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Integrated scenarios of regional development in Ceará and Piauí

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Abstract. Scenarios of the future are an important tool for supporting sustainability-oriented regional planning. To assist regional planning in two federal states in semi-arid Northeastern Brazil, Ceará and Piauí, we developed integrated qualitative-quantitative scenarios which show potential developments of the agricultural and water resources situation until the year 2025. In these states, regional development is negatively influenced by the high seasonality of rainfall and El-Niño-related drought years. Two reference scenarios, "Coastal Boom and Cash Crops" and "Decentralization — Integrated Rural Development" were generated by first creating the storylines and then quantifying the development of the driving forces. Then, an integrated model, which includes modules for simulating water availability, water demand and agricultural production and income, was applied to compute the temporal development of relevant system indicators in each of the 332 municipalities of Ceará and Piauí. These indicators include the fraction of the irrigation water demand than can be satisfied, the volume of water which is stored in the reservoirs at the beginning of the dry season, agricultural productivity and production as well a the internal migration among scenario regions. In addition, the impact of certain policy measures was assessed on the background of both reference scenarios. Reference and intervention scenarios were derived by an interdisciplinary group of scientists and were discussed and refined during policy workshops with planning agencies of Ceará.

1 Introduction

An aim of the WAVES program (http://www.usf.uni-kassel.de/waves) was to identify sustainable development paths for Ceará and Piauí, two states in the semi-arid Northeast of Brazil. In these states, regional development is negatively influenced by the high seasonality of rainfall and El-Niño-related drought years. The research focussed on the interrelation between climate variability, water availability, agriculture and quality of life, and it was geared towards supporting regional planning in the study area. For sustainability-oriented research and regional planning, scenarios are an important tool. Many of today's activities and decisions will have a significant impact in the quite distant future, and it is therefore necessary to get an idea about their impact if sustainability is to be achieved. The generation of scenarios helps to see how the uncertain future might unfold (Nakicenovic and Swart 2000) and how the future might be influenced by today's decisions. In our understanding, scenarios are consistent and plausible images of alternative futures.

Fig. 1 illustrates how regional planning for sustainable development is related to integrated systems analysis (which was also a WAVES research approach) and to scenario generation. On the one hand, the goal of sustainability requires a regional planning in which policy measures and projects are not only assessed with respect to financial and technological feasibility, but with respect to — ideally — all technological, ecological, economic and social aspects. Thus, an integrated analysis of the system of interest is needed. On the other hand, regional planning that takes into account inter-generational equity, a core idea of sustainability, needs to consider the (long-term) future and is thus supported by the generation of scenarios. Scenarios show different possibilities of how the future might look like. A scenario neither predicts the future nor should it be qualified by a probability. Scenarios should be just images of possible futures that rich enough to help decision making. Preferably, they do not represent a the situation at a certain point in time but the dynamic development of the system. Regional scenarios also show the consequences of larger-scale (global, continental, national) developments for the region.

The robustness of a certain policy can be tested by assessing its impact in different possible future situations (Fig. 1). Thus, scenarios can help to demonstrate what impact regional planning might have. Scenarios are always integrated to some extent as it is not possible to derive images or stories of the future that do not include demographic, economic and technological aspects. Obviously, the planning (or research) aim and scope will determine which parts of the image, i.e. which aspects and processes, are refined and which are only considered in a coarse manner. In general, scenario building is based on an integrated systems analysis. Both integrated systems analysis and scenario building require, and thus encourage, interdisciplinary communication (Minx et al. 1993).

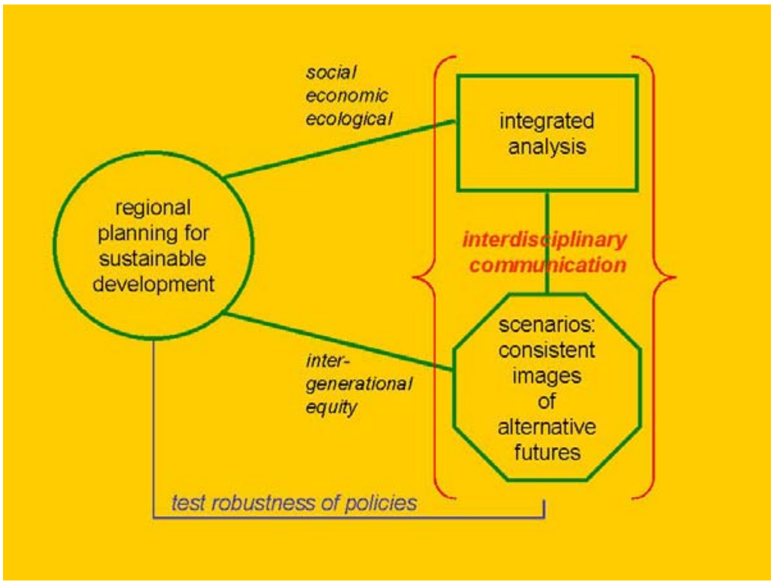

Fig. 1. Relationship between regional planning for sustainable development, integrated analysis and scenarios.

In the WAVES program, integrated analysis was mainly achieved by two integrated models (at two different spatial scales) which combined various newly developed disciplinary models. Scenarios for Ceará and Piauí were generated by a multidisciplinary Scenario Group, which experienced that scenario development is a means for integration and interdisciplinary communication. In order to improve the relevance of the developed scenarios for regional planning, three scenario workshops with the regional planning authorities of Ceará were organized during the last year of the WAVES program. In these workshops, policy options for reducing vulnerability to drought were discussed as well as the plausibility of the scenario assumptions (compare section 3). In addition, interesting policy measures (interventions) were defined, the impacts of which were then assessed by applying simulation models (compare section 4).

This paper is organized as follows. In the next section, the methodology to derive qualitative-quantitative scenarios is described. In section 3, the two reference scenarios that were derived within the WAVES program are presented, including the storylines, the quantification of the driving forces and the modeled system indicators. The impact of selected policy measures is assessed in section 4. In section 5, conclusions are drawn with respect to scenario development in general and to the situation in Ceará and Piauí until 2025. Finally, recommendations for an improved integration of scenarios into regional planning are given.

2 Methodology to derive qualitative-quantitative scenarios

Scenarios can be qualitative (pure narratives of alternative futures), quantitative (only numerical output) or a combination of both. In two recent global scenario building efforts, the global greenhouse gas emissions scenarios of the Intergovernmental Panel on Climate Change (Nakicenovic and Swart 2000) and the World Water Vision scenarios (Cosgrove and Rijsberman 2000), qualitative-quantitative approaches were taken. In WAVES, we adapted these approaches and derived qualitative-quantitative scenarios in which qualitative knowledge and ideas are combined with quantitative mathematical modeling. The methodology to derive qualitative-quantitative scenarios encompasses the following steps:

1. Identification of problem field
2. System definition including driving forces as well as temporal and spatial resolution and extent (base year, time horizon and time step, scenario regions)
3. Definition of indicators of the system state (in practice related to the mathematical models that are available to compute the indicators)
4. Generation of qualitative reference scenarios (storylines)
5. Generation of quantitative reference scenarios
   a) Quantification of the driving forces
   b) Computation of the indicators using mathematical models
6. Generation of intervention scenarios
   a) Modification of selected driving forces or parameters of reference scenarios
   b) Computation of the indicators using mathematical models
7. Evaluation of the scenarios

Ideally, scenarios are derived by an interdisciplinary group of scientists, policy makers and stakeholders. Döll et al. (2001) describe the scenario building methodology in more detail and show in an exemplary fashion how the methodology was applied in the WAVES program to derive reference and intervention scenarios for Ceará and Piauí. In this paper, we concentrate on steps 4 to 6.

A storyline is the narrative description of a scenario where an image of a future is created by considering the behavior of the main driving forces of the system (step 4). Reference scenarios describe futures without any specific policy measures. (Implicitly, however, they necessarily reflect certain policies that are part of the respective futures.) They serve as the baselines to assess the impact of policy measures on the future state of the system. It is recommended to produce two or four reference scenarios with quite distinct storylines. With three reference scenarios, there is the tendency to adopt the "intermediate" scenario as the "the most probable", while the others are not given full consideration (Alcamo 2001). Intervention scenarios are defined in order to assess the impact of a certain intervention on the future situation. “Baseline scenario” and “policy scenario” are synonyms for “reference scenario” and “intervention scenario”, respectively.

Once the storylines have been written, the driving forces of the reference scenarios must be quantified (step 5). Here, we define driving forces as those scenario variables that cannot be computed by the applied models but are needed as model input. Both the quantified driving forces and the computed model variables (indicators) are part of the quantitative scenario. In order to make assumptions about the future development of certain driving forces, their historical development is first analyzed. Then, numerical values of the driving forces that reflect the respective qualitative scenario are defined for future times. Care must be taken to quantify driving forces that are known to be correlated in a consistent manner. In addition, it must be taken into account that different driving forces act at different spatial scales. For example, driving forces like greenhouse gas concentrations or some food prices are global-scale driving forces which affect smaller spatial units like federal states, but which can barely be influenced by any actions at that smaller (e.g. state) scale. Now, if smaller-scale driving forces are defined, they should be consistent with the development of the global-scale driving forces (scale consistency). When all input necessary for the various models is quantified, the models can be used to compute the system indicators for the various reference scenarios.

Intervention scenarios are defined by modifying one or more driving forces or parameters of the reference scenarios (step 6). In general, to test the robustness of the intervention, the impact of an intervention is assessed on the background of all reference scenarios.

It is important to note that the study area is generally subdivided into homogeneous spatial subunits, the scenario regions, for which the storylines and the quantitative assumptions of the development of the driving forces are developed (step 2). The scenario regions are usually larger than the spatial subunits of the mathematical models used to compute the systems indicators.

Scenario building is an iterative process, and it is desirable to discuss preliminary scenarios available after step 5 has been performed for the first time, preferably among scientists, decision makers and stakeholders, and then to revise storylines and quantifications. In a regional planning process, steps 3 to 7 are likely to be repeated. After a first computation and evaluation of the system indicators, in particular the indicator definition can be refined, and new interventions might become interesting.

3 Reference scenarios of regional development

In the WAVES program, qualitative-quantitative scenarios of the situation in Ceará and Piauí up to the year 2025 were generated (base year 1996/98). Two reference scenarios and a larger number of intervention scenarios were devised. Reference scenario A (RS A) is called “Coastal Boom and Cash Crops”, reference scenario B (RS B) “Decentralization — Integrated Rural Development”. For scenario building, the study area was subdivided into eight scenario regions (Fig. 2), which are assumed to differ with respect to the future development of the driving forces. Criteria for the configuration of the scenario regions were: similar agro-economic conditions, similar natural conditions (precipitation, position within river basin, sedimentary vs. crystalline subsurface) and administrative boundaries. The driving forces were applied to each of the 332 municipalities of the states of Ceará and Piauí which are the spatial units to compute system indicators.

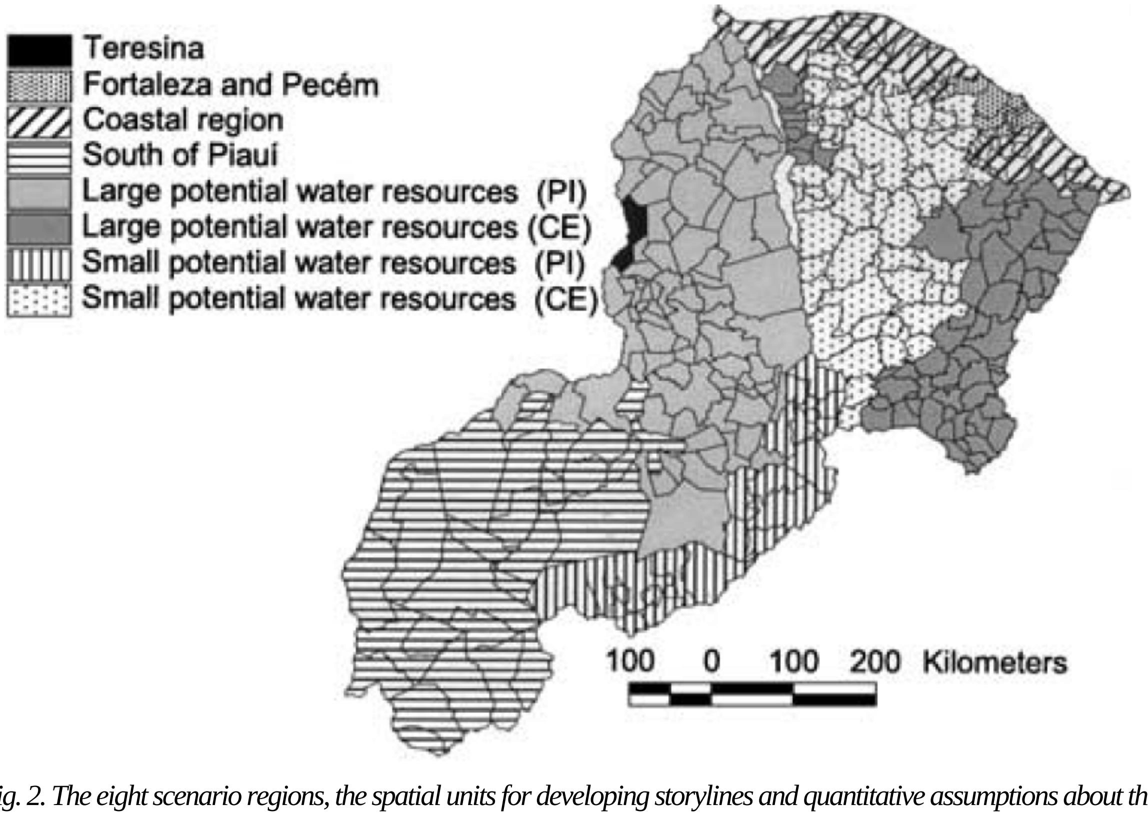

Fig. 2. The eight scenario regions, the spatial units for developing storylines and quantitative assumptions about the development of driving forces. The white areas between Piauí and Ceará are disputed between both states and are almost uninhabited. The outlines of the municipalities, for which the system indicators are computed, are shown, too.

3.1 Storylines

For each of the two reference scenarios, a storyline was written that covers aspects that are important with respect to rural development and to the water scarcity problems in the study area. The detailed storylines for each of the scenario regions can be found at http://www.usf.uni-kassel.de/waves/szenarien/reference_scenarios.html. Table 1 provides a concise characterization of RS A and RS B. Each reference scenario continues certain existing trends. RS A (“Coastal Boom and Cash Crops”) carries on the current trend of increased cash crop production for the Brazilian and external market, the efforts to promote tourism mainly along the coast and the fast economic development in the growing metropolitan area of Fortaleza, the capital of Ceará. RS B (“Decentralization — Integrated Rural Development”) takes up the strengthening of regional centers, e.g. by the establishment of universities, which has recently begun in the study area.

Table 1. Characteristics of the two reference scenarios

Reference scenario A (RS A) “Coastal Boom and Cash Crops”	Reference scenario B (RS B) “Decentralization — Integrated Rural Development”
• strong economic development (commerce, industry, tourism) in the coastal regions of Piauí* and Ceará • Fortaleza grows very fast • where water is available for irrigation, the production of cash crops by large companies dominates over subsistence farming • Brazilian and global markets for agricultural products dominate • centralized governance prevails	• regional centers prosper (attractive medium-sized towns with improved infrastructure) • regional centers have become the markets for local and regional agricultural products • small-scale agro-industry has extended • local initiatives prevail • Piauí and Ceará show a high degree of autonomy in relation to the Brazilian South • international agencies support sustainable agriculture in crisis-prone regions

* The small coastal region in Piauí consists of only two municipalities.

As regional development is strongly influenced by global development, the two reference scenarios were designed such that they can be embedded into global scenarios. For the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), four global scenario families were developed (Nakicenovic and Swart 2000). A comparison of the storylines of the global scenarios to those of our regional scenarios shows that RS A can be embedded in global IPCC scenario family A1 and RS B in scenario family B2 (Fig. 3).

	oriented mainly towards economic growth	oriented mainly towards the environment and social innovation
globalized world	global A1/ regional RS A	global B1 / none
regionalized world	global A2 / none	global B2 / regional RS B

Fig. 3. Correspondence of regional reference scenarios for Piauí and Ceará with the global IPCC scenario families (Nakicenovic and Swart 2000).

The A1 storyline describes a future world of very fast economic growth and the rapid introduction of new and more efficient technologies. A strong globalization with intensive economic and cultural exchanges leads to a convergence of wealth and lifestyle among the world regions. In such a world, the strong economic development in the coastal region and the cash crop production in the hinterland with enough water for irrigation that is assumed in the regional reference scenario RS A is plausible. The globally strong economic development results in buyers for industrial and agricultural products, increased investments of foreign companies and an increasing number of tourists from countries that do not yet participate in global tourism. The B2 storyline describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. The B2 world of 2025 is less globalized than the A1 world but still more globalized than today’s. It is a world with intermediate levels of economic development, less rapid and more diverse technological change than in the A1 storyline, and with strong social innovation. In such a world, we can imagine Piauí and Ceará as described in the integrated rural development scenario RS B. Local and regional markets become more important, while global (and Brazilian) markets are rather weak,. Without an economic boom and intensive cash crop production, it might be easier to achieve environmental sustainability. Finally, the diversification of production in agriculture and (small-scale) agro-industry requires social and economic innovations.

3.2 Quantification of driving forces

The mathematical models applied for the quantification of scenarios require many input variables, i.e. driving forces which need to be quantified beforehand for each of the eight scenario regions. In general, it is assumed that all municipalities within a scenario region are subject to the same change of a driving force. The Scenario Group quantified only those driving forces which were of overall importance (the main driving forces population, gross domestic product GDP, irrigated area etc.). For the latest documentation of the quantified main driving forces, see http://www.usf.uni-kassel.de/waves/szenarien/tabelas_cenario.pdf, in Portuguese, while the scenario assumptions are discussed in more detail in Döll et al. (2000). The disciplinary working groups then quantified the remaining driving forces (and parameters) of their models in accordance with the main driving forces and the storylines. Here, we only present the quantification of population, per-capita GDP, irrigated areas, areas that are potentially available for agricultural production, reservoir construction and climate change. Other driving forces are described in Krol et al., Döll et al., and Höynck and de Sousa Bonfim (this volume).

Table 2. Spatial distribution of population: Historical data and scenarios

	Fraction of total population of Ceará and Piauí in each scenario region [%]			
Scenario region	1991	1996	2025 RS A	2025 RS B
Teresina	6.7	6.9	8.1	7.3
Metropolitan area of Fortaleza and Pecem	26.1	27.6	35.4	30.6
Coastal region	12.7	12.8	17.4	13.3
Southern part of Piauí	3.1	2.9	2.4	2.9
Regions with large potential water resources (PI)	14.5	13.9	11.4	13.5
Regions with large potential water resources (CE)	19.4	19.0	15.5	18.4
Regions with small potential water resources (PI)	2.9	2.7	1.6	2.3
Regions with small potential water resources (CE)	14.7	14.1	8.2	11.7

Population. Population scenarios are necessary for simulating migration, water use and the agro-economy (agricultural production and income). For RS A and RS B, two different population scenarios were derived. They differ with respect to the distribution of population among scenario regions (Table 2) but total population growth in the study area is assumed to be the same in both scenarios. In RS A, the fraction of the population living along the coast and in the two capitals increases strongly, while in RS B, the current trend of migration from the hinterland to the coast weakens. The historical population development of the study area is strongly influenced by migration towards the economic centers in the South of Brazil. Fertility has been above the Brazilian average but with a decreasing trend. Using a simple cohort population model which was calibrated for the period 1991-1996, the total population scenario was derived by analyzing fertility, mortality and migration rates of Piauí and Ceará, by comparing them to the respective values for the whole of Brazil, and by taking into account IPCC population scenarios (Nakicenovic and Swart 2000) and a population scenario for Brazil (IBGE 1997). It is assumed that fertility and mortality continue to decrease in the future, and that the more recent trend of decreasing net migration continues. By 2025, both the fertility rate and the net migration will have dropped to approximately 65% of the 1996 value, and the mortality rate to approximately 85%. The resulting fertility and mortality rates of 2025 are still higher than the values for the Brazilian average as predicted by the Brazilian population scenario for 2020. According to the population model, the number of inhabitants of the study area increases from 9.5 million inhabitants in 1996 to 11.9 million in 2025.

Gross domestic product. Like population scenarios, GDP scenarios determine migration, water use and the agro-economy. Per-capita GDP in the study area is approximately one half of the Brazilian average, and the average growth rate since 1970 has been somewhat higher than the Brazilian one. The global IPCC scenario A1 (to which RS A fits) shows a higher growth rate of per-capita GDP than the global scenario B2 (RS B) (Nakicenovic and Swart 2000). In the case of both IPCC scenarios, the growth rates for the global scenario region to which Brazil belongs are much higher than the average historical growth rates from 1950 to 1990. We think that this type of GDP growth assumption, with an average of 4.7%/yr until 2025, is not plausible for the regional scenarios for Ceará and Piauí; per-capita GDP growth is likely to be smaller, and more similar in RS A and RS B. Therefore, we assume a value of 2.7%/yr from 1996 to 2025 in RS A (except for Teresina and the regions with small potential water resources, with 2.5%/yr), and 2.2%/yr in RS B (except for regions with large potential water resources, with 2.4%/yr). The sectoral distribution of the GDP is assumed to shift differently in the two reference scenarios. In Ceará, the agricultural sector remains unchanged at 7%, while the service sector increases from 68% of total GDP today to 74% in RS A and 71% in RS B. In Piaui, the agricultural sector is assumed to become more important than today (14% in RS A and 18% in RS B as compared to 13% today), while the fraction of the industrial sector remains virtually unchanged at 21%.

Irrigated areas. Irrigated areas have a very strong impact on water use and thus water scarcity as well as on the agro-economy of a region. In Brazil, irrigated areas were extended at a rate of 7%/yr in the 1970s, by 5% in the 80s but by only 1.2%/yr between 1990 and 1998 (FAO 2000). Here, and in the following, the term “irrigated areas” refers to the areas that are equipped for irrigation. This decreasing trend is observed in most countries and is due to restricted water and land resources. In Ceará and Piauí, however, rural development is still considered to be strongly linked to irrigated agriculture. Therefore, large increases of irrigated area are foreseen in both reference scenarios, with an average over the study area of 3.8%/yr in RS A and 2.5%/yr in RS B. For RS A, all public irrigation projects planned in 1998 according to Lopes Neto (1998) are assumed to be implemented, while private irrigation, which accounts for approximately half of the current irrigated areas, increases by 2%/yr from 1996/98 to 2025. The 2% increase represents the average for the study area Piauí and Ceará and differs among the scenario regions. These assumptions lead to an increase of irrigated areas in the study area from 56,000 ha in 1996/98 to 161,000 ha in 2025, with 84,000 ha in new public projects and 21,000 as new private irrigation. For RS B, with its decentralized development based on small-scale local initiatives, it is assumed that only a fourth of the area in each of the planned public irrigation projects is implemented up to 2025, but that private irrigated areas increase by 2.9%/yr. Irrigated area in 2025, for RS B, is 112,000 ha (new projects: 21,000 ha, new private irrigation: 35,000 ha). In both scenarios, the additional private irrigated areas of a scenario region is distributed among the municipalities according to the following rule: 50% of the additional areas is distributed homogeneously over all municipalities, and 50% in proportion to the 1996/98 irrigated area.

Potential agricultural areas. The potential agricultural area is a constraint in the regional economic optimization model of the agricultural sector in Ceará and Piauí RASMO (Höynck and de Sousa Bonfim, this volume). In the case of both reference scenarios, it is assumed to increase in all scenario regions. In Teresina, Fortaleza and the coastal region, the increase in RS A is somewhat larger than in RS B, while in the other scenario regions, the opposite is true. In the whole study area, the potential agricultural area increases from 5.65 mio ha 1996 to 7.25 mio ha in 2025 in the case of RS A, and to 7.45 mio ha in the case of RS B. In RS A, the fraction of large farms increases, in RS B, the fraction of medium-size farms, and in RS A, the fraction of small farms remains higher than in RS B. The reference scenarios differ appreciably with respect to the increases in the coastal region and the metropolitan area of Fortaleza (higher increase in RSA due to the more favorable marketing conditions) and the regions with low potential water resources (higher increase in RSB due to governmental policies). The areas with high potential water resources are expected to be favored for agricultural production in both scenarios.

Reservoir construction. In particular in Ceará, where groundwater resources are very small, reservoirs are the main source of water supply. Over the last 100 years, the construction of reservoirs has been one of the main strategies to extend the availability of surface water into the dry season or into coming drier years, and to perennize rivers. The largest number and total capacity (not considering the Represa Sobradinho in Bahia) of reservoirs in Northeastern Brazil is found in Ceará. There, the large storage capacity installed already limits the possibilities to further increase water availability by this strategy with a high efficiency. While in the case of Piauí, we do not take into account the construction of new reservoirs, in the case of Ceará we assume, for both reference scenarios, that the Castanhão dam in the Jaguaribe basin will be finalized in 2001 (storage capacity $4450 \cdot 10^6$ m^3). The investments for additional reservoirs will continue at the present rate (8 mio R$/yr) until 2025, which results in a total of 51 reservoirs with $3150 \cdot 10^6$ m^3 of additional storage capacity in Ceará. The sequence of reservoirs follows a prioritization list of the State of Ceará (PROGERIRH), but in RS A investments are more concentrated in the coastal zone.

Climate change. Climate change scenarios for the years 2000-2050 (daily values) were derived by a statistical downscaling method, taking into account precipitation change in Northeastern Brazil as computed by global climate models for a 1% yearly increase of greenhouse gas concentrations, and historic station data for 1921-1980 (Gerstengarbe and Werner, this volume). The applied climate models were the ECHAM4 climate model of the Max-Plank-Institute, Hamburg, Germany and the HadCM2 model of the Hadley Centre for Climate Prediction and Research, Bracknell, Great Britain. Both models result in quite different precipitation developments in the study area. However, the major changes with respect to today as well a pronounced difference between the two scenarios only appear after 2025 (Krol et al., this volume). The average precipitation over the study area of the period 2011-2040 is 864 mm/yr according to ECHAM4 and 1053 mm/yr according to HadCM2, compared to 875 mm/yr for 1939-1968 and 905 mm/yr for 1969-1998. Climate variability dominates climate change.

3.3 Model-based quantification of indicators

Within WAVES, a number of disciplinary models (climate, water availability, water use, agricultural productivity, agro-economy/land use and migration) were developed for both the state level (spatial resolution: municipalities; spatial extent: Ceará and Piauí) and the focus region level, and were coupled to form two integrated models. All these models can be used quantify the indicators of the scenarios. In the following, we focus on a few integrating indicators that are derived by the large-scale integrated model SIM (Krol et al., this volume): water demand, water supply, a water supply sufficiency index for irrigation, agricultural productivity of maize, tomato production, farm income and migration. Only the results based on the ECHAM4 climate scenario are shown.

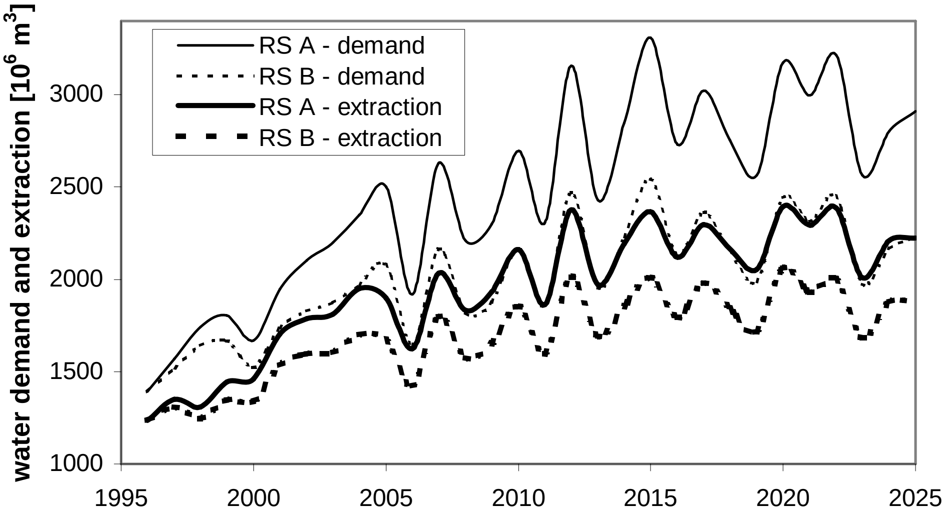

Fig. 4. Total annual water demand and water extraction in Ceará and Piauí.

Water scarcity. In principle, water scarcity is a function of water supply and water demand. Water scarcity is the most direct impact of drought conditions or overuse of the natural resources. In both reference scenarios, withdrawal water demand increases strongly until 2025 (Fig. 4), reaching approximately 110% in the case of RS A, and 60% in the case of RS B. Almost 90% of these increases are due to the assumed extension of irrigated agriculture, while increased water demands in the domestic, industrial, tourism and livestock sectors may be regionally important but overall are less relevant (Döll et al., this volume[1]). Water demand for irrigation shows a strong interannual variability as it is negatively correlated with precipitation volumes. The increase in water extraction (volume of water that can actually be withdrawn to fulfil the demand) is smaller than that of water demand, as water supply does not meet demand, especially for increased irrigation (see below).

Even though the total renewable water resources (annual surface runoff and groundwater recharge, modeled as described in Güntner and Bronstert, this issue) will not change appreciably until 2025, water supply does, due to the construction of new reservoirs, adding to the surface storage capacity. Potential water supply can be partially represented by the total volume of water that is stored in large reservoirs at the beginning of the dry season. This value is mainly determined by the water storage infrastructure and the climatic conditions, with small differences between the two scenarios (Fig. 5). The water volume stored is generally very large, but large shares of it do not cover large water demands. For example, the Boa Esperança reservoir (Parnaíba basin) at the western border of Piauí, with a capacity of $5000 \cdot 10^6$ m^3, is used for hydropower generation. The increase in the year 2001 is due to the newly constructed Castanhão dam.

Fig. 5. Water storage in large reservoirs, at the beginning of the dry season (1st of July).

The net effect of the increasing trends of both water demand and supply on water scarcity depends critically on the spatial distribution of water availability and water demand. To quantify the scarcity, a water sufficiency index was calculated, evaluating which part of demand can actually be covered by the availability. This indicator is computed for each of the water use sectors irrigation, livestock, households, industry and tourism, which differ with respect to their sources of water (groundwater, surface water). In case of water scarcity, the irrigation sector will only be provided by the water volume that is not needed by the other four sectors, which is according to the legal requirements in the study region. Fig. 6 shows the temporal development of water supply sufficiency for the irrigation sector, where a value of 1 indicates a complete coverage of demand (no scarcity impact). The irrigation sector is selected here because it is the dominant use sector, and because it mainly depends on surface water. There is a gradual downward trend in water sufficiency for RS A from 88% down to 80%, whereas for RS B the value remains at 88%. The decreasing water sufficiency in the case of RS A is fully attributable to negative tendencies in the regions with large

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[1] Please note that the irrigation water demand given in Döll et al. (2001) is smaller than the values computed by the integrated model for this publication. The latter are based on different estimates of precipitation and potential evapotranspiration and take into account multi-cropping.

potential water resources and the coastal zone. This indicates that in these regions, water scarcity is increasing with time, and the additional water demands from expansion of the irrigated area cannot be met. In the case of RS B, the expansion in irrigated area in all regions is better adapted to the available and increased water supply.

In the scenario assumptions of RS A and RS B, precipitation reduces by 7% until 2025, but the effects of climate change until 2025 are small compared to the effects of increasing demands and the expansion of supply systems.

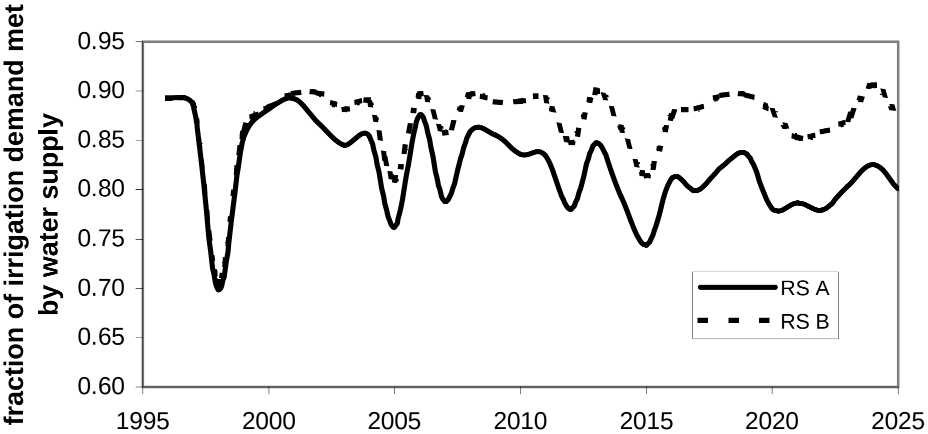

Fig. 6. Water supply sufficiency for irrigation: fraction of the water demand for irrigation that can be covered by water supply.

Agricultural production. Agricultural production is strongly affected by climate, but also by the possibilities for irrigation. Both rainfed and irrigated production depend on precipitation. Rainfed production is directly affected by negative anomalies in precipitation, especially when the rainy season is significantly shortened or when longer dry spells within the rainy season occur, depleting soil moisture. Irrigated production is affected by unfavorable climatic conditions in two ways. Firstly, water supply for irrigation is less in drier years, especially after a sequence of drier years. Secondly, irrigation water demand is higher.

Rainfed yields strongly depend on the climate, and the differences between RS A and RS B play a negligible role (only through the way in which they impact on the spatial distribution of cropping areas). Until 2025, climate change shows little influence on the yield of, for example, maize (Fig. 7): both mean yield and variability do not exhibit a significant trend.

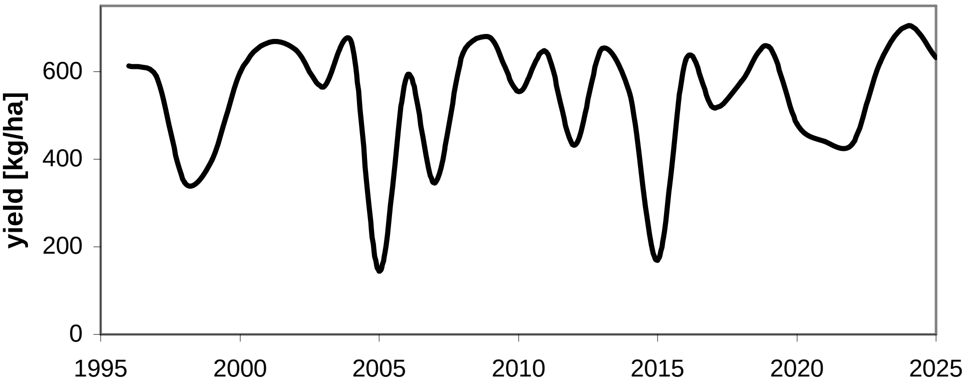

Fig. 7. Temporal development of mean rainfed maize yield in both reference scenarios.

For the irrigated production of e.g. tomato, clear trends and differences between the two scenarios appear, which are due to a higher increase of irrigated tomato production in RS A (Fig. 8). In

RS A, production increases by 340%, in RS B by 220%, even though in RS A, a larger part of the area equipped for irrigation cannot be irrigated due to lack of water (Fig. 6).

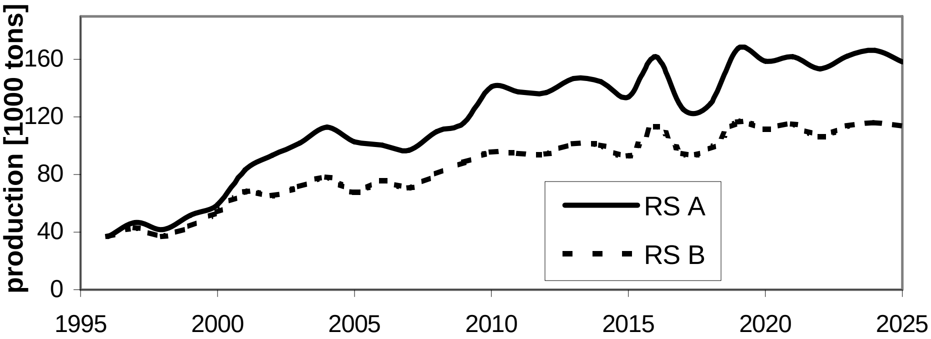

Fig. 8. Tomato production in Ceará and Piauí in RS A and B.

For almost all crops, production increases are found in both reference scenarios, except for cassava, mostly cultivated on smaller farms, whose areas are decreasing. For crops that are mostly grown under rainfed conditions, production increases are very similar for the RS A and RS B scenario; for crops with relevant share of irrigated production, production increases in RS A are stronger, due to the faster expansion of irrigated areas.

As a result, total farm income grows faster in RS A than in RS B. The interannual variability of agricultural GDP remains very large, with negative net values for the 3 driest years until 2025. Due to the large variability, a statistically significant growth trend cannot be identified. The difference between RS A and RS B, however, shows an increasing trend, which is due to the different proportions of high-value irrigated crops. The difference reaches approximately half of the mean agricultural GDP of the 1990s but results are very uncertain, as the assumed costs and prices are uncertain; in particular the profitability of smaller farms is uncertain (Höynck and de Sousa Bonfim, this volume).

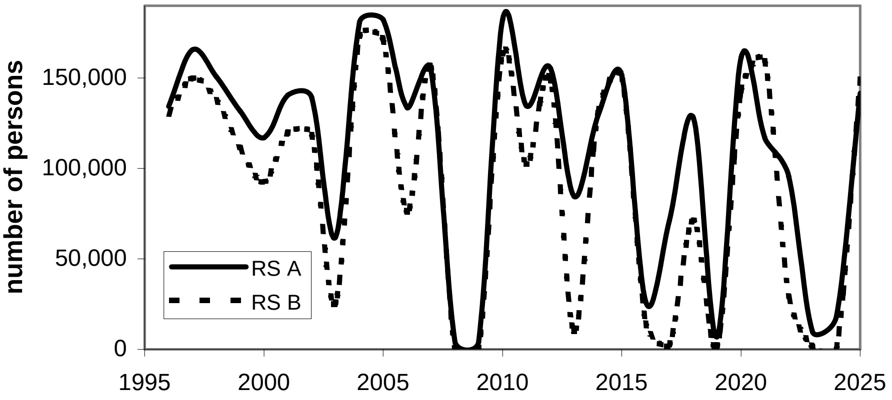

Fig. 9. Annual net migration from the Sertão.

Migration. Scenarios of migration are to be interpreted with caution. Migration is simulated to be mainly driven by gradients in income, mimicking large scale migration within the states of Ceará and Piauí and outside of these states over longer periods (Fuhr, this volume). This makes GDP (total and agricultural) and its growth rates the main drivers of migration, but the income drop in drought years, enhancing the rural-metropolitan income gradient, as the direct incentive for migration. Model simulations successfully reproduce the assumed tendencies in population development and its regional distribution. Considering net migration from the Sertão (scenario regions with large and small potential water resources), the dynamical feature of high migration in drought years remains due to the continued variability of agricultural GDP (Fig. 9), with persistently lower numbers for RS B (total migration is 25% higher in RS A). Unfortunately, there are no historic data of migration from the Sertão nor annual values of migration from the whole study area that could be used to check the plausibility of the computed migration; the annual net migration from the study area averaged over the period 1991-1996 was 60,000 (Döll et al.. 2000). In the migration simulation, the effect of emergency measures, which support the rural population in drought years, is not taken into account explicitly, such that migration peaks are likely to be highly overestimated. In summary, the present (incomplete) quantitative understanding of migration indicates that there will be no consistent decrease in migration from the Sertão, even under the assumption of economic growth in the Sertão.

4 Intervention scenarios

In an exemplary manner, the impact of three different policies or management measures is analysed on the background of the two reference scenarios: water pricing, reduced reservoir construction and introduction of high-yield cashew varieties.

4.1 Water pricing

Appropriate pricing of water helps 1) to achieve the economically most efficient use of water, 2) to avoid its wasteful use and thus to protect the environment and 3) to generate monies to improve water supply and water (demand) management. In the regional water use model NoWUM, water use in households connected to the public water supply and water use by industry is simulated to be influenced by the water price due to the price elastiticy of water use (Döll et al., this volume). With a price elasticity of -0.5, for example, water use decreases by 5% if water price increases by 10%. Price elasticity in the domestic sector is lower than in the industrial sector. While in the domestic sector, public-supplied and self-supplied households are distinguished (the latter not being affected by water pricing), this distinction cannot be made in the industrial sector due to lack of data; this is likely to lead to an overestimation of the responsiveness of industrial water use to water pricing by the public water suppliers. Unfortunately, there is a lack of reliably data on price elasticities in Brazil, which leads to significant uncertainties in the computed impact of water price on water use. Besides, it is at present not possible to apply the price elasticity concept for irrigation water use as there is no knowledge about price elasticities in this water use sector.

In general, the current water prices in Piauí and Ceará only cover operation and maintenance costs, but not investment costs, e.g. for an extension of water supply, or environmental costs. However, it is widely recognized that sustainable development requires a full-cost pricing for water services (World Water Commission for the 21st Century 2000). Currently, approximately 1% of the average per-capita GDP in the study area is spent for (public) water supply, which is comparable to the situation in Germany, with a tenfold per-capita GDP and the same per-capita water use. The increase assumed for both reference scenarios (6%/yr) from 1996/98 to 2025 (compare section 3.2) is smaller than the historic price increases in Ceará during the last decade (which was 8-11%/yr, based on 1989-1998 data from CAGECE, the main water provider in Ceará). A price increase of only 2.5%/yr results in an approximately constant fraction of the total income that is spent on water, and it is unlikely that with such a price development, investment costs could be covered. A price increase of 11%/yr (the price increase of the fixed fee component of the water tariff in Ceará during the last decade) leads, on average, to a water price that, with the same per-capita water use, amounts to about 10% of the per-capita GDP. Please note the prices per volume of freshwater will effectively double when households get connected to the sewage system (in 1996/98, only about 10% of the urban withdrawals are discharged into a sewage system).

With an 11%/yr increase of water price, total domestic water use (including self-supply) decreases by approximately 45% as compared to the reference scenarios (where 6%/yr was assumed), while with 2.5%/yr, it increases by about 40%. The impact of different water pricing is approximately the same in both reference scenarios. By 2025, industrial water use intensity (withdrawal water use divided by industrial GDP) will have decreased to 16%, 37% and 66% of the present value in the cases of 11%, 6% and 2.5% water price increase per year, respectively. Consequently, industrial water use in the study area decreases by 58% in the case of 11%/yr, and increases by 80% in the case of 2.5%/yr as compared to the reference scenarios.

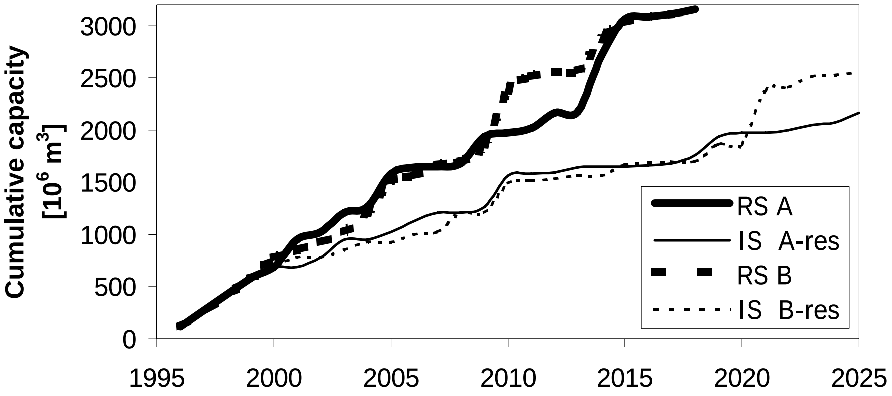

Fig. 10. Cumulative capacity of reservoirs constructed from 1996 to 2025, for reference and intervention scenarios.

4.2 Reduced reservoir construction

To assess the beneficial effects of the reservoirs that are assumed to be constructed until 2025 in the reference scenarios, variants of the scenarios were defined in which less dams are constructed. While in both RS A and B, it is assumed that annual investments in new reservoirs remain constant at year 2000, the investment volume is assumed to be only half this size in the intervention variants. As in the reference scenarios, dam construction has priority in the scenario region with high potential water resources in scenario B, and both in these regions and in the coastal region in scenario A. In Fig. 10, the intervention scenarios are denoted by IS A-res and IS B-res, IS standing for Intervention Scenario and –res for reduced dam construction.

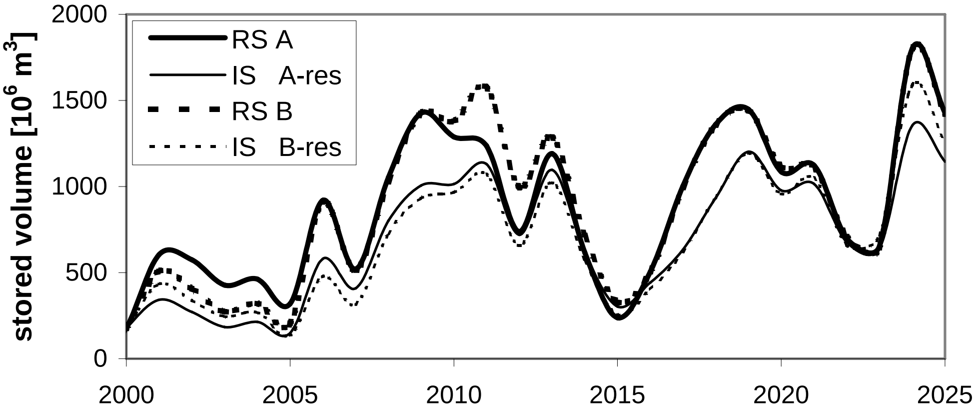

Fig. 11. Increase in stored water volume at the beginning of the dry season by reservoirs constructed after 1996, for reference and intervention scenarios.

In the model simulations of IS A-res and B-res, stored water at the beginning of the dry season is less than in RS A and RS B (Fig. 11) for most years, illustrating the positive effect of newly installed water storage capacity on the availability of water. However, in the dry years after 2010, the reduced reservoir construction in the intervention scenarios does not lead to a reduction of the volume of stored water. The relative filling of the new reservoirs at the start of the dry season is higher in the intervention scenarios (Fig. 12). This holds for both the scenarios A and B and indicates that the total installed storage capacity in the case of the interventions scenarios is nearing a level where the efficiency of new dams is highly reduced.

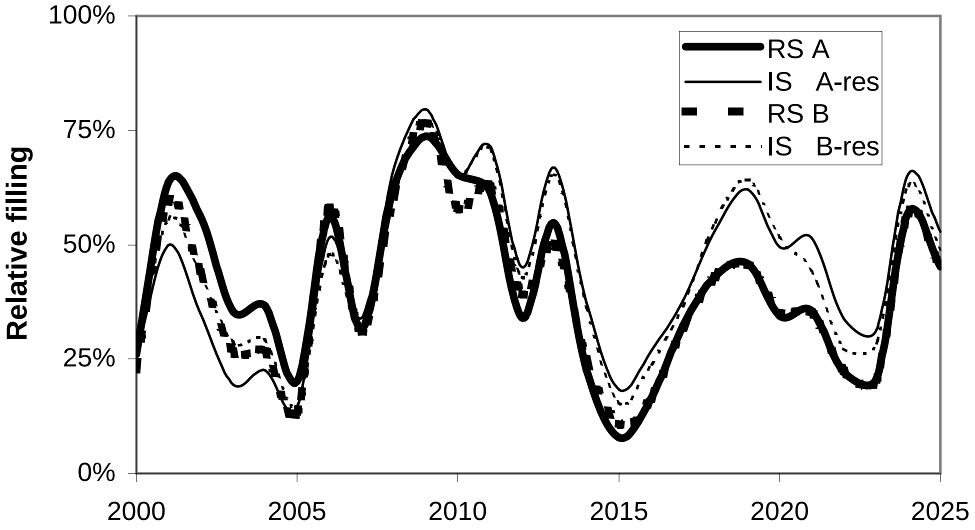

Fig. 12. Relative filling at the beginning of the dry season by reservoirs constructed after 1996, for reference and intervention scenarios.

Reduced dam construction has only a very small impact on water scarcity. The smaller number of new reservoirs in IS A-res as compared to RS A lowers the mean sufficiency of water supply for irrigation between 2016 and 2025 from 80.5 % to 80.1%; for the B scenarios, the sufficiency declines from 88.0% to 87.8%. The impact of climate change on the efficiency of water storage infrastructure and water sufficiency is not apparent until 2025 but is a potentially very significant process afterwards (Krol et al., this volume).

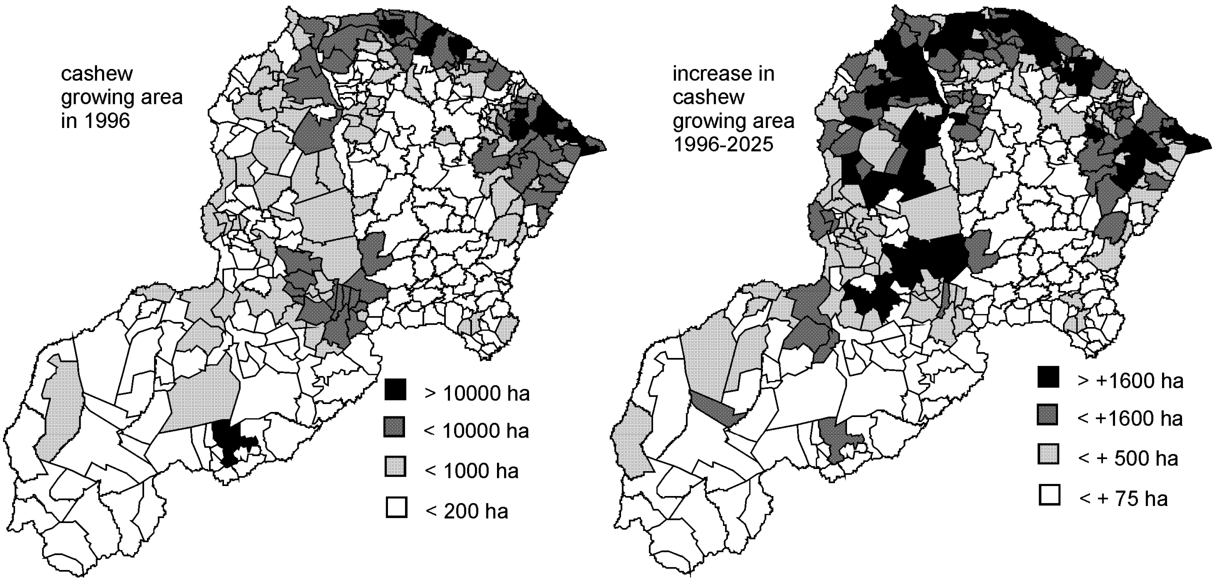

Fig. 13. Distribution of cashew cultivation in 1996 and change in cashew cultivating area as induced by the intervention, which results in a very significant productivity increase.

4.3 Introduction of high-yield cashew varieties

Improved crop varieties, especially of cash crops, are being developed to increase yields and to support market orientation of the agricultural sector. In the intervention scenario “Cashew” it is assumed that the traditional cashew varieties are replaced by improved varieties with a four-fold yield potential from 2010 on. Prices for cashew nuts are assumed to remain stable. The potential benefit through the marketing of cashew fruits is not considered. The impact of this intervention is only assessed on the background of RS A.

RASMO (Höynck and de Sousa Bonfim, this volume) computes the changes in agricultural land use resulting from the introduction of the high-yield cashew varieties. The cashew-growing area (both rainfed and irrigated) increases by 44% (from 363 to $522 \cdot 10^3$ ha), especially in northern Piauí, the coastal municipalities and the lower part of the Jaguaribe catchment (Fig. 13). Cashew production increases by 440% (Fig. 14). The net effect on agricultural GDP amounts to about +10% in the first decade after 2010, lowering to about 8% to the end of the simulation period.

The projected net effect on migration is very small (0.5%), partly because most migration-prone areas are simulated to benefit the least from the intervention due to restrictions by soil (clayey and stony soils in the Sertão), climate and irrigation possibilities. The intervention would thus implicitly result in supporting regional development in the regions with competitive advantages (coastal zone and regions with large potential water resources).

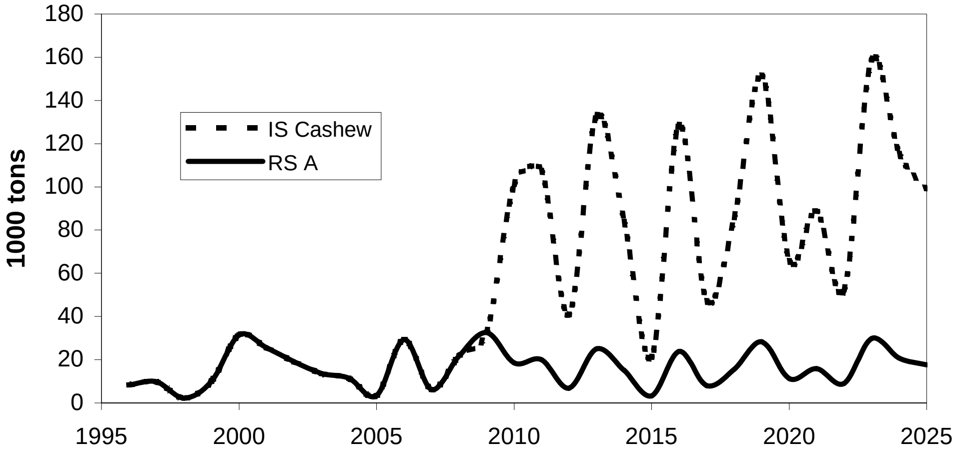

Fig. 14. Total production of cashew nuts in Ceará and Piauí in scenario A: reference scenario and intervention scenario "Cashew".

5 Conclusions and recommendations

Integrated scenario development has the potential for supporting sustainability-oriented regional planning in Ceará and Piauí. Scenario development requires, and thus encourages, interdisciplinary communication as well as the exchange with stakeholders and policy makers, which is a prerequisite for the applicability of research results. Scenarios combine a large amount of qualitative and quantitative knowledge into consistent descriptions of alternative future development paths. They can be presented in the form of stories and therefore transmit the results of the integrated analysis in a transparent and understandable way, facilitating communication and diffusion of results. The consistency of the derived scenarios is strongly supported by the application of models, and of an integrated model in particular. (In the presented scenarios, for example, the extension of irrigated crop production is restricted by water availability, while both variables are affected by climate change.) The quantification of appropriate system indicators (e.g. for water scarcity) is decisive for a successful integration of scenarios into regional planning, but it is limited by the capabilities of the applied mathematical models, which again are often restricted by data availability.

The model-based quantification of the system indicators related to water stress, agricultural production and migration results in the following conclusions with respect to the development of Ceará and Piauí until 2025:

1. Water stress increases significantly only in case of RS A ("Coastal Boom and Cash Crops"), which is mainly due to the extension of irrigation (implementation of all currently planned public irrigation projects) and not caused by climate change.

2. If, in Ceará, the investments for new reservoirs do not continue until 2025 at the current rate of 8 million R$/yr but drop to only half the value, the volume of water which is stored in the new reservoirs at the beginning of the dry season will not be reduced much after 2010, and not at all in drought years. More importantly, water scarcity, as expressed as the sufficiency of water supply to fulfill water demands, will not be significantly affected by the reduced dam construction.
3. Therefore, it is likely that the implementation of all currently planned irrigation projects would lead to low sufficiency of water supply for irrigation even if more reservoirs were constructed than assumed in the reference scenarios (investment rate 8 million R$/yr).
4. Due to the high price elasticity of domestic and industrial water demand, domestic and industrial water use can be efficiently managed by water price, in particular if all the industries were charged. (However, there is a lack of reliably data on price elasticities.) If the annual (inflation-corrected) water price increase is less than 6%/yr (assumed in the reference scenarios), water stress will increase as domestic and industrial water demand will increase significantly. However, the impact of water price on the dominant water use sector, irrigation, could not be assessed.
5. In RS A, the agricultural GDP increases more strongly than in RS B (“Decentralization — Integrated Rural Development”) which is due to higher production of irrigated crops. However, in both scenarios, interannual variability remains very high.
6. Assuming constant prices, introduction of high-productivity cashew varieties increases agricultural GDP by 8-10%.
7. Migration from the Sertão is less in the case of RS B than in the case of RS A, but will not decrease significantly until 2025.

Please note that the uncertainty of the computed system indicators and thus of the above conclusions is high. The lack of knowledge about present-day irrigation, in particular about irrigated areas and multicropping, which leads to significant uncertainty of the modeled water demand. Modeling of agricultural production and GDP suffers from a lack of reliable data on present-day cropping as well as coarse representation of price formation processes, credit availability and informal marketing in the model. As to migration, only few of the reasons for migration that are well known qualitatively can be quantified, such that the impact of important drivers could not be included in the scenario generation.

A very important source of uncertainty are climate data, both historic data and climate change scenarios, which have a strong impact on computed water availability, irrigation water demand and crop productivity. For example, when the precipitation over Ceará is estimated based on about 200 measurement stations as compared to about 30 in the standard climate data set, 1969-98 long-term average annual precipitation is estimated to be 844 mm instead of 924 mm, which results in a 50% increase of computed irrigation water demand in Ceará. However, the conclusion concerning the modest effect of reduced investments for reservoir construction with respect to alleviating water scarcity (conclusion 2) is quite robust as to different climate change scenarios. It holds for the climate change scenario with declining precipitation volumes (ECHAM4, applied in this paper), but similarly for a constant climate, for which the installed capacity is high already, and also for the scenario with increasing precipitation (HadCM2), for which water scarcity will mainly decrease due to a reduced water demand and a better filling of the already available storage capacity.

Ideally, scenario development should start at the beginning of projects that are concerned with sustainability-oriented research. To make it relevant for regional planning, it should be performed in co-operation with policy makers and stakeholders. An extended scenario group consisting of researchers, policy makers and stakeholders would first define whether explorative or normative scenarios will be developed. Explorative scenarios are the the type that have been developed in the WAVES program, while normative (or sustainability) scenarios are based on the definition of "desirable futures" and help to identify the conditions and interventions that are necessary to reach the desirable future system state. Explorative scenarios should be formally evaluated by the extended scenario group, e.g. by performing a multi-criteria analysis. The evaluation of explorative scenarios and the development of normative scenarios requires the identification of suitable sustainability indicators and the definition of threshold values.

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