Chapter 3

Qualitative-quantitative scenarios as a means to support sustainability-oriented regional planning

P. Döll
Center for Environmental Systems Research, University of Kassel
Kurt-Wolters-Str. 3, 34109 Kassel, Germany

Scenario analysis facilitates a better understanding of future environmental change and is a useful means to support a regional planning that is geared towards sustainable development. In particular if developed by close cooperation of decision-makers and scientists, scenarios help to understand the consequences of today's decisions in a quite distant and uncertain future. Scenarios describe a range of plausible futures in an integrated manner, considering the most important driving forces of the socio-environmental system of interest. Ideally, they combine qualitative and quantitative elements, i.e. narratives (storylines) with mathematical modeling. In this paper, a methodology to develop environmental scenarios is described, considering, in particular, the issues of participation and scale. Examples for scenarios which explore the impact of climate change on water resources and irrigation requirements in the whole Mediterranean region are provided. Due to the high uncertainty of the precipitation changes computed by global climate models, it is not possible to determine, on the river basin scale, how different greenhouse gas emission scenarios will translate to changes in water resources and irrigation requirements.

1. Scenario analysis

How can people, institutions and businesses plan for the future when they do not know what tomorrow will bring? Most of us prefer to only think of what we believe is the likely future, instead of really considering that the future can look very different. However, "to operate in an uncertain world, people need to be able to question their assumptions about the way the world works" [18]. Scenario analysis is a methodological approach to deal with the uncertain future, and it helps to arrive at better decisions. An example from the past is the "oil crisis" of the 1970s when the oil price increased drastically, after being more or less constant since World War II. Of the big oil companies, only Shell was prepared as they had worked before with scenarios. Some of these assumed a constant oil price, while others considered the impacts of an oil price hike by OPEC. As a consequence, Shell's position among the big oil companies improved strongly in the following years [18]. Nowadays, scenarios are not only well used in the business world but are widely applied to assess environmental problems, in particular those related to global change.

A. Marquina (ed.), Environmental Challenges in the Mediterranean 2000-2050, 47–60.

Scenarios are consistent and plausible images of alternative futures, i.e. they show various possibilities of how the future might look and how it will be reached. They rely on a rather high degree of systems (or process) knowledge, i.e. knowledge about the interdependencies and feedbacks between various system components. Scenarios focus on laying out complex causal relations and try to answer "what if" questions. They are not predictions of the future, and should not be qualified by a probability. Predictions are only possible if system complexity is rather low and process knowledge and data availability is high. Prediction of engineered systems is often possible, while prediction of natural or human systems mostly is not, unless the time horizon is short.

Scenarios can be qualitative, quantitative or qualitative-quantitative. Purely qualitative scenarios are, in most cases, narratives of the futures. These describe, in the form of storylines, how relevant aspects of the system under consideration will develop in the future. Purely quantitative scenarios are generated, for example, by running mathematical models of the system of interest such that future states of the system are computed. State-of-the-art environmental scenarios combine qualitative with quantitative elements, i.e. storylines with model calculations. The storylines are the basis for quantifying the driving forces and thus the input for the models that are then applied to compute numerical estimates of environmental indicators. The quantitative modeling part may also help to improve the consistency of the storylines, e.g. if the computed impact of the change of a certain system component on another one proves to be quite different from what was thought before the quantitative modeling. Examples for global-scale qualitative-quantitative environmental scenarios are:

- the greenhouse gas (plus sulphate) emission scenarios developed for the Intergovernmental Panel on Climate Change IPCC [15], which serve as input to climate models but also include scenarios of population and Gross Domestic Product until 2100,
- the scenarios of the water situation in 2025 developed in the framework of the World Water Vision [3, 5] and
- the scenarios of the Global Environmental Outlook 3 of the United Nations Environment Program [19].

Qualitative-quantitative scenarios can be a good tool for supporting regional planning, as they show the consequences of today's decisions in the distant future. The robustness of a certain policy can be tested by assessing its impact in alternative futures. A robust policy measure is one that performs reasonably well in all plausible futures. In the context of regional planning, scenario development should be done by scientists and stakeholders (policy makers, representatives of the civil society, etc.) together. A close cooperation, or participation, leads to the "ownership" of the scenarios by the stakeholders that is necessary for the scenario process to become relevant for actual decision making. Scenario development can be an ideal means for establishing the often desired communication between stakeholders and scientists, and among scientists of different disciplinary backgrounds; it requires, and thereby encourages, interdisciplinary communication and cooperation. Environmental scenarios are always interdisciplinary, as it is not possible to derive images or stories of the future state of the environment that do not include demographic, economic and technological aspects. They are integrated in the sense that disciplinary knowledge must be made consistent.

In Section 2, the most important steps involved in the development of qualitative-quantitative scenarios are described, and the questions of participation and scale issues in scenario development are discussed. In Section 3, the implications of global-scale qualitative-quantitative scenarios for water resources in the Mediterranean region are shown. Finally, some conclusions are drawn.

2. Methodology

For developing qualitative-quantitative scenarios which are to support sustainability-oriented regional planning, we propose the following steps:

1. Identification of the problem field and of the participants of the scenario process (stakeholders and scientists)
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 (related to the mathematical models that are available to compute indicators)
4. Development of qualitative reference scenarios in the form of storylines (narrative descriptions of alternative futures)
5. Development of quantitative reference scenarios
   a) Quantification of the driving forces
   b) Computation of indicators using mathematical models
6. Development of intervention scenarios
   a) Identification of interventions of interest
   b) Modification of selected driving forces or parameters of reference scenarios
   c) Computation of indicators using mathematical models
7. Evaluation of the scenarios (based on defined targets, e.g. by multi-criteria analysis, cost-benefit analysis, equity analysis)

Generally, intervention scenarios serve to test the robustness of an intervention (or policy measure) on the background of all reference scenarios, i.e. on the background of alternative plausible futures. They are defined by modifying one or more driving forces or parameters of the reference scenarios.

The steps listed above reflect those that were taken during scenario development for two federal states of Northeastern Brazil, in the framework of the German-Brazilian research cooperation program WAVES [6]. The WAVES scenarios cover the problem fields of water scarcity, agriculture and migration up to the year 2025, taking into account climate change as well as demographic and socioeconomic changes (step 1). Participants in the scenario process were a group of about eight scientists and a larger group of policy makers and technicians of Brazilian authorities dealing with regional planning. The involvement of the policy makers and technicians occurred during three workshops in the final year of the program. The indicators were calculated using an integrated model which combines the following modules: water use, hydrology, agricultural productivity, agricultural income and migration. They were computed for each of the 332 municipalities of the two federal states, while for the storylines and the quantification of the driving forces, eight scenario regions were distinguished. These eight scenario regions were defined based on similar (agro)economic and natural (sedimentary vs. crystalline subsurface, location with river basin, precipitation) conditions (steps 2 and 3).

Two different reference scenarios were developed which served as the background to test the impact of various policy interventions. Alcamo [2] recommended producing two or four reference scenarios with quite distinct storylines, in order to avoid that one scenario is considered as the "most probable", while the others are not given full consideration. The two storylines were formulated for the whole of the study region, distinguishing the events and developments occurring in each of the eight scenario regions. Each of the reference scenarios continues certain existing trends. The "Coastal boom and cash crops" scenario carries on the current trend of increased cash crop production for Southern Brazilian and international markets, the efforts to promote tourism mainly along the coast and the fast economic development of the capital of one of the two states. The "Decentralization – integrated rural development" scenario takes up the strengthening of regional centers e.g. by the establishment of universities, and thus increasing regional demand for agricultural products (step 4).

Based on the storylines, driving forces and indicators the reference scenarios are quantified (step 5). Here, those variables are defined as driving forces that cannot be computed by the applied models but are needed as model input. Both the quantified driving forces and the computed model output (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 time periods. Care must be taken to guard consistency in quantifying driving forces that are known to be correlated. When all input necessary for the various models is quantified, the model(s) can be used to compute the system indicators of the reference scenarios. Examples of interventions considered in WAVES were changed water prices or reduced investments in reservoir construction (step 6). To test the robustness of an intervention, its impact was generally assessed on the background of both reference scenarios.

A formal evaluation (not done in WAVES) helps to analyze the results of a scenario analysis (step 7). Depending on the system of interest and the applied models, each scenario will include a large number of indicators, and it might be difficult to recognize which intervention performs best in alternative futures. Any "best" performance depends, of course, on the ideas, goals and visions we have. Different stakeholders (and scientists) are likely to have different ideas, and it is therefore recommended to discuss these openly. With respect to sustainability-oriented regional planning, goal functions, ecotargets and orientors have been identified [13]. Cost-benefit analysis is a well-known tool to assess which solution is best (most efficient), but it is difficult to monetarize non-financial costs and benefits, in particular the external costs of measures that are related to their negative impact on the environment. Multi-criteria analysis provides a flexible framework to include many different criteria and to weigh them against each other, thus deriving an "optimal" solution. In multi-criteria analysis, a number of criteria are developed in each of the categories under consideration. These criteria can be qualitative or quantitative. They will be quantitative if numerical indicator values were determined, e.g. by mathematical models, which allow to quantify to which degree a certain criterion is fulfilled. A large variety of mathematical techniques are available to derive the overall score of a certain intervention scenario based on the fulfillment of the different criteria, and the simplest one (weighted summation) is used most often [12]. If various techniques are used in one evaluation, the stakeholders may gain valuable insights [4]. Equity analysis, which determines whether different parts of society are affected differently by the intervention of interest, can complement multi-criteria analysis or can be handled as a part of it [14].

Generally, scenario development is an iterative process. Quantitative analysis (step 5), for example, might show some inconsistencies in the storylines, which will therefore be modified after step 5 has been performed for the first time. Besides, after a first discussion of the qualitative-quantitative scenarios, stakeholders might want to enhance either the qualitative or quantitative scenarios by other aspects or system components. 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 may become interesting.

2.1. PARTICIPATION

Farrell [10] recommended to view environmental assessments as social processes or communication processes rather than as an end product, a document. This recommendation is also applicable to scenarios, which are often part of integrated environmental assessments. In the context of regional planning, scenario development should be regarded mainly as a tool to support the strategic thinking and decision-making of the stakeholders. Then the success of a scenario process should be judged based on what participants have learnt during the process. Certainly, the learning does depend on the quality of the developed scenarios themselves: their consistency, their meaningful indicators, the quality of the involved models, etc. This success criterion can be referred to as the credibility of scenarios. It is recommended to openly discuss the uncertainties of the involved quantitative assessments to thus increase the (long-term) credibility. The other two important success criteria are the saliency and the legitimacy of scenarios. The former relates to the relevance for the addressees of the scenarios (e.g. the stakeholders), the latter to the political acceptability, the satisfaction of the participants or addressees with the scenario process and the "ownership" of the developed scenarios. There are trade-offs among the three criteria, and depending on the stage of the scenario process or the dominance of societal vs. scientific interest, it might be useful to put the emphasis on one of the three criteria.

The question is how to organize participation in the scenario analysis process. Certainly, the type and number of participants will strongly influence the process and its results. In general, it can be recommended to involve stakeholders from the very beginning of the scenario process. However, it might be useful to involve different people at different stages of the scenario process, e.g. more technical experts in the beginning and more policy-makers towards the end.

2.2. SCALE ISSUES IN SCENARIO DEVELOPMENT

Scale issues in scenario development include all issues related to the spatial, temporal and institutional scales of the system for which scenarios are developed. They arise in all stages of the scenario analysis process, including the definition of the addressees of the scenarios, the formulation of the storylines, the quantification of the driving forces and the computation of indicators by models. Scale issues concern both the saliency and the credibility of the scenarios. It is recommended to explicitly address scale issues in any scenario analysis process.

As a first consideration, how can the spatial scale of the analysis be matched with the spatial sphere of influence or interest of the stakeholders? A correspondence is a prerequisite for saliency. With respect to the system definition and the development of storylines, it is important to consider cross-scale impacts. For example, a certain region (the chosen spatial unit for the scenarios) is subject to global-scale developments like climate change or change in world market prices that cannot be influenced by stakeholders inside the region but which have a strong impact on the region. Figure 1 illustrates a scheme which can be used to identify and lay out cross-scale impacts when developing local-scale scenarios. In the WAVES program, we designed the two regional-scale reference scenarios such that they fit to two global-scale scenarios that were developed by the IPCC [15]. In addition, we elaborated scenarios for each of eight scenario regions in a consistent manner, thus considering explicitly developments at smaller scales [17].

In most scenarios, the spatial units which are distinguished in the storylines and for the quantification of the driving forces are necessarily larger than the units of the models that are used to compute the system indicators. Thus, downscaling is required, and this might lead to unreasonable assumptions for the individual computational units. The challenge is to make scale implications and restrictions transparent to the addressees of the scenarios. In conclusion, the explicit consideration of multiple scales in the scenario analysis process leads to richer and more plausible environmental scenarios.

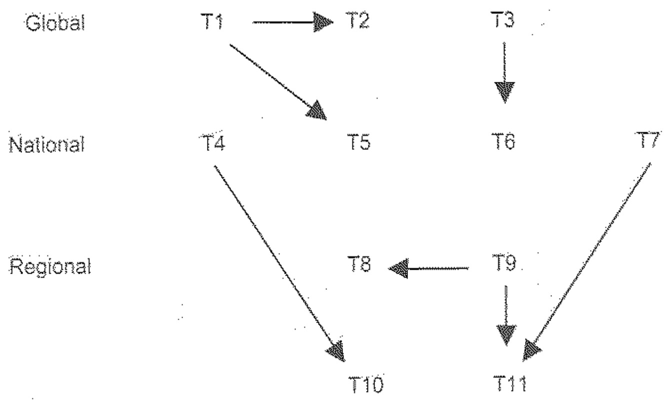
3. Applications in the Mediterranean region

The described qualitative-quantitative scenario approach has the potential to be applied to many problems related to the environmental future in the Mediterranean region. For example, what type of agricultural products can be grown in an economically and ecologically sustainable manner, e.g. without degrading water quality? How can freshwater be allocated among the irrigation, domestic and industrial water use sectors in an optimal manner? How can a region develop in which overgrazing has almost destroyed vegetation and soils? Scenarios can be derived for the whole Mediterranean region (e.g. to assess water quality issues of the Mediterranean Sea), individual countries, river basins or small sub-national regions. Depending on the region of interest and the problem field, the qualitative and quantitative parts can be flexibly chosen. In case of a reasonable amount of quantitative knowledge and tools, the share of the quantitative part of the scenario process may become much more important than in cases of low data availability and a small budget for the scenario process.

Unfortunately, I cannot illustrate the proposed scenario methodology with an example of integrated qualitative-quantitative scenarios for the Mediterranean. An interesting project that combines qualitative and quantitative approaches and will lead to land use change scenarios in the Mediterranean is the ongoing MEDACTION EU project (http://www.icis.unimaas.nl/medaction/).

Figure 1. Multi-scale relationship among drivers for community forest management

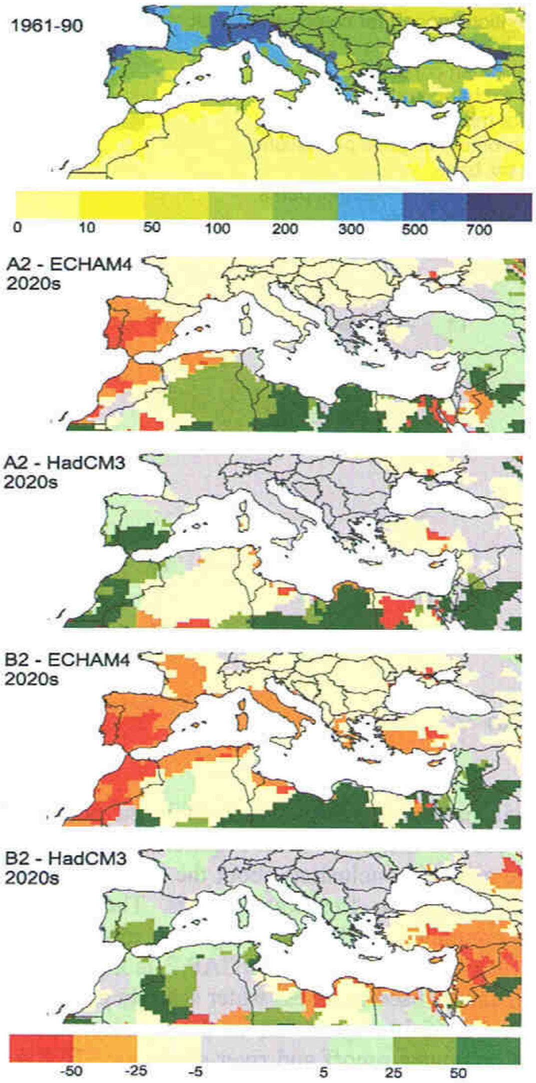
T1 Global demand for forest products
T2 UN convention support for community forest management
T3 GATT trade requirements
T4 World Bank loan conditions
T5 Currency exchange rates
T6 Support for mining
T7 Policy to promote oil palm plantations
T8 Regional tax base
T9 Designation of nearby national parks
T10 Local customary law
T11 Destructive use of forests by outsiders



Source: Wollenberg et al., 2000

In this chapter, I will present scenarios which show the potential impact of climate change on water resources and irrigation water requirements in the Mediterranean. They allow me to draw some general conclusions about the current possibilities for assessing the impact of climate change on freshwater issues. These climate change impact scenarios have been computed with the integrated global-scale model of water availability and water use WaterGAP 2. WaterGAP 2 is a global water resources and water use model which can be used to assess water scarcity problems [1]. With a spatial resolution of 0.5° by 0.5° (55 km by 55 km at the equator), the hydrological model WGHM of WaterGAP computes runoff and river discharge [7]. Fig. 2 (top) shows the long-term average water resources in the river basins of the Mediterranean region for the climate normal 1961-90, as computed by WGHM. WGHM was used to assess the impact of climate change on water resources. The studied climate change is based on the qualitative-quantitative global IPCC scenarios that show possible development paths between 1990 and 2100 [15]. The IPCC developed four global scenarios, which encompass both storylines as well as quantitative estimates of the development of population, Gross Domestic Product GDP, energy consumption and greenhouse gas (plus sulphate) emissions, distinguishing four world regions.

Figure 2. Long-term average water resources in the river basins of the Mediterranean region [mm/yr], computed by WaterGAP 2 for the climate normal 1961-90 (top), and percent change of water resources due to climate change between 1961-90 and the 2020s (bottom).



The storylines describe divergent futures along the lines of more or less globalization and more or less emphasis on the environment (Fig. 3). The differences among the storylines cover a wide range of key characteristics, such as technology, governance, and behavioral patterns.

Nakicenovic and Swart summarize the four storylines as follows (in their section 4.2.1):

- "The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. (...)
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels."

Figure 3. The IPCC global scenarios

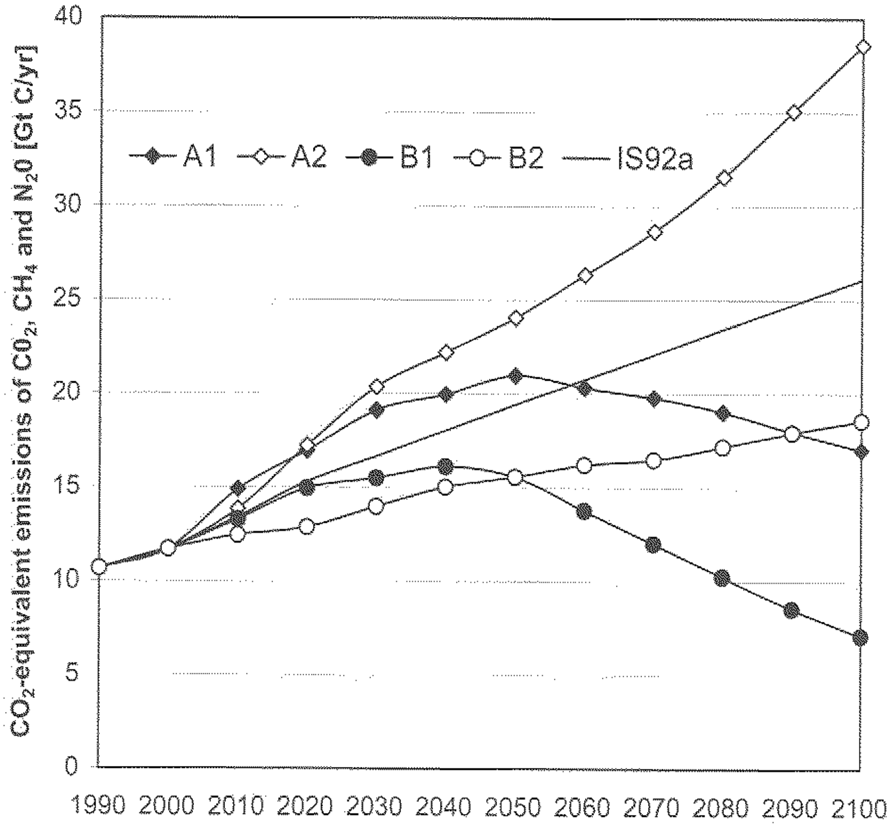
	oriented mainly towards economic growth	oriented mainly towards the environment and social innovation
globalized world	A1	B1
regionalized world	A2	B2

Source: Nakicenovic and Swart, 2000 [15]

In the following analysis, only the greenhouse gas (plus sulphate) emission scenarios A2 and B2 are considered. In the A2 scenario, considerably more greenhouse gases are emitted after 1990 than in the B2 scenario, as the latter assumes a more environmentally conscious development of society than A2 (Fig. 4). The temperature and precipitation changes resulting from the two different emission scenarios were taken from two state-of-the-art global climate models, the HadCM3 model [11] and the ECHAM4/OPYC3 model [16]. The spatial resolution of the HadCM3 model is 2.5° latitude by 3.75° longitude, while the spatial resolution of the ECHAM4 model is approximately 2.8° by 2.8°. The changes in simulated long-term average monthly precipitation and temperature between the 2020s (2020-2029) and the climate normal 1961-90 were first interpolated to the 0.5° grid and then applied as input to WGHM (by scaling the observed monthly precipitation and temperature time series from 1961-90). Fig. 2 (bottom) shows the computed impact of climate change on water resources in the river basins of the Mediterranean region.

Obviously, the computed impacts depend more on the applied climate model than on the assumed emission scenario. This is also true for the 2070s when the emissions differ

Figure 4. The SRES greenhouse gas emission scenarios of IPCC A1, A2, B1 and B2, as well as the older IPCC IS92a scenario, which has been the basis of most published climate change modeling results until approximately the year 2001.



between A2 and B2 even more than in the 2020s (not shown). With the ECHAM4 climate scenarios, water resources are reduced by 5% to more than 50% until the 2020s in almost all the drainage basins of the Mediterranean. With the HadCM3 climate scenarios, resources either increase or remain constant, except for Turkey and some parts of North Africa (Fig. 2). The discrepancy between the impacts as based on the two climate models results from the very different precipitation pattern that the two models produce. For the emission scenario B2, for example, ECHAM4 computes a strong reduction of precipitation for most of the Mediterranean between the climate normal 1961-90 and the 2020s, in particular the eastern part of the Iberian Peninsula, while HadCM3 results in an increase of precipitation in the western Mediterranean, Southern Italy and Greece. Global climate models still have a low capability to simulate precipitation, both historic and future distributions. While different climate models agree quite well with respect to computed temperature changes, they differ strongly with respect to precipitation changes. Please note that on the scale of river basins, the changes in water resources can be larger for B2 than for A2, even though the emission changes are much smaller (compare the Iberian Peninsula, ECHAM4 model, in Fig. 2) such that we cannot simply conclude that a reduction in greenhouse gas emissions will lead to less changes in water resources. The changes until the 2070s are generally larger than until the 2020s.

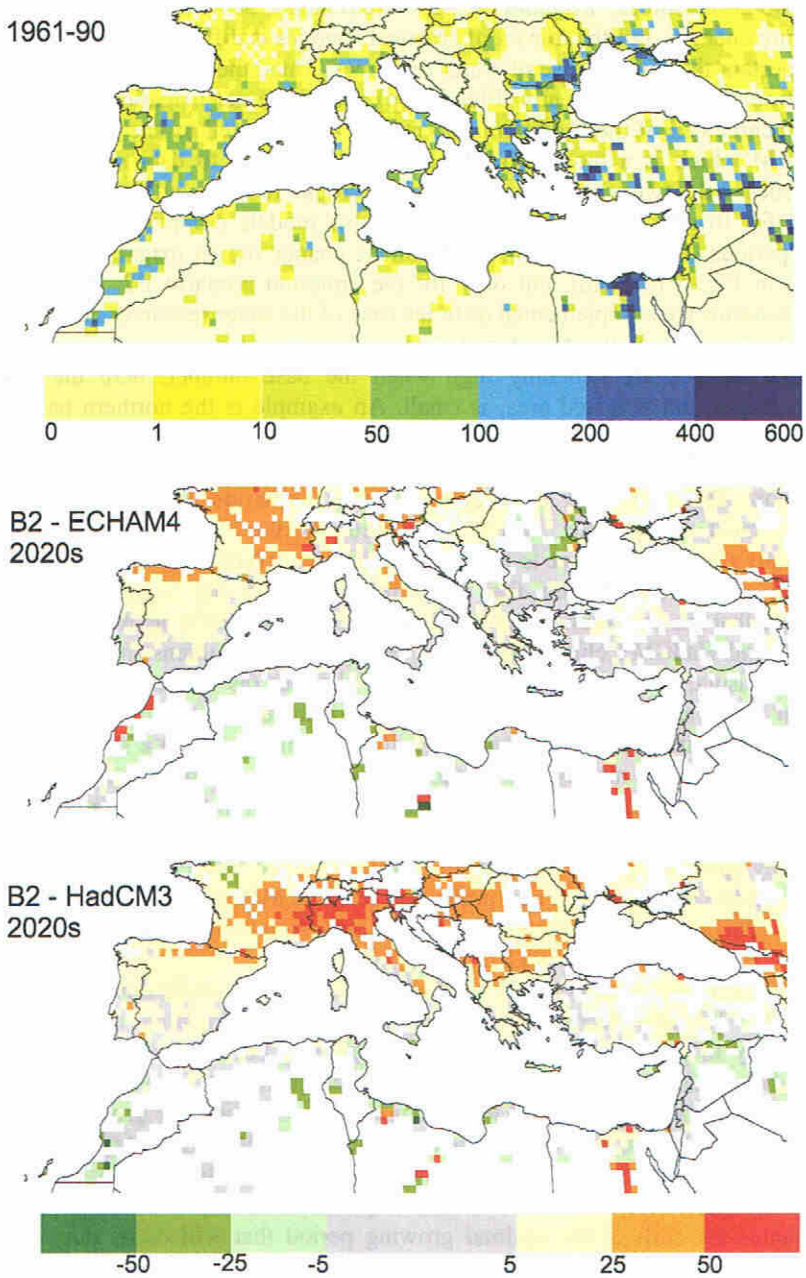
Like water resources, irrigation water requirements depend on precipitation and temperature changes, but the impact of seasonal changes is different, and temperature is more important than in the case of water resources. Thus, the uncertainty in simulating precipitation plays out differently. Fig. 5 (top) shows the net irrigation requirement in each 0.5 degree cell of the Mediterranean region, as computed by the Global Irrigation Model GIM which is a module of WaterGAP 2 [9]. Due to data restrictions, GIM distinguishes only two crops, rice and other crops. It takes into account the area equipped for irrigation and the climate, and also models cropping patterns and the growing periods. The potential impact of climate change on net irrigation requirements is shown in Fig. 5 (bottom), but only for the emission scenario B2. The two GCM climate scenarios were implemented as in the case of the water resources computations.

When looking at the climate induced changes in irrigation requirements, consider that percentage changes are generally high when the base number, here the irrigation requirement per unit irrigated area, is small. An example is the northern part of Italy with its low requirement per unit irrigated area, where a strong percentage increase of irrigation water requirements occurs if there are only a few days with a decreased precipitation. Different from the water resources scenarios, irrigation requirements increase almost everywhere, which is caused by the fact that irrigation water requirements are more sensitive to temperature than runoff (renewable water resources).

Another difference between the water resources and the irrigation requirement scenarios is that the irrigation requirement scenarios do not differ as much between the ECHAM4 and HadCM3 climate scenarios, except for the Balkans. In the case of the Iberian Peninsula, the rather similar pattern of changes (as compared to the strongly discrepant water resources changes, (Fig. 2), is explained mainly by the fact that the increase in precipitation as computed by HadCM3, which leads to a strong increase in water resources, occurs mainly outside the growing period. As an example, in a grid cell in Central Spain, annual precipitation increases from 428 mm to 443 mm in the case of HadCM3 and decreases to 319 mm in the case of ECHAM4. The precipitation during the 150-day growing period starting in April, however, decreases for both climate scenarios, from 134 mm to 120 mm in the case of HadCM 3 and to 96 mm in the case of ECHAM4. This results in an increase of the net irrigation requirement per unit irrigated area from 776 mm to 803 mm and 823 mm.

Thus, net irrigation requirements increase by 3% and 6% while annual precipitation increases by 4% and decreases by 25%, respectively. Irrigation requirements are sensitive only to precipitation changes in the growing period, such that shifts in the seasonal distribution of precipitation lead to different impact on water resources and irrigation requirements. Computed temperature changes during the growing period are rather similar, plus 0.9°C for HadCM3 and plus 1.0°C for ECHAM4. Another reason for the similarity of irrigation requirement changes between climate scenarios might be that GIM does not model the impact of climate change on a crop with a fixed growing period but simulates the shift of the optimal growing period that will occur due to climate change. Cropping patterns and growing periods are modeled based on precipitation and temperature [9]; the growing period during which optimal temperature and precipitation

Figure 5. Net irrigation water requirements in the Mediterranean region [mm/yr averaged over 0.5° cell area], computed by WaterGAP 2 for the climate normal 1961-90 and the irrigated areas of 1995 (top), and percent change of net irrigation requirements due to climate change between 1961-90 and the 2020s (bottom).



conditions prevail is determined, e.g. such that precipitation is high during the first 50 days of the growing period. In many cells, the two climate scenarios lead to a different shift of growing seasons towards the respective wetter and warmer period, which makes the irrigation requirements in two climate scenarios more similar [8].

4. Conclusions

The development of qualitative-quantitative scenarios is a state-of-the-art approach for assessing possible futures and thus for supporting sustainability-oriented regional planning. It is flexible because it can be applied to almost any type of problem, and with varying fractions of quantitative vs. qualitative analysis. If there is little data, little modeling experience and restricted funds, the fraction of the quantitative modeling analysis will be lower than in the case of good data, existing models and extensive funds. Still, the development of the then dominant qualitative part of the scenario will help to transfer knowledge between scientists and policy makers and will provide both scientists and policy makers with a clearer idea of possible futures and the options to achieve sustainable development. In a scenario analysis which explicitly considers scale issues, regional planners will learn about the feedback between global (or other coarser) scale developments and the development in their region.

From the scenario analysis of the impact of climate change on water resources and irrigation water requirements in the Mediterranean we conclude that

- due to the low capability of global climate models to realistically simulate precipitation, in a scenario analysis of climate change impacts for which precipitation change is a relevant driver (water resources, water use, agricultural productivity, erosion,...) it is advisable to apply the results from at least two different climate models
- the differences between the precipitation change patterns (and thus the derived water resources changes) as computed by two global climate models is often larger than the differences between the results of one model for two different greenhouse gas emission scenarios. Therefore, it might not be absolutely necessary to be consistent in a scenario analysis in which climate change impacts are compared to the impacts of the changes in other driving forces. It appears appropriate, for example, to use one emission scenario as interpreted by two climate models to compute two water resources scenarios and combine these scenarios with a water use scenario that is based on assumptions about the economic and demographic development that are not consistent with the respective assumptions for the emission scenario.

References

1. Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., and Siebert, S. (2003) Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences Journal* 48, 3, 317-338.
2. Alcamo, J. (2001) Scenarios as Tools for International Environmental Assessment. Environmental issue report 24, European Environment Agency, Copenhagen.

3. Alcamo, J., Henrichs, T., and Rösch, T. (2000) World Water in 2025. Global modeling and scenario analysis for the World Commission on Water for the 21st Century, Kassel World Water Series 2, Center for Environmental Systems Research, University of Kassel, Kassel. http://www.usf.uni-kassel.de/usf/archiv/dokumente.en.htm
4. Bell, M.L., Hobbs, B.F., Elliott, E.M., Ellis, H., and Robinson, Z. (2001) An evaluation of multi-criteria methods in integrated assessment of climate policy, *Journal of Multicriteria Decision Analysis 10*, 229-256, DOI 10.1002/mcda.305.
5. Cosgrove, W.J., and Rijsberman, F.R. (2000) World Water Vision: Making Water Everybody's Business. Earthscan.
6. Döll, P., and Krol, M. (2003) Integrated scenarios of regional development in two semi-arid states of Northeastern Brazil, *Integrated Assessment 3*, 4, 308-320
7. Döll, P., Kaspar, F., and Lehner, B. (2003) A global hydrological model for deriving water availability indicators: model tuning and validation, *Journal of Hydrology 270, 1-2*, 105-134.
8. Döll, P. (2002) Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic Change 54*, 269-293.
9. Döll, P., and Siebert, S. (2002) Global modeling of irrigation water requirements. Water Resources Research 38, 4, 8.1-8.10, DOI 10.1029/2001WR000355.
10. Farrell, A., Van Deveer, S.D., and Jäger, J. (2001) Environmental assessments: four under-appreciated elements of design. *Global Environmental Change 11*, 311-333.
11. Gordon, C., Cooper, C., Senior, C.A., Banks, H., Gregory, J.M., Johns, T.C., Mitchell, J.F.B., and Wood, R.A. (2000) The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics 16 2/3*, 147-168.
12. Janssen, R. (2001) On the use of multi-criteria analysis in environmental impact assessment in The Netherlands, *Journal of Multicriteria Decision Analysis 10*, 101-109. DOI 10.1002/mcda.293.
13. Müller, F., and Leupelt, M. (eds.) (1998) *Eco Targets, Goal Functions, and Orientors*, Springer-Verlag, Berlin.
14. Munda, G. (1995) *Multicriteria Evaluation in a Fuzzy Environment: Theory and Applications in Ecological Economics*. Physica-Verlag, Berlin.
15. Nakicenovic, N., and Swart, R. (eds.) 2000 Emission Scenarios. IPCC Special Report on Emission Scenarios, Cambridge University Press. can be downloaded from www.grida.no/climate/ipcc/emission/index.htm
16. Röckner, E., Arpe, K., Bengtsson, L., Christoph, M., Claussen, M., Dümenil, L., Esch, M., Giorgetta, M., Schlese, U., and Schulzweida, U. (1996) The atmospheric general circulation model ECHAM-4: Model description and simulation of present day climate, MPI-Report No. 218, MPI Hamburg.
17. Rotmans, J., van Asselt, M., Anastasi, Ch., Greeuw, S.C.H., Mellors, J., Peters, S., Rothman, D., and Rijkens, N. (2000) Visions for a sustainable Europe, *Futures 32*, 809-831.
18. Schwartz, P. (1998) The Art of the Long View, Wiley.
19. United Nations Environment Programme (UNEP) (2002) Global Environmental Outlook 3, Nairobi. (http://www.grid.unep.ch/geo/geo3/index.htm)
20. Wollenberg, E., Edmunds, D., and Buck, L. (2000) Using scenarios to make decisions about the future: anticipatory learning for the adaptive co-management of community forests, *Landscape and Urban Planning 47*, 65-77.