Chapter 18
A Top-Down Meets Bottom-Up Approach for Climate Change Adaptation in Water Resource Systems

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Abstract The adaptation to the multiple facets of climate/global change challenges the conventional means of water system planning. Numerous demand and supply management options are often available, from which a portfolio of adaptation measures needs to be selected in a context of high uncertainty about future conditions. A framework is developed to integrate inputs from the two main approaches commonly used to plan for adaptation. The proposed "top–down meets bottom–up" approach provides a systematic and practical method for supporting the selection of adaptation measures at river basin level by comprehensively integrating the goals of economic efficiency, social acceptability, environmental sustainability, and adaptation robustness. The top-down approach relies on the use of a chain of models to assess the impact of global change on water resources and its adaptive management over a range of climate projections. Future demand scenarios and locally prioritized adaptation measures are identified following a bottom-up approach through a participatory process with the relevant stakeholders and experts. Cost-effective combinations of adaptation measures are then selected using a hydro-economic model at basin scale. The resulting adaptation portfolios are climate checked to define a robust program of measures based on trade-offs between adaptation costs and reliability. Valuable insights are obtained on the use of uncertain climate information for selecting robust, reliable, and resilient water management portfolios. Finally, cost

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Climate Adaptation Modelling, Springer Climate,
https://doi.org/10.1007/978-3-030-86211-4_18

allocation and equity implications are analyzed through the comparison of economically rational results (cooperative game theory) and the application of social justice principles.

Keywords Climate change adaptation · Water management · Robustness · Climate check · Top-down · Bottom-up

Introduction

Uncertainty and Adaptation in Water Resource Systems

The challenge of adaptation in water resource systems (WRS) includes coping with high/deep uncertainty about future resources ("end of stationarity") and demands. Water management problems, often classified as "wicked" management problems, involve dealing with multiple stakeholders with conflicting interests in a context of great complexity and shifting dynamics. There is a very broad range of potential adaptation options with different environmental and socioeconomic implications. Adaptation to climate/global change challenges the conventional means of water system planning, calling for a new paradigm in water management.

In any case, uncertainty cannot be an excuse for inaction. Flexible and dynamic adaption policies are to be set. Effective adaptation should combine both structural and non-structural measures, including regulatory and economic instruments. Selected adaptation is expected to be economically efficient, environmentally sustainable, socially acceptable, and robust. These are key requirements for the success of adaptation strategies. However, the integration of these factors in the decision-making process of the adaptation is a very complex issue still to be solved. This work presents a framework to include these attributes in the development of adaptation portfolios for river basins or WRS.

Top-Down Versus Bottom-Up Adaptation Strategies

Two main approaches are commonly implemented in the design of climate change adaptation plans. The "top-down" (TD) approach involves downscaling climate projections from General Circulation Models (GCM) under a range of emission scenarios to provide inputs for hydrologic and management models to estimate potential impacts and analyze adaptation measures. But this approach faces the problem of the "cascade of uncertainties", with uncertainty expanding at each step of the process when going from the global and regional projections to the study of the local impacts used to define the adaptation responses (Wilby and Dessai 2010).

Alternatively, in a "bottom-up" (BU) approach, vulnerability thresholds and local responses are empirically studied to define locally suitable adaptation strategies.

There are several interpretations of BU. Some authors refer to it when using local knowledge through participative approaches to foresight future scenarios and define locally relevant adaptation strategies (e.g., Bhave et al. 2014; Girard et al. 2015a), view adopted herein. Other authors consider BU as a scenario-free, robustness-based planning process; for example, in the "decision-scaling" approach (Brown et al. 2012; Poff et al. 2016; Ray et al. 2019). As for the later view, unlike the top-down method, the BU approach relies more on possibilities than on probabilities (Blöschl et al. 2013). However, this approach also depends on top-down information when assigning the probability to risky future climate conditions or selecting adaptation measures (e.g., Ray and Brown 2015).

Several authors have discussed the benefits of integrating TD and BU in the adaption process (e.g. Wilby and Dessai 2010; Ekström et al. 2013), although only a few studies have combined them in practice. We, herein, describe a framework for robust adaptation decision-making that departs from traditional methods, lying in the interface between the two aforementioned approaches. The purpose is the selection of portfolios of supply–demand measures for adaptation to climate change integrating the objectives of economic efficiency, environmental sustainability, acceptability, and robustness at basin scale.

Our views are shaped by recent experiences of developing adaptation strategies in two Mediterranean basins in France and Spain. In the Orb basin (1580 km^2), South-East France, climate change is expected to exacerbate the difficulty in meeting growing demands (high population growth and expectations of quick expansion of irrigated vineyards) while maintaining environmental in-stream flows. The management of the Jucar basin, Eastern Spain, larger (22,260 km^2), highly regulated, and with high share of water use for irrigation (around 80%), is already challenged by water scarcity and long recurrent multiannual (4–5 years) droughts.

Bottom-Up Approach

There are two main approaches for developing future land and water use scenarios for agriculture. One option is modeling land-use change (LUC) (e.g. Pulido-Velazquez et al. 2015). LUC modeling requires determining the drivers of change and spatial land use allocation applying machine learning techniques to historical observations. Using a combination of neural networks and cellular automata that learns from the past, we can translate regional projections from global scenarios into a map of future agricultural land use. The other option is the use of participatory approaches, involving the relevant actors through scenario-building workshops to develop plausible alternative futures (e.g., Rinaudo et al. 2013; Faysse et al. 2014).

Developing Future Demand Scenarios Through Scenario Building Workshops

Qualitative or quantitative approaches can be applied for the development of future scenario through a participatory approach. Qualitative scenarios can be useful for generating ideas and strategies and incorporating multiple viewpoints, bridging gaps among experts, decision-makers, and stakeholders Quantitative land-use scenarios, in contrast, describe plausible futures using numerical descriptions and spatial allocations of land uses associated with a potential pathway (Mallampalli et al. 2016). We adopt a mixed approach, using narrative texts (storylines) and translating them into quantitative scenarios. Next, the impacts triggered by the expected changes are assessed through model simulations. There is a broad range of methods for translating narrative scenarios into quantitative assessments of land use change (Mallampalli et al. 2016).

To identify future irrigation water demand in the Orb case study under climate change, we first defined future scenarios of land use changes through workshops. Agroclimatic simulation models were then used to determine the changes in irrigation needs (Girard 2015). Monthly average water demands were computed for nine climate projections. Future urban demand was also estimated using an econometric model, based on population, average household income, price, and climate.

As agriculture is by far the main water use in the Jucar basin, the characterization of future scenarios of this sector is crucial for water management. A first round of expert interviews were carried out to identify main drivers and trends in the agricultural sector in the basin. The interviews were helpful for adapting the main elements of the narratives of selected global Shared-Socioeconomic Pathways (SSPs) to the local context. The SSPs describe potential socioeconomic futures addressing different challenges in relation to both mitigation and adaptation policies (O'Neill et al. 2017). We conducted two focus workshops with representatives from the local agricultural sector in the two main agricultural areas to discuss two contracting SSPs global scenarios: SSP3 (regional conflicts, reversed globalization trends, with high challenges for both mitigation and adaptation) versus SSP5 (accelerated globalization, with low challenges for adaptation but high for mitigation). Global narratives were translated into local storytellings and depicted as fake future (2030) news in two local newspapers (Ortega-Reig et al. 2018). Local participation was key for developing an integrated vision of the evolution of agriculture and implications for water management in the context of the two SSPs and the climate change conditions corresponding to RCP 8.5. Changes in crop types, irrigated crop areas, and irrigation practices were discussed in accordance with the future socioeconomic and climate conditions presented to the participants. The associated changes in irrigation water requirements were estimated using crop simulation models considering climate change impact, which allowed to determine future water demand for the region.

Developing Portfolios of Water Management Adaptation Options at the Basin Scale

For the Orb river basin, after developing scenarios about the most likely evolution of urban and agricultural water use in the basin by 2030, possible adaptation measures were screened (Girard 2015). A first catalog of measures was elaborated by combining literature review and personal communications with consultation workshops involving local experts and stakeholders. Planned adaptation included optimization of reservoir operation, further development of groundwater, desalination, improved efficiency of large public agriculture irrigation schemes, leakage reduction in municipal water distribution networks, and implementation of tariffs as water conservation incentives (Girard et al. 2015a). Autonomous adaptation included water conservation actions at households, municipal services, and commercial activities under incentives. The stakeholder consultation process led to the identification of a list of priority measures (462 possible local measures of 13 types), while other measures were discarded (e.g., rainwater harvesting, wastewater reuse) based on technical, economic, legal, or acceptability criteria.

A participatory approach was also used in the Jucar basin for developing the portfolio of adaptation options for future scenarios. The suitability at basin scale of the adaptation measures previously proposed by the farmers was discussed at a third workshop that involved representatives of the main stakeholders in the basin (policymakers, users from agriculture, urban and hydropower sectors, environmentalist groups, etc.). After introducing each adaptation measure, participants discussed feasibility and potential implementation barriers, and graded each measure (both quantitatively and qualitatively) using an interactive participatory presentation platform through their mobiles. The qualitative assessment defined each measure as priority or supplementary, and identified potential-related issues (environmental impacts, social support, lack of training, political divisiveness, funding, effectiveness, and operational cost). Each measure was graded by the participants in a 0–10 scale (where 0 was meant for rejection) (Marcos-Garcia 2019). The measures consist of a new desalination plant, a wastewater reuse project, substitution of pumping by surface water in Mancha aquifer, and increase in irrigation efficiency by modernization (from flood to drip irrigation). Each measure was characterized in terms of water yield (effectiveness) and cost.

Top-Down Impact Assessment

The top–down approach starts by selecting a set of climate projections considering several emission scenarios and GCMs Models to account for uncertainty. These climate projections are then downscaled and bias-corrected to construct local climate change projections using dynamic or statistical downscaling techniques.

Local climate change projections are used as input to hydrological models to simulate the impact on the available resources. The local climate projections are also the input for the agro-climatic models.

For the Orb case, we used climate scenarios downscaled from nine GCMs. In order to capture the range of impacts introduced by climate change, results of all climate projections were considered equally likely. Large variations were observed in the results for the different climate models. A monthly lumped two-parameter rainfall-runoff model, forced by historical climatic data (precipitation and potential evapotranspiration) was calibrated and validated on each of the 11 sub-basins using the observed monthly discharge (Girard 2015).

For the Jucar case, combinations of GCMs-RCMs for the case study where selected by comparing observed versus simulated time series of mean annual precipitation and temperature for the control period (1971–2000). Hydrological changes were obtained from a Temez rainfall-runoff model modified to improve the simulation of stream–aquifer interaction. The resulting inflows in the climate change scenarios showed great variability across GCM/RCM model combinations, revealing high uncertainty in future water availability. Results also highlighted the spatial variability of climate change impacts in the basin. Temperature increase and precipitation decrease would be higher in the upper basin, where most reservoir storage capacity is located. Both meteorological and hydrological droughts are expected to grow in intensity, magnitude, and duration (Marcos-Garcia et al. 2017).

Integrating Top-Down and Bottom-Up Approaches

Monthly inflow time series for each climate projection at each subbasin obtained from the top-down approach and adaptation measures selected in the BU were integrated into a water management model used as decision support system (DSS) for the definition of adaptation strategies to climate change. The DSS consisted in a hydroeconomic model of the basin that, through optimization, selects the most cost-efficient combination of adaption measures for future scenarios. Hydro-economic models enable the definition of economically efficient adaptation by integrating hydrologic, engineering, environmental, and economic aspects of water resource systems within a coherent framework (Harou et al. 2009). They have been applied to assessing climate change impacts and the value of adaptation strategies for water systems (e.g. Escriva-Bou et al. 2017).

In the Orb basin, a river basin optimization model was used to select the combination of adaptation measures that minimizes the total annualized cost of adaptation while meeting the demand and minimum in-stream flow targets (Girard et al. 2015a, b). Constraints were defined to ensure certain reliability of deliveries to urban and agricultural demands and fulfillment of minimum environmental flow requirements. 11 subbasins, 64 urban and 19 agricultural demands were considered in the optimization model, which selected the optimal adaptation among 347 measures over 20 years of future monthly inflow. Optimal portfolios of lower cost measures were obtained for each future climate and land use scenario. The different portfolios of measures were characterized in terms of cost and reliability. In order to test the robustness of the optimal strategies, the performance of each of the nine portfolios was tested across the other climate projections, considering tradeoffs between adaptation cost and reliability of supply to agricultural demands. A multicriterion method was used to identify the most robust and least regretful solutions (Girard et al. 2015a).

In the Jucar basin, a water management hydroeconomic model integrating environmental restrictions, allocation rules (in accordance with Spanish and river basin regulations), and existing agreements was used to identify economically efficient adaptation strategies. For most climate scenarios, the selected measures allow to significantly reduce the average annual water deficit in the system.

Addressing Equity in Cost Allocation

Stakeholders will only agree to implement actions prescribed by a cost-effective plan if perceived as equitable. Cost-allocation scenarios were first designed by applying cooperative game theory based on the principle of economic rationality. The results were then contrasted with cost allocation scenarios representing alternative principles of social justice, investigated through semi-structured interviews with key local actors to obtain insights on the definition of a fair allocation of adaptation cost within the basin (Girard 2015). The comparison of the cost allocation scenarios led to contrasted insights to inform the decision-making process and potentially reap the efficiency gains from cooperation in the design of river basin adaptation portfolios (Girard et al. 2016).

Conclusions and Recommendations

The main contribution of this work is the development of a framework to identify adaptation options to climate change at the basin through the combination of a top-down (TD) approach to assess climate change impacts at the local scale with vulnerability assessment and definition of socioeconomic scenarios and adaptation options through participative methods (BU approach). The proposed “TD meets BU” approach provides a systematic and practical method for supporting the selection of adaptation measures at the basin by comprehensively integrating the goals of economic efficiency (through river basin optimization), social acceptability (through BU definition of scenarios and measures, and by addressing equity in cost allocation), environmental sustainability (through environmental constraints in water management), and robustness (testing robustness of adaptation portfolios across scenarios, and selecting robust/least-regret programs).

The “scenario foresight” approach has been shown to be useful for a BU exploration of local alternative futures. Experts and farmers have helped to analyze in a structured way the consequences of various global scenarios of climate and socio-economic change on future agriculture in a local context, and identify adaptation measures. Scenario workshops can usefully supplement modeling methods in the design and assessment of climate and global change scenarios and the selection adaptation strategies.

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