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Selecting and analysing climate change adaptation measures at six research sites across Europe

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Abstract

As Europe is faced with increasing droughts and extreme precipitation, countries are taking measures to adapt to these changes. It is challenging, however, to navigate through the wide range of possible measures, taking into account the efficacy, economic impact and social justice aspects of these measures, as well as the governance requirements for implementing them. This article describes and evaluates an approach to selecting and analysing climate change adaptation measures that was applied at six research sites across Europe. It describes the steps that were taken in collecting, selecting and analysing adaptation measures, in a process with local stakeholders, with concrete examples from the case studies. The governance analysis focuses on the requirements associated with the measures and the extent to which these requirements are met at the research sites. The socio-economic impact focuses on the efficacy of the measures in reducing the risks and the broad range of tools available to compare the measures on their societal impact. Finally, the social justice analysis focuses on the distributive impacts of the adaptation measures. In the discussion, we identify some key findings with regard to the different kind of measures. In the conclusion we briefly assess the main pros and cons of the different analyses that were conducted. The main conclusion is that although the research sites were very different in both the challenges and the institutional context, the approach presented here yielded decision relevant outcomes.

1 Introduction

Along the process of adapting to climate change, finding and defining appropriate adaptation measures is an obvious but at the same time complex task. Moreover, it is the key activity to increase the resilience to future climate change induced risks (Dogulu and Kentel, 2015). In addition, good practice in selecting adaptation measures is a fundamental task in adjusting water infrastructure to climate change, which is globally needed (Wilby, 2019).

This article presents the approach of selecting and analysing adaptation measures to increasing extreme weather events caused by ongoing climate change, that was developed and applied in the H2020 project BINGO (Bringing Innovation to Ongoing Water Management). The project was conducted by over 20 project partners at six research sites in Europe, ranging from the island of Cyprus to the city of Bergen, Norway. The project followed a comprehensive approach from decadal predictions of weather events, hydrological analysis of the impact of the weather events on water systems, to risk analysis and risk treatment.

The work presented in this paper focuses on the treatment of risks following extreme precipitation or drought. Risk treatment in project BINGO was organised as a collaborative process between scientists and local stakeholders, through the so called Communities of Practice (CoPs). Based on the risks that were identified and analysed in the risk analysis, the CoPs selected and analysed adaptation measures, with the goal of informing decision makers about the expected efforts and gains for the implementation of these measures. The next paragraphs describe the process of selecting and analyzing promising adaptation measures in the logic order as conduced within the BINGO project for all cases: (1) Collecting and selecting adaptation measures, (2) governance analysis of selected adaptation measures (3) analysis of socio-economic implications (4) social justice analysis. These steps are illustrated with examples from the case study in the city of Badalona, Spain as well as from other sites in brief. Finally, in the discussion, we will draw some general conclusions based on the results from all six cases.

2 Collecting and selecting adaptation measures

Two approaches were taken to collect potential adaptation measures suitable to the climate change risks identified at the six research sites, namely a desk study of previous adaptation research and consultation of stakeholders involved in the local CoPs. With regard to the desk study, the primary sources for adaptation measures were two previous EU research projects CarpathCC and PREPARED. From both projects databases were available with adaptation measures including a brief analysis of their potential impact and risk reduction potential. From these databases the BINGO research partners selected measures potentially relevant for the hazards the research sites are facing (based on initial hazard and risk identification analyses also performed within BINGO). At the same time, in each of the six research sites the first CoP meeting was organised. In this meeting, local stakeholders discussed and identified potential future hazards as a result of climate change for their research site and identified adaptation measures that were either already planned or considered suitable. These measures were collected as part of the workshop reports (Van Alphen et al., 2017a) and compiled, together with the measures collected in the desk research, as the portfolio of adaptation measures (Van Alphen et al., 2017b). The Portfolio of Adaptation Measures is now available as an online tool, which is accessible to anyone who is interested in adaptation measures to extreme weather events. In the portfolio, different types of measures are distinguished. Informational measures (such as raising awareness for behavioral change), financial measures (such as insurance and subsidies), regulatory measures (such as standards and legal bans) and infrastructural measures (technical and bio-physical changes).

A first assessment of potential risks at the research site was then made and discussed with stakeholders. Local stakeholders could make a first closer selection of adaptation measures from the longlist provided by the project team and/or the measures that were developed locally. This first selection of measures was done by focusing on the following governance aspects related to the measures: (1) responsibility for implementation, (2) participation/division of roles, (3) availability of necessary resources; (4) potential challenges. During the CoP meetings at the six research sites, these issues were discussed for the different measures and a selection was made either through scoring or through voting. For instance, in the case of Cyprus, measures were first scored in relevance and feasibility and then voted on by the stakeholders.

3 Governance analysis of selected adaptation measures

3.1 Three Layer Framework

The Three Layer Framework for Water Governance, a tool for assessing water governance practices (Havekes et al., 2016), was used for analyzing the governance needs of the adaptation measures. The framework builds on the work done by the Organization for Economic Co-operation and Development (OECD 2011) on governance gaps in water governance, and elaborates on these gaps with the building blocks for good water governance identified by the Dutch Water Governance Centre. The framework distinguishes between three layers of governance: the *content layer*, the *institutional layer* and the *relational layer*. For the purpose of this study, the framework has been adapted to assess the governance requirements for the implementation of the adaptation measures.

First, the *content layer* looks into the substance of adaptation measures. Measures are characterized by the risk that they address (such as from floods, combined sewer overflows or droughts) and the type of intervention (informational, financial, regulatory, infrastructural). Also, the content layer addresses the type of knowledge and expertise needed to implement the measure (technical knowledge, administrative knowledge, knowledge about interest and preferences). Second, the *institutional layer* deals with the broad range of organizational requirements for the implementation of adaptation measures. This entails: (1) the involvement of the necessary actors and a clear division of roles and responsibilities between them; (2) the administrative resources to implement the measure, such as staff, accounting and monitoring capacities, regulatory capacity and knowledge infrastructure; (3) the legal requirements and the connection with EU regulation, policy and directives; and finally (4) the financial requirements and the way these funds can be generated. Third, the *relational layer* of the framework refers to the requirements placed on the wider governance context of adaptation to climate change. This entails: (1) the potential cultural or ethical issues that may support or obstruct implementation of adaptation measures; (2) the requirements with regard to public accountability, communication and participation. Based on this Three Layer Framework, a questionnaire was developed to assess each individual measure selected by the research sites partners. The questionnaires were filled in by the research partners or in a collaborative effort with experts and local stakeholders.

3.2 Application in the Badalona case

Following the methodology outlined above, three adaptation measures were selected for the Badalona research site with the objective of minimizing the impacts of urban floods and combined sewer overflows. These include: an increase of inlets, drainage and retention capacity; the development of Sustainable Urban Drainage Systems (SUDS) and the implementation of an Early Warning System (EWS).

For each one of the adaptation measures a thorough analysis of the governance assessment was performed by following the expert analysis of the three-layer-framework. The results of the analysis demonstrate that: (1) the structural measure (increase of sewer capacity) meets the knowledge and legal requirements (this measure was already included in the Drainage Master Plan of 2012) but does not have the financial, organizational and relational requirements for its implementation; (2) the SUDS development meets the technical and relational requirements (it has quite support given it is a "green solution") but does not meet the financial, legal and organizational requirements to foster its implementation; (3) the Early Warning System meets almost all the requirements except from the relational layer regarding public accountability, communication and participation.

This governance assessment (together with the socio-economic assessment explained next) has allowed the Badalona City Council to have a clear roadmap to support decisions towards urban adaptation.

4 Analysis of socio-economic implications

4.1 Challenges in analysing socio-economic implications of climate change adaptation measures

To achieve a viable climate change adaptation is a complex task that is highly dependent on factors such as the financial means of involved stakeholders and the social impacts that the implementation of a measure is accompanied by. A variety of potential adaptation measures exists, with various costs and benefits of implementation. The availability of data to analyse and compare alternative solutions poses a challenge to the decision maker. This issue is also linked to the decision-making process as different decision criteria are available to different stakeholders. These range from financial criteria (e.g. tangible costs and benefits), to non-monetary criteria, such as technical effectiveness, co-benefits or welfare implications. All of this indicates that finding a suitable analytical framework to assess the socio-economic implications for decision making in climate change adaptation is a major challenge (Markanday et al., 2019; Dogulu and Kentel, 2015).

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4.2 Guidance in selecting fitting analysis frameworks

Within the BINGO project a so called toolbox was compiled that summarizes the state-of-the art suitable methods for evaluating and comparing alternative strategies and measures for climate change adaptation (Koti et al., 2017). This toolbox has been used as a background framework to analyse and prioritize fitting risk reduction measures for the six research sites, customized to local stakeholders' needs. The experiences made during this process can be generalized for future applications, giving the analyst a straightforward guideline which evaluation approach to choose. The work conducted in the BINGO project inter alia resulted in the preparation of a decision tree that supports stakeholders to identify suitable assessment methods, respectively depending on their requirements and preferences to the analysis process. Complementing the comprehensive BINGO-toolbox, the decision tree in fig. 1 focuses on those analysis frameworks applied in the BINGO-case studies.

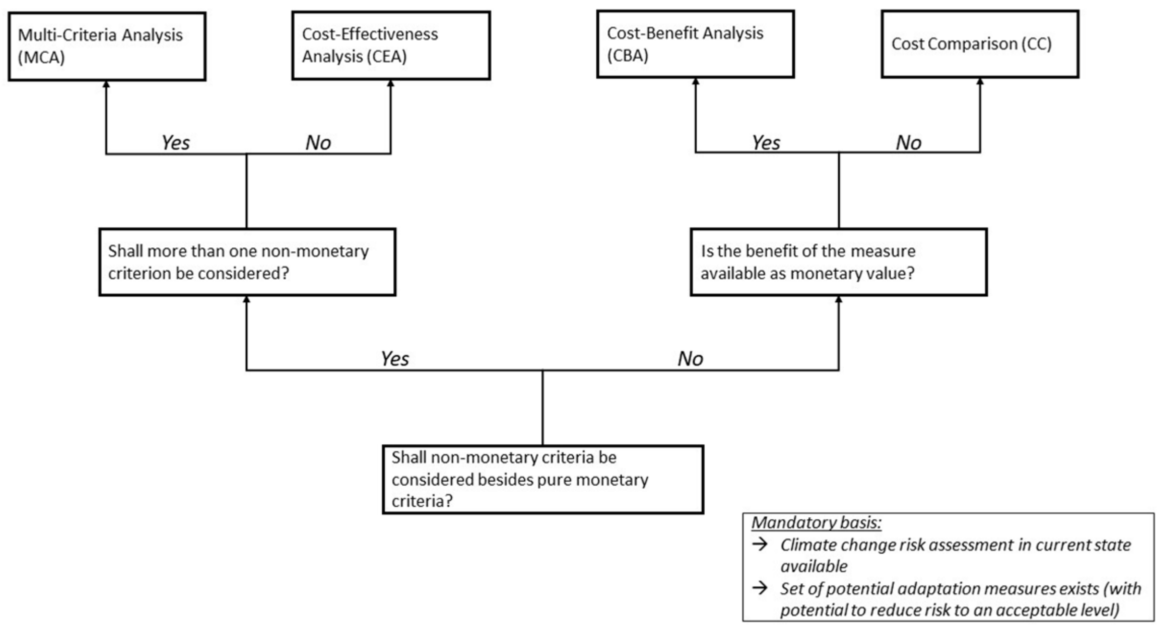

Figure 1: Decision tree supporting the definition process of a fitting analytical framework to evaluate socio-economic implications of climate change adaptation measures

The application of the decision tree presupposes the definition of potential adaptation measures. This is due to the fact that the provided methods aim to support the analyst in prioritizing a set of potential adaptation measures instead of giving the analyst a support in finding measures from scratch. The work conducted in the BINGO case studies showed that the nature of potential adaptation measures (e.g. infrastructural measures, behavioural measures, etc.) might have a major influence on the requirements of the analysis methods and relevant indicators, underlining the importance of determining the set of adaptation measures before the definition of a suitable analysis method. The methodology described in part 1 represents a suitable

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approach for this presupposed step. Furthermore, a risk assessment in the current state must be conducted before the analysis to enable the decision maker to check if the different measures have the potential to reduce the existing risks to an acceptable level. The case study of the Große Dhünn reservoir might serve as an example to indicate this importance. Here efforts were made to analyse the cost-effectiveness of the measure "water savings", although in a later stage this measure turned out to be insufficient to reduce the risk to an acceptable level. In case of a preliminary and rough examination of the respective measures' risk reduction potential, many efforts in later stages can potentially be saved. If both requirements are fulfilled, the analyst may follow the procedure of the decision tree. To do so, the question of the box at the bottom of the tree has to be answered with yes or no. Depending on the given answer, the analyst is led to the next box via one of the two arrows labelled with yes and no. This procedure is repeated one stage above, finally leading the analyst to one of four analysis frameworks. These frameworks are Multi-Criteria Analysis (MCA), Cost-Effectiveness analysis (CEA), Cost-Benefit Analysis (CBA) and Cost-Comparison (CC).

For the selection process on which evaluation framework will be applied and thus for the use of the decision tree, the integration of all relevant stakeholders that are affected by the adaptation measures turned out to be of high importance. These stakeholders might be water boards, relevant authorities, NGOs, farmers, local residents or similar. The experiences made in the BINGO case studies showed clearly that all stakeholders have to get the chance to express their points of view and major concerns. This holistic integration enabled the definition of sets of criteria that were considered in the prioritization of adaptation measures and that ensured the final acceptance of the results of all stakeholders. In turn, an omission of this broad stakeholder integration might lead to a lack of stakeholders' acceptance of the analysis results and thus to potential major barriers in the realization of the finally chosen adaptation measures.

Limitations in the final choice of an evaluation framework are possible due to insufficient data availability, e.g. because required data does not exist or because the efforts to get the required data is incommensurate with the gained benefits.

The following sections briefly highlight the decision support frameworks as proposed in fig. 1. Moreover, they indicate why and in which case studies of the BINGO project the decision support frameworks have been successfully applied. This is not a comprehensive presentation of the analysis results, since an extensive presentation would be out of the limits of this article. Details can be found throughout the documentation in BINGO project reports (current webpage: http://www.projectbingo.eu/resources and after migration soon: http://bingo.web.spi.pt/).

4.3 Cost-Benefit Analysis

A CBA is a valuable framework to obtain a rank of available options in monetary terms. It is a commonly used approach to prioritize flood risk reduction measures for climate change adaptation (Penning-Rowsell et al. 2010, Zhou et al. 2012). Costs represent the resources necessary to implement a certain measure. In this context, benefits account for the expected reduction of monetary damages brought by the measures implementation. In addition, co-benefits can be included for measures that

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improve ecosystem services provision, such as green infrastructure, which are evaluated in monetary terms by available valuation methods (OECD 2018, Gerner et al. 2018, Hanley and Barbier 2009).

A CBA was conducted for the Badalona case study, due to suitability with the data available and general interest among stakeholders. The costs of the measures under assessment contain: (1) initial investments, included gradually in a linear trend following the assumptions of future implementation times, (2) operating costs for the time horizon of the analysis (set until 2100), (3) rehabilitation and disposal costs, considering technical assumptions on the duration of the assets.

Benefits were assessed using the avoided cost methods, consisting in the estimation of the difference between estimated damages in the baseline scenario and in each of the alternative scenarios. Expected Annual Damage (EAD) is used as the indicator (Martinez-Gomariz et al., 2019), developed previously for Badalona risk assessment from historical data of the National Reinsurance Consortium (Consorcio de Compensación de Seguros). In addition, for the green roof and other green areas proposed as measures, ecosystem service benefits were identified as regulating (air quality and temperature control), supporting (habitat creation), and cultural (aesthetic) services. Monetization of the changes on the environmental variables were estimated using market prices for the marketed items (e.g. reduction of electricity consumption from temperature control), and also non-market prices for those items that do not have a market for trade (e.g. increase of property value after green roof implementation). For non-market prices, benefit transfer method has been applied, using reference studies and adapting the values in economic and size terms. For more details on the methodologies and results, please refer to the deliverable D5.3 of the project.

4.4 Cost-Effectiveness Analysis

The core idea of a CEA is to relate the costs of a measure to its effectiveness, like the technical performance (Levin and McEwan 2001). Both key figures, the costs as well as the effectiveness, which is measured with a suitable indicator, need to be quantified to calculate the ratio. Within BINGO, a CEA was used in the case study of the so called Große Dhünn reservoir in the western part of Germany. The reservoir, operated and owned by the Wupperverband (regional water board), usually stores up to 81 M. m³ of water especially used for drinking water production, supplying up to 1 M. people. In this case the risk assessment conducted in the project pointed out the potentially hazardous event of more than 1,000 days with an insufficient reservoir water storage (defined as less than 35 M. m³ water storage) in the worst case decadal climate change projections. Therefore, the focus of this case study was to explore infrastructural and non-infrastructural adaptation measures that reduce the risk to an acceptable level. The most important indicator to assess a potential measure was a non-monetary indicator, namely its technical performance which was defined as the additional amount of available water per anno. The Wupperverband had the capacities to simulate the additional amount of water by simulating a reduction of the low water elevation (non-infrastructural measure) and by simulating a transfer pipeline from the so called Kerspe reservoir to the Große Dhünn reservoir (infrastructural measure). Moreover, the additional water availability by a new horizontal well (infrastructural measure) and

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by water saving devices coupled with water use restrictions as emergency action (non-infrastructural measure) could be estimated. The data availability allowed a cost estimation for all four measures. Thus, a cost-effectiveness analysis was the best fitting decision support method in this case, offering the possibility to rank technically and/or organizationally feasible risk reduction measures by their cost-effectiveness ratio, advising the Wupperverband and other regional stakeholders in the prioritization of climate change adaptations for their regional situation. More details can be found in Strehl et al. (2019a).

4.5 Multi-Criteria Analysis

An MCA describes a class of analysis methods that consider a variety of different parameters to achieve a prioritization of the potential measures. One very common manifestation is the weighted sum method. To apply this method, first the stakeholders affected by the potential adaptation measures have to agree on a set of relevant indicators to evaluate the impacts of the different measures. Afterwards the stakeholders have to give a weighting to each indicator. In the subsequent step each indicator is evaluated by the stakeholders with respect to its manifestation for each respective measure, e.g. by applying a scale from 1 (negative manifestation) to 5 (positive manifestation). It is crucial that this evaluation is normalized for each indicator so that no additional, unintended weighting is given to the indicators. Finally, the score for each measure is determined by summing up the products of the weighting and the evaluation score of each measure. These final scores serve as ranking of the measures (Carrico et al. 2014).

An application example for this methodology is given by the Veluwe case study. The Veluwe is a region in the Netherlands dealing with hazards of long-term droughts and warming/heat stress. To reduce the risks connected to these hazards, three potential adaptation measures were identified, namely the reduction of areas covered by pine-trees, the implementation of surface water infiltration and a limitation of sprinkler irrigation. As a separate cost-effectiveness analysis was conducted in the Veluwe case, an MCA was chosen as second decision support that focused on 19 different non-monetary criteria that the group of relevant stakeholders agreed on. This methodology enabled a focused investigation of the manifestation of different non-monetary criteria besides the cost-effectiveness analysis, allowing to take a well-founded and holistic decision for or against the respective adaptation measures. For detailed information, please refer to deliverable 5.3 of the BINGO project (Strehl et al. 2019a).

4.6 Cost Comparison

Cost comparison (CC) is a dynamic approach used to compare the costs. Investment expenditures as well as operational expenditures for implementing and operating an adaptation measure are accounted for along the lifetime of a measure, also minding discounting. From a finance-mathematical point of view two ways are common in literature and practice: either accounting and comparing costs for measures by the present value or by annual costs, calculated by applying the annuity method (Götze et al. 2015, DWA 2012). The advantage of a CC in general is that it allows a straightforward comparison of adaptation measures by one single common criteria. Thus, this method is a viable approach to support decision making in climate change adaptation if only cost data is available for potential adaptation measures, or if the costs are the most important criteria and other criteria are negligible.

Within the BINGO case studies, no solely CC was conducted as the data availabilities in all case studies allowed a more complex analysis, incorporating more than one single criteria for decision support analysis. However, the underlying methodology for a CC was used in many of the case studies, e.g. to calculate the annual costs for adaptation measures in the case study for the Große Dhünn reservoir.

4.7 Combining frameworks

The decision tree explained above serves as a guidance that is suitable for a variety of cases where decisions for or against certain adaptation measures need to be taken. However, sometimes a combination of analysis frameworks might be necessary or desired. Within the BINGO project, this was essential for the case study in the German city of Wuppertal, located in the western part of Germany. The spatial boundaries of that case study covered an area of approx. 8 km² around a small urban water course called the Mirke creek. The area is known as endangered flood zone (MKULNV 2015) and recent flood damage events triggered the urgency of involved stakeholders to act since flood risk might also aggravate with further climate change in the future. The aim of the case study was to compare potential flood risk reduction measures at several so called critical hotspots along a 6 km long course of the creek. The explored measures needed to be ranked by their cost-effectiveness, in order to advise stakeholders where to spend time and financial resources first (Strehl et al. 2019b).

To capture all relevant socio-economic details, the customized approach for Wuppertal had to combine some of the frameworks mentioned in fig 1 above. Spoken in generic terms, the decision tree framework does not have to be followed strictly in any case, ending in one exclusive method to follow for the desired decision support. Anyhow it is a guideline supporting the user to determine a fitting analysis path and sometimes results in the identification of different methods which are more useful in a combined approach.

In the Wuppertal case, stakeholders stated from the beginning of the project that non-monetary indicators are also relevant for this case study. However, as stated above, the primary aim was to rank the solutions in order to guide stakeholders how to spend time and financial resources wisely, beginning at a hotspot with the best cost-effectiveness. This is why a CEA was combined with an MCA framework. Additionally, to calculate the costs for the CEA, the same basic methodology as used for a CC was followed.

The MCA framework followed in the Wuppertal case study was aligned to the so called Analytical Hierarchy Process (AHP) based on Saaty (2008) and Saaty (1987). Here, at first the importance of the investigated parameters is determined by the stakeholders in pairwise comparisons, followed by an evaluation of the parameters' manifestations themselves. Both values per parameter were afterwards combined to a final value that indicates the respective measure's effectiveness in non-monetary terms. The resulting single value was related to the costs for each measure (as calculated by the principles of a CC). In other words, the result was a calculation of a cost-effectiveness ratio for each risk reduction measure that is in turn based on information gained from an AHP analysis. Details on the followed approach and results of the case can be found in the BINGO D5.3 report (Strehl et al. 2019a).

5 Social justice analysis

5.1 Why a social justice analysis?

Social justice and equity principles have been highlighted by the IPCC (2018) as key aspects of a climate-resilient development of societies. Adaptation to climate change is difficult to regulate because the causes and effects of a changing climate are spread both geographically and in time. For policy-making on climate adaptation to be legitimate and effective, it has to take justice and equity principles into account (Gupta 2005, Caney 2005b). Adaptation policies also contribute to human well-being and social capital, and increase the overall adaptive capacity of societies (Reckien et al. 2018).

Until today, the debate on social justice and climate change has mainly centred on the recognition of responsibility for global climate change (Pielke et al. 2007), inter-generational justice (Caney 2005a) as well as distributional justice, especially in the context of vulnerability to impacts of climate change (Adger 2006, Breil et al. 2018). It is only recently that social justice is emerging as a central concept to guide decision making for adaptation policy. In the face of climate change, the scope of the transition ahead calls for a high degree of support from all parts of society. The successful implementation of adaptation action thus depends on transparent and legitimate decision making processes as well as a systematic consideration of equity principles (Patterson et al. 2018). A social justice analysis of adaptation measures can serve to assess the probable acceptability of proposed measures, can inform their context-adequate design and enhances the legitimacy of the planning process with a view to the long-term support by the wider public.

5.2 The concept of social justice in BINGO

There is not a commonly agreed definition of social justice or equity in the context of adaptation (Breil et al. 2018), and the prioritization of principles and values varies according to the specific regional context (EEA 2018). In essence, social justice theorizes about fair allocations of burdens and benefits among different members of a society (Rawls 1971). According to Miller (1999) social justice thus concerns the question of "how the basic structure of a society distributes advantages and disadvantages to its members". These distributions are often based on, and legitimized through, "distributive" or "equity" principles (Buchanan 1972, Cook 1987). The BINGO social justice analysis seeks to map the distributions of costs or negative impacts and benefits of the adaptation measures among different actors or groups in society in the specific context of each research site. This was done using a standardized questionnaire (see fig. 2). Participants also received a short introduction paper, highlighting the concept of social justice to them as well. The questionnaire was developed based on three equity principles generally distinguished in the environmental-philosophical literature (Shue 1999, Low and Gleeson 1998, Paavola

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& Adger 2002, Ikeme 2003, Anand 2004): (1) the egalitarian principle is based on Mill's and Benthams' utilitarian "greatest happiness principle". Distributions aim to maximize the positive effects and minimize the negative effects for society as a whole. An example of this principle in adaptation governance are the upcoming international weather insurances and bonds, which pay out after a certain weather disaster irrespective of the needs of the victims (Dlugolecki & Keykhah 2002); (2) the solidarity principle aims to neutralize "involuntary inequalities" between people. Distributions follow Rawls' "maximin" principle which involves maximizing the well-being of those who are worst-off. A practical example of the operation of this principle in adaptation governance is the United Nations Adaptation Fund that finances adaptation projects in developing countries (Person & Remling 2014); (3) the deontological principle is based on Kant's notion that people are rational and act intentional, and can therefore be held responsible for their choices and actions. Nozick's elaborated on this notion in his "entitlement theory", which holds that any "patterned" redistributions focused on outcomes are unjust and (re)distributions should always put individual rights and liberties at the basis. The "polluter pays" principle is a practical example of this principle (Tol & Verheyen 2004).

As the evaluation of social justice is highly context dependent, the analysis does not present a conclusive result for each measure but rather presents a qualitative summary of distributional impacts for decision makers to consider in addition to the rating which is produced in the socio-economic assessment.

Analysis of social justice

1. How are costs for the implementation and upkeep of this measure shared between parties?
2. Does the adaptation measure incur any negative side-effects (indirect/social costs)? If so, what kind of effects?
    a. If yes: To what extent and how are these side-effects mitigated, and by whom (who is paying for the mitigation)?
    b. If no: Who will carry the burden of the negative side-effects?
3. Which actor(s) will directly benefit from this measure, e.g. in terms of economic revenue, or access to products or services created by the measure? Or does the measure benefit the general public?
4. Does the adaptation measure incur any positive side-effects (additional social benefits)? If so, what kind of effects?
5. Which actor(s) will enjoy these indirect benefits?
6. Considering the answers to the questions above, which equity principles do you recognize in these distributions?
7. To what extent and in what way does the adaptation measures reduce or strengthen existing social (in)equalities?

Figure 2: Questionnaire for social justice analysis.

5.3 Application in BINGO - the Badalona case study

In the BINGO case study of Badalona, the application of the social justice analysis for the three selected adaptation measures shows that (1) all adaptation measures will have positive impacts on Badalona's citizens. The general public will benefit from the reduction of flooding and combined sewer overflows and the social perception in the municipality's efficiency will increase; (2) none of the adaptation measures will incur negative side-effects; on the contrary, the implementation of nature-based solutions will incur social co-benefits such as: enhanced public amenity, enhanced air quality, increase of ecosystem services and the reduction of the "heat island effect"; (3) regarding equity principles, both the deontological and egalitarian principles may apply in the case of climate change adaptation given that, on the one hand, Badalona's citizens are paying for the proper performance of the urban drainage system and at the same time the society as a whole receives the positive consequences of such adaptation.

5.4 Limitations

Pre-existing inequalities or specific vulnerabilities of certain groups of the respective municipalities could only be considered to a limited extent (question 7 of the questionnaire). However, the analysis of specific social vulnerabilities at the level of the municipality is advisable when designing adaptation measures as well as the participation of vulnerable groups in the planning process to ensure that the contextual and procedural equity are also taken into account (Breil et al. 2018).

6 Discussion

When looking at the measures selected by the research sites, a strong focus on technical infrastructure measures (table 1) can be identified. This may be explained by the familiarity of the stakeholders and end users with these types of measures. Often, the knowledge and administrative resources for implementation of these measures are present at the sites, and implementation does not require the involvement of a broad range of stakeholders. Also, the effectiveness of these measures can often be modelled and is less uncertain than for instance behavioral measures.

However, it shows in the analysis that technical infrastructure measures are often expensive and can take a long time to implement. It was also found that construction works due to implementation can cause disruption to social and economic activities and the surrounding environment. The sewer separation proposed in Bergen and the increase of the sewer systems capacity in Badalona both require large investments. These funds are difficult to obtain either because financial means are lacking or they are not properly allocated for climate adaptation. In the Wupper River Basin, the building of a retention basin, alignment protection and new water transportation systems also require large investments and long implementation times. Artificial retention at the Veluwe also requires large investments and may cause debate about the disruption to the natural area caused by large scale construction activities. The modernization of the irrigation system in the Sorraia Valley is very costly and the same goes for the use of desalinated water and the uptake of irrigation scheduling technologies in Cyprus. On the other

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hand, three out of the four technical infrastructure measures for Cyprus are sustainable practices aiming at reducing irrigation demand (irrigation scheduling technologies), improving local groundwater recharge, while maintaining downstream flows (groundwater recharge systems), and making use of locally available treated sewage water (use of treated sewage water for irrigation). However, it is important to investigate the possible long-term effects of emerging contaminants such as pharmaceuticals, which are present in the treated sewage water, on soils, groundwater, ecosystems and human health.

A second issue with most of the technical infrastructure measures is that they are usually not very flexible. They are often literally set in concrete and built for a fixed capacity. Although the BINGO-project provides decadal prediction until 2025, the life time of technical infrastructure is often much longer (30-50 years is no exception). In that time frame the extent and impact of climate change is still uncertain, which makes decisions on the capacity of the infrastructure very difficult. Building too much capacity is a waste of money, while building too little capacity is less effective in reducing the risks.

A third issue with technical infrastructural measures, is that they often serve a single purpose and do not create many side benefits. Particularly in situations where financial means and/or building space are scarce, measures that serve more than one purpose can be surprisingly efficient. However, it is often difficult to quantify these side benefits and transfer these benefits to the investors of the measures.

Table 1: Overview of technical infrastructure measures selected by the research sites

Research site	**Technical infrastructure measures**
Wupper River Basin, Germany	Technical protection measures for property Alignment protection Retention Basin Transition between reservoir catchments Alternative water sources
Veluwe, The Netherlands	Artificial infiltration
Sorraia Valley (Tagus basin), Portugal	Rehabilitation and modernization of irrigation networks
Troodos, Cyprus	Irrigation scheduling technologies Desalination Use of treated sewage water for irrigation Groundwater recharge systems
Bergen, Norway	Sewer separation
Badalona	Increase of sewer capacity

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This is much less the case with measures that involve the combination of multiple functions and benefits, such as blue/green solutions or the multifunction use of infrastructure in Bergen, using streets additionally as safe flood way in extreme situations (Table 2). In this category of measures, changes in the natural or built environment help reduce the risk, while also performing other functions and creating potential side benefits. The land use change at the Veluwe (changing pine forests into broadleaf forests and open areas) does not only increase the groundwater recharge, it also increases biodiversity, reduces the risks of fires and creates a more varied and attractive landscape.

Table 2: Blue/green solution

Research site	Blue/green solutions
Veluwe	Land use change
Bergen	SUDS Safe Flood Ways
Badalona	SUDS

The SUDS that are analyzed by Badalona and Bergen show similar characteristics. Both measures are primarily used to decrease the risk of flash floods and CSOs by increasing the retention capacity of the built environment. These measures also have many side benefits, such as urban cooling, increased biodiversity, increased water and air quality and they can provide recreational space for citizens.

Implementing SUDS, however, is more challenging from an institutional perspective. It often requires cooperation between different sectors (urban planning, water, building & construction, etc.). If there are no institutional arrangements for these sectors to collaborate, this can be challenging. In Bergen, SUDS are now primarily planned in government owned areas, which makes coordination less difficult. If private owners need to be involved as well, things get much more complicated. Private owners need financial incentives to make changes to their property, either in the form of subsidies, or clearly identifiable benefits, such as less flood damage, or increased energy efficiency. In the case of Badalona, SUDS have a limited effect, because of the small area (2%) that is suitable for implementation. However, due to their side-benefits, they are more cost effective than the technical infrastructure measures.

The third category of measures is aimed at behavioral change, either of individuals or institutional actors (Table 3). It is a rather broad category, but they have in common that they do not involve structural changes to the environment. In the case of Badalona, the Early Warning System provides information on expected hazards and requires a broad range of actors (emergency services, citizens, health care, police, etc.) to act on this information. It follows from the cost benefit analysis done for Badalona, that this is the most cost effective measure to reduce the impact of flash floods and CSOs. However, it is very complicated to implement. Protocols have to be set up with the involvement of a broad range of actors and once these are in place, they have to be enacted once a hazard occurs. It is always uncertain whether people will act as expected (or agreed upon) which makes this a challenging measure. Coordination of actors is also an issue in Cyprus. The institutional/governance framework for the maintenance of the check dams, which are part of the groundwater recharge systems, is not clear. Better coordination of the different levels of government involved is required to overcome these administrative obstacles. For the land use change measure at the Veluwe this is also important. A broad range of land owners need to be involved and large scale land use change in a Nature2000-area may even require the involvement of national level political actors. Coordination of different actors is also central to the Tagus water resource management model that is being developed at the Portuguese research site. It requires almost all actors involved with water use/supply in the Tagus area to be involved in the development of the framework.

Table 3: Behavioral measures

Research Site	Behavioral measures
Wupper River Basin	Water Saving Reduction of low water elevation
Veluwe	Agricultural water restrictions
Tagus	Tagus water resources management model
Bergen	Public involvement
Badalona	Early Warning System

Changing the behavior of individuals with regard to climate change adaptation is also a common challenge across the research sites. The Public Involvement measure in Bergen was considered an important measure by the Bergen research site and has been further developed in project BINGO. It proved the challenge to involve the public through a digital platform, particularly to make it appealing to different societal groups. In the Wupper River Basin, convincing individuals to take up water saving or private property owners to apply technical protection measures was also considered a challenge. In both cases a lack of incentives can be identified (cheap water) or a lack of awareness of individual responsibility (flood protection is considered a governmental responsibility). In the case of the Veluwe it is the farmers who have to be involved to change their practices by either adopting irrigation scheduling technologies or stop using sprinkler irrigation. Reduction of low water elevation is the most special measure in this category. It does not really require behavioral change from a specific actor, but sets a different (lower) limit for discharge from the reservoir, so that water authorities have the option to keep more water in the reservoir. This does not require any infrastructural change or changes in the landscape.

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7 Conclusion

The application of the BINGO approach has been successful in generating decision-relevant outcomes for developing adaptation strategies at the research sites. Although the research sites were very different, both in their challenges as well as their socio economic and institutional context, the approach presented in this paper yielded useful results in all cases. This support the transferability of the approach to other case in Europe.

However, we can identify specific benefits and limitations for each of the analyses (Table 4). The main benefit of the governance analysis is that is provides a systematic overview of the requirements for implementing a certain measure, with attention to a broad range of building blocks for adequate governance. This not limited to technical and economic aspects, but also includes cultural, communicative and legal aspects. A limitation in the way that the method was applied is that it does not provide specific values for the required level of these indicators, other than reported by the researchers and stakeholders involved.

The socio-economic analysis contributed in structuring decision relevant information on adaptation measures focusing on potential outcomes of each measure. The methods applied help to quantify and/or rank indicators affecting costs and benefits of the selected measures, from a socio-economic point of view. Moreover, the methods can be integrated in a broader, scenario-based approach to assessing adaptation strategies. Limitations of the method primarily deal with the availability of data, which has a strong effect on the validity and reliability of the conclusions drawn from the analysis.

Finally, the social justice analysis gives a broader perspective than the plain focus on the outcomes of adaptation and also considers the distributional effect on different groups in society. This may result in the identification of unbalanced burdens or co-benefits which leads to better informed decisions and helps to realise climate justice. However, in the way the method was applied, the acquisition of meaningful social-justice information and derived interpretations relevant for decision makers, highly relies on the interview partners. They need to have a specific knowledge of the local adaptation measures/options planned, and the socio-economic environment.

Table 4: Assessment of the applied analyses

BINGO analysis	Benefit	Limitation
Governance analysis	Provides systematic overview of requirements and whether they are met; takes into account broad range of factors, not only finances and technical capability.	Method itself does not provide standards in whether requirements are sufficiently met; relies on self-reporting by researchers and stakeholders.

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Socio-economic analysis	Helps to structure decision-relevant information about adaptation alternatives, focusing on measurable outcomes of each option; applied science offers straightforward methods to quantify or at least rank relevant indicators affecting costs and benefits from a socio economic point of view; methods for a socio-economic analysis are flexible to integrate the scenario based thinking of climate change projections.	Limitations arise with data availability; in cases with very broad decision-relevant socio-economic criteria to cover, (un)reliable input data for a quantitative analysis effects the robustness of conclusions drawn from the analysis.
Social-justice analysis	Helps to focus not only on plain outcomes of adaptation, but also on distributional effects among society; broadens the scope of the analysis, eventually leading to identify additional co-benefits or unbalanced burdens for stakeholders of climate change adaptation measures, allowing a better informed decision.	Information acquisition for a social-justice analysis relies on qualitative input, e.g. by interviews and pre-structured questionnaires as conducted in the BINGO-project; time and financial resources and available interview partners may limit the scope of the analysis.

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Code and data availability. Model files and data are not provided due to the confidentiality of the data and models. Notwithstanding, in agreement with the other project stakeholders, the authors of this paper will try to address specific requests for scientific purposes.

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Competing interests. The authors declare that they have no conflict of interest.

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