80%	73%	93%	84%	75%	93%	73%	70%
River Paraguay	100%	68%	60%	59%	73%	54%	40%	81%	91%	92%	90%	85%	147%
River Parnaiba	100%	69%	59%	56%	70%	54%	47%	32%	19%	14%	34%	13%	10%
River São Francisco	100%	73%	57%	43%	72%	46%	30%	38%	42%	47%	43%	45%	53%
NE Atlantic, West	100%	88%	87%	86%	92%	85%	80%	72%	62%	59%	71%	52%	47%
South Region	100%	95%	93%	92%	95%	90%	86%	111%	109%	116%	109%	101%	107%
River Paraná	100%	80%	74%	67 %	83%	67 %	47%	84%	84%	93%	94%	88%	110%

Energy Sector. Climate change has implications on energy production and consumption, especially on some renewable energy sources. In order to investigate the vulnerability of the Brazilian energy system, the potential impacts on hydropower generation, liquid biofuel production and the demand for air conditioning in the residential and service sectors by 2035 were analysed. The impacts on the wind potential and thermal power generation were also reviewed, but these are not as significant.

The main impact identified was a decline in the reliability of the hydropower system and substantial regional effects on hydropower generation in the North and North East regions. In general, although the average energy was maintained virtually constant under scenarios A2-BR and B2 BR, the firm energy plummeted – it dropped by 30%. When the data are disaggregated by river basin, the most severely affected basins are in the North East region (primarily) and North region, in terms of both average and firm energy. In fact, the average energy in the system is maintained solely due to the positive variation in the South and South East river basins, especially the Paraná river basin, which contributes a significant share to the national aggregate. The water balance results for the North East river basins are extremely negative. In the Parnaíba and East Atlantic river basins, the water surplus drops by over 80% in some sections of the projection, with a strong decline in energy production (Table 2).

Table 2. LESS ELECTRICITY IN 2100: firm energy declines in all river basins, especially in the North East and North regions

RIVER BASIN	VARIATION IN RELATION TO CLIMATE CHANGE-FREE SCENARIO			
	Scenario A2-BR		Scenario B2-BR	
	Firm Energy	Average Energy	Firm Energy	Average Energy
Amazonas	-36%	-11%	-29%	-7%
Tocantins/Araguaia	-46%	-27%	-41%	-21%
São Francisco	-69%	-45%	-77%	-52%
Parnaiba	-83%	-83%	-88%	-82%
East Atlantic	-82%	-80%	-82%	-80%
South East Atlantic	-32%	1%	-37%	-10%
South Atlantic	-26%	8%	-18%	11%
Uruguay	-30%	4%	-20%	9%
Paraguay	-38%	4%	-35%	-3%
Paraná	-8%	43%	-7%	37%
TOTAL	-31.5%	2.7%	-29.3%	1.1%

Agricultural Production. Impacts were assessed according to the methodology adopted by the Ministry of Agriculture and Agrarian Development's climate risk zoning programme which informs agricultural credit and insurance schemes. Zoning establishes levels of risk at regional level for several types of crops, with maximum harvest losses at 20%; it indicates which crops should be grown, where and when to grow them in accordance with the climate available in the region and three types of soils. The future climate scenarios were used in order to rearrange the allocation of crops in view of increased temperatures. The resulting increase in evapotranspiration and water deficit was also taken into account. In order to assess water supplies in the soil during the critical crop stages, the concept of WRSI (Water Requirement Satisfaction Index) was used, which was represented by the ratio of actual evapotranspiration to maximum evapotranspiration, which is typically around 0.60. Estimates were taken of variations in farming areas, the number of municipalities suitable for farming, production and economic figures associated to yield variations, all based on the 2007 official climate risk zoning. The models employed in this study link the impacts of expected climate changes in Brazil's agriculture, but they did not explicitly and comprehensively take into consideration the effects of climate extremes in agriculture and livestock. Therefore, they do not represent agricultural losses associated to the projection of more frequent heat waves, droughts, short summer droughts, heavy rains, humid spells, etc., which are known to be the main environmental cause of losses to the agricultural sector. In view of this, some positive impacts that occur primarily in the South region of Brazil could be mitigated or even become negative impacts if the effects of climate extremes were explicitly considered.

The analyses show that all crops will have negative results, except sugarcane and partly manioc. Rising temperatures are expected to cause low production risk areas to shrink, such as in the extreme case of soybeans, which under scenario A2-BR will have its suitable growing area reduced by 41% by 2070. Sugarcane, on the other hand, can experience an expansion of as much as 118% under the same scenario and timeframe. The greatest impacts will be on soybeans, maize and coffee crops. Maize, rice, beans, cotton, and sunflower crops should bear a significant impact in the North East *Agreste*, which currently accounts for the majority of the regional maize production, and in the North East *Cerrados*, i.e., south of Maranhão and Piauí and west of Bahia.

Land Use Patterns. The decision made by farmers as to how to use their lands does not depend solely on the phenology of plants and their response to climate change, but also on economic variables that lead to major regional differences in terms of adaptation strategies adopted by rural producers. For example, depending on the price of inputs in a typical soybean producing area whose yield undergoes a dramatic decline as a result of higher temperatures, it may make sense to use more fertilisers to offset the "phenological" effect over the crop. In specific terms, this section looks at the effects of climate change on cropping, pasture and forestry areas in Brazilian farms, based on a land use simulation model at municipal level.

Under the land use model used herein, the estimated parameters for the pasture, cropping and forestry equations are a tool to analyse how land allocations respond to changes to the several explanatory variables (product pricing, input pricing and agro-climatic factors). Based on these, one can simulate the impact of climate change on area variations.

Climate change could cause a 15-20% reduction in forest and wood areas situated on farms, which would give way to other uses depending on the scenario and timeframe considered. Conversion of forest areas shall take place primarily for livestock rearing, with pasture lands increasing by 7-11%.

Table 3. PROPERTIES WITH LESS FOREST COVER: Reduction ranges from 15% to 20% and paves the way to cattle raising

REGION	Scenario A2-BR								
	2010 - 2040			2040 - 2070			2070 - 2100		
	Cropping	Pasture	Forest	Cropping	Pasture	Forest	Cropping	Pasture	Forest
Brazil	**-1.7%**	+11.1%	**-17.1%**	+3.1%	+11.1%	**-19.36%**	+11.0%	+6.5%	**-15.4%**
North	**- 2.4%**	+17.7%	**-14.6%**	+17.9%	+16.7%	**-15.8%**	+44.1%	+10.4%	**-13.3%**
North East	**-27.6%**	+28.3%	**-17.9%**	**-18.9%**	+25.1%	**-18.7%**	+31.8%	+9.8%	**-27.2%**
South East	**-7.0%**	+4.9%	**-23.2%**	+11.1%	+5.9%	**-30.6%**	**-7.6%**	+9.6%	**-23.8%**
South	+27.9%	**-6.0%**	**-32.2%**	+30.4%	**-4.6%**	**-40.2%**	+33.4%	**-16.8%**	**-13.1%**
Mid West	**-6.4%**	+8.4%	**-14.2%**	**-7.1%**	+10.2%	**-17.4%**	**-12.0%**	+9.3%	**-14.7%**
REGION	Scenario B2-BR								
	2010 - 2040			2040 - 2070			270 - 2100		
	Cropping	Pasture	Forest	Cropping	Pasture	Forest	Cropping	Pasture	Forest
Brazil	+0.5%	+9.9%	**-16.2%**	+2.7%	+10.6%	**-18.2%**	**-3.0%**	+10.1%	**-15.0%**
North	+4.0%	+13.0%	**-11.3%**	+10.3%	+15.5%	**-14.0%**	24.9%	12.8%	**-13.3%**
North East	**-26.6%**	+25.5%	**-15.3%**	**-23.5%**	+25.1%	**-16.4%**	+12.6%	+14.1%	**-22.3%**
South East	+13.6%	+3.5%	**-25.2%**	+16.3%	+3.7%	**-28.6%**	**-20.3%**	+13.6%	**-24.0%**
South	+22.6%	**-2.7%**	**-31.8%**	+27.1%	**-1.7%**	**-42.1%**	+15.9%	**-8.6%**	**-4.7%**
Mid West	**-5.1%**	+8.0%	**-13.8%**	**-9.1%**	9.6%	**-15.9%**	**-15.2%**	+10.0%	**-15.3%**

NB percentage variations in relation to the present time

Special mention should be made of the positive variation in cropping and pasture lands in the North region; which points to increased deforestation pressure in the Amazon region; dramatic wood reduction and an increase in pasture lands in the North East region; significant enlargement of cropping areas to the detriment of pasture lands and forests in the Mid-West region; and increased pressure on the remaining forests in the South and South East regions.

In addition to the issue of changes to land use, an analysis was performed of the impacts of climate change on the average yield of seven crops: rice, sugarcane, beans, tobacco, maize, wheat, and soybeans. The results suggest that the North, North East, and Mid-West regions will be adversely affected by climate changes in terms of agricultural yield. In particular, the expected decline in yields of staple crops in the North East region (beans, rice and maize undergo declines of 20-30% according to scenario and timing) could have major socio-economic consequences since it has a direct impact on family farming.

Systemic Economic Effects

A spatial computable general equilibrium (SGCE) model was used to simulate two climate change-free scenarios regarding the future of Brazil's economy that are consistent with the global economic development trends under IPCC's scenarios A2 and B2, which in this study are called scenarios A2-BR and B2-BR, respectively. Climate shocks, i.e., unusual changes that generate impacts, that were projected by INPE for Brazil and captured by the model through impacts on water resources, the agricultural/livestock and energy sectors were applied to these scenarios. The socio-economic trends of the scenarios with and without global climate change were reviewed in terms of benefits and costs for Brazil and its regions.

The SCGE model interacts with the agricultural/livestock and energy sector studies through variables such as energy generation and consumption for different sectors and regions, replacement of sources of energy in the production process and consumption by the residential sector, agricultural yields and land use, etc. These, in turn, are dependent on climate variables, future water supply and other economic factors.

Development of the two socio-economic scenarios for Brazil relied on an integrated modelling system for the generation of temporal scenarios, with a SCGE model as its core model. Its overall objective is to specify and implement an integrated information system for macro-economic, sector-specific and regional projections, and the analysis of economic policies.

Once the baseline trends were defined (two scenarios with no global climate change), the next step was to establish deviations in relation to these trends caused by climate change. Inputs from other models that provide the shocks to be fed into the main model were: (i) changes to the allocation among cropping, pasture and forestry, by state (UF); (ii) changes to agricultural yields, by UF; and (iii) changes to Brazil's energy matrix.

Macroeconomic results. The climate change-free simulations show that Brazil's GDP grows by 4.20% per year between 2008 and 2035, and 3.77% during the period 2035-2050, under scenario A2-BR; and 4.24% and 3.95% under scenario B2-BR during the same timeframes.

Regarding the impacts of climate change on the economy, the simulations reveal a permanent loss for Brazil's GDP by 2050 of approximately 0.5% when the trends for A2-BR with and without climate change are compared, and about 2.3% between trends for B2-BR with and without climate change. Although B2-BR involves more significant losses than A2-BR, an important caveat must be made: in absolute terms, the Brazilian economy will have more benefits without and with climate change if the trend for B2-BR is followed, rather than the trend for A2-BR.

In order to calculate annual GDP losses that are accrued until 2050 at their present value, three different discount rates were used: 0.5%, 1% and 3% per year. Losses range between 13.6% and 147% of the GDP for 2008. Hence, if the costs from climate change in Brazil by 2050 were brought forward to today, at an intertemporal discount rate of 1.0% per year, for example, the cost in terms of the GDP would be between R$719 billion under A2-BR and R$3.655 trillion under B2-BR, which would account for 25-125% of the GDP for 2008.

Sectoral and regional results. The economic impacts of climate change are experienced in different ways across the business sectors, regions, states, and large cities. For example, agriculture is the business sector more directly sensitive to climate, with a permanent decline in production of 3.6% under A2-BR and 5.0% under B2-BR by 2050.

From the regional perspective, the greatest threat looms over the poorest regions in the country. It is fair to conclude that climate change exacerbates regional inequalities in Brazil. The most significant discrepancy can be found in the trend for A2-BR by comparing the effects of climate change in the South region (gains of 2%) to the effects in the Mid-West region (losses of 3%) in relation to the same scenario A2-BR without climate change. When the states are considered, the exceptions are the southern states, which will have milder temperatures and, therefore, will become more suitable for agriculture. All other states will incur dramatic losses. At the city level, the results show that the most substantial losses should be sustained away from the big cities. It should be pointed out that only GDP losses from the perspective of goods and services production were calculated; impacts of climate change on the urban infrastructure have yet to be incorporated.

Socio-economic results. With regard to welfare aspects, the average Brazilian would suffer losses of R$534 (US$291) under A2-BR in comparison to this scenario without climate change, or R$1,603 (US$874) under B2-BR against this scenario without climate change. The present value in 2008 of reductions in consumption accrued by 2050 would be between R$6,000 and R$18,000, thus accounting for 60% to 180% of the current annual per capita consumption.

Finally, as far as poverty is concerned, the results for the per capita GDP are consistent with the results for the GDP. A permanent loss of approximately 0.5% (A2-BR) and 2.3% (B2-BR) of the national per capita GDP by 2050 is calculated for the comparison with a climate change-free world. Interestingly, these tend to marginally increase poverty in Brazil.

Table 4. DETAILS OF THE IMPACT ON SOCIETY: effects by sector, region, state, networks of cities, and poverty level. Regional inequalities are exacerbated

COSTS OF CLIMATE CHANGEIN BRAZIL. AS A % OF GDP				
REGIONS AND STATES [1]	Scenario A2-BR		Scenario B2-BR	
	2035	2050	2035	2050
North	**- 0.7%**	**- 1.2%**	**- 2.1%**	**- 3.1%**
Rondônia	-0.9%	-1.7%	- 2.7%	- 4.1%
Acre	-0.2%	- 0.5%	- 1.5%	- 2.1%
Amazonas	-0.6%	-1.0%	- 2.3%	- 3.2%
Roraima	- 1.1%	-1.8%	- 2.6%	- 3.6%
Pará	-0.6%	-1.1%	- 1.7%	- 2.5%
Amapá	-0.1%	- 0.4%	- 2.0%	- 3.1%
Tocantins	-1.6%	-2.7%	- 2.8%	- 4.3%
North East	**- 1.0%**	**- 1.6%**	**- 2.1%**	**- 2.9%**
Maranhão	-3.8%	- 5.5%	- 5.0%	- 7.0%
Piauí	-0.8%	-1.3%	- 3.6%	- 5.5%
Ceará	-1.6%	-2.7%	- 3.5%	- 4.4%
Rio Grande do Norte	-0.8%	-1.4%	- 2.5%	- 3.6%
Paraíba	-1.6%	- 2.6%	- 2.7%	- 1.1%
Pernambuco	-0.8%	-1.4%	- 2.6%	- 4.1%
Alagoas	-6.2%	-8.2%	- 6.5%	- 7.6%
Sergipe	-0.5%	-1.0%	1.2%	1.7%
Bahia	0.2%	-0.1%	- 0.3%	- 0.7%
South East	**- 0.3%**	**- 0.6%**	**- 1.5%**	**- 2.4%**
Minas Gerais	-0.5%	-1.0%	- 1.7%	- 2.7%
Espírito Santo	-2.4%	- 3.6%	- 3.0%	- 4.5%
Rio de Janeiro	0.2%	0.1%	- 0.9%	- 1.4%
São Paulo	-0.3%	- 0.5%	- 1.6%	- 2.5%
South	**1.3%**	**2.0%**	**0.0%**	**0.0%**
Paraná	1.8%	2.9%	0.5%	0.8%
Santa Catarina	0.1%	0.2%	- 1.6%	- 2.5%
Rio Grande do Sul	1.5%	2.3%	0.4%	0.6%
Mid-West	**- 1.8%**	**- 3.0%**	**-3.0%**	**- 4.5%**
Mato Grosso do Sul	-2.1%	- 3.5%	- 3.3%	- 5.2%
Mato Grosso	-6.7%	- 9.9%	- 7.7%	- 11.1%
Goiás	-0.3%	-0.7%	- 1.8%	- 3.1%
Federal District	-0.1%	- 0.2%	- 1.2%	- 1.8%
SECTORS				
Livestock	- 1.7%	- 2.5%	- 2.9%	- 4.5%
Industry	-0.2%	- 0.3%	- 1.3%	- 2.0%
Services	-0.1%	- 0.4%	- 1.4%	- 2.1%
NETWORKS OF CITIES [2]				
Metropolitan areas	-0.1%	- 0.3%	- 1.3%	- 2.0%
Capital cities	-0.2%	- 0.4%	- 1.4%	- 2.1%
Small towns	-0.5%	- 0.8%	- 1.8%	- 2.6%
SOCIAL				
GDP/per capita [3]	-0.3%	- 0.5%	- 1.5%	- 2.3%
Poverty [4]	0.02%	0.02%	0.06%	0.06%

[1] In comparison with the respective GDPs that were projected without climate change.
[2] In percentage terms of the respective regional GDPs that were projected without climate change. Metropolitan areas: Manaus, Belém, Fortaleza, Recife, Salvador, Belo Horizonte, Rio de Janeiro, São Paulo, Curitiba, Porto Alegre; capital cities, microrregions of state capitals. **[3]** In comparison with the respective figures that were projected without climate change. **[4]** Annual average percentage variation for the period.

Conclusions

This study of economic impacts from climate change in Brazil, despite the limitations, shows that the problem is of great importance for the country's development agenda. Potential costs and risks are high and a burden to the poorer and more vulnerable brackets of the population above all, particularly in the North and North East region. In addition to this high social relevance, fighting climate change is both an opportunity and a requirement for public policies to be integrated.

The projections of climate change impacts on the Brazilian economy over the next 40 years suggest the possibility of associating ambitious growth targets with the reduction of greenhouse gases emissions. From a strictly economic perspective, it is about increasing the country's competiveness and ensuring wide access to markets that tend to favour low carbon emission goods and services.

Therefore, it is essential to ensure that the energy matrix continues to be 'clean' and that GDP growth also takes place in a 'clean' way. Based on the current conditions of the Brazilian economy, none of these factors would mean any restrictions for Brazil. Ambitious growth targets and growing in a 'clean' fashion are one of the main challenges for building the future.

Regional perspective. In regional terms, the main impact of climate change is the bigger threat to poorer regions in the country, intensifying regional inequalities. They increase the concentration of activity in these spaces and also reinforce social inequalities, increasing poverty. The reduction of well-being in rural areas may generate pressure on urban clusters, although there may be sectors and regions that benefit from the process. The biggest losses will probably take place in the interior areas of the country. The impacts of climate change on urban infrastructure require further studies. The areas most vulnerable to climate change in Brazil are the Amazon and the Northeast, which are exactly the poorest regions. In the Amazon, gradual warming may reach 7-8°C by 2100 in scenario A2-BR, meaning a radical change in the Amazon Forest – so called 'savannisation'. One of the key questions to be answered by scientists is: What are possible tipping points after which the savannisation process of the Amazon would be irreversible? Without a doubt this is one of the most relevant and complex issues related to climate change in Brazil and research is still in its initial stages.

In the case of the Northeast, rainfall levels tend to decrease during the 21st Century, at a rate of 2-2.5 mm/day. This will lead to agricultural losses in all states of the region and its concomitant change to livestock. With the advance of livestock, the future situation of the northeastern rural zone tends to deteriorate even more, as the dominant livestock practices show low yield levels. In this sense, it is necessary to better investigate the caatinga biome, in terms of expected impacts and its future support capacity.

Development and response capacity. The impacts of climate change are more intense in the long run than in the short term. Their effects in 2035 will reach a Brazil with a per capita income equivalent to South Korea today. By 2050, it will be a bit below Japan today. This suggests that the best 'remedy' for the problem would be to simply grow and develop, because with these income levels it would be possible to protect against the effect of climate change and at the same time reduce greenhouse gas emissions through technologies yet to be developed. In addition, the poorest would be less poor and thus, less vulnerable to the impact of climate change.

However, such thesis, which cannot be immediately discarded, does not take into consideration the uncertainties related to climate change and the risks of irreversible effects reaching catastrophic dimensions, threatening the survival of the planet itself, as well as humanity. Growth and development are indeed appropriate responses; the Netherlands for example, country extremely vulnerable to sea level rise, does not worry as much as Bangladesh in relation to the same problem, because its defence capabilities are much superior. However, response capacity and reliability have clear limits, regardless of national income levels. The devastation caused by Hurricane Katrina is a sad point in the history of the wealthiest country in the world, in theory with the best technology available and appropriate adaptation and defence infrastructure for facing natural disasters, which tend to become more intense with climate change.