Social Choices and Public Decision-Making in Mitigation of Hydrogeological Risk

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Abstract. Due to climate change effects, the EU is experiencing heavier rainfalls and storms and sea level rising, which resulted at local and regional level in an increasing intensity and frequency of flooding. Increasing territories resilience and mitigating hydrogeological risk have become, therefore, one of the greatest challenges that our society is facing today. In this context, the successfulness of public decision processes play a key role. Due to the dramatic complexity of these decision process, which involve different stakeholders and actors, whose stakes are high and who may have conflicting objectives, policy-makers and planners require robust, transparent and coherent decision tools to support them in pursuing their arduous task. In this paper, we propose a methodological approach, which aims at increasing legitimation, accountability and transparency in public decision-making related to prioritization of hydrogeological risk mitigation strategies, by creating consensus via a participative approach. In detail, we discuss the potential of absolute AHP models in the prioritization of hydrogeological risk mitigation strategies. We argue that, due to the specific characteristics of absolute AHP measurement, once the hierarchy of criteria has been set and weights have been determined, the absolute model can be implemented on any set of alternatives, which does not need to be defined a priori, but can evolve over time, thus accounting for changes in single-criterion valuation of alternatives, contingent to variations in boundary conditions of the decision environment.

Keywords: Mitigation of hydrogeological risk · Social choices · Public decision process · Multicriteria decision aid

1 Introduction

Due to climate change effects, the EU is experiencing heavier rainfalls and storms and sea level rising, which resulted at local and regional level in an increasing intensity and frequency of flooding [1–3]. According to the 2018 European Court of Auditors (ECA) report, the costs of hydrogeological events across the EU territory amounted to €166 billion in the period 1980–2017 [4]. In a business-as-usual scenario, costs of damages have risen from €7 billion per year in the control period 1981–2010 to €20 billion

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per year by the 2020s, and will rise to €46 billion per year by the 2050s [4]. In this context, it is undoubtful the ever growing attention to mitigation of hydrogeological risks paid by Member States. Floods can cause loss of life, significant economic costs and damage to the natural and built environment, including cultural heritage assets. Due to climate change, floods are becoming more frequent and severe. In recent years, the number of medium to large magnitude flash floods has become twice as great than those recorded in the Eighties [4]. In response to the challenges posed by the rising incidence of flooding, in 2007 the EU enacted Directive 2007/60/EC, better known as Floods Directive, which focuses on effective flood prevention and mitigation, and mobilizes support from Member States in the event of a major emergency. In this respect, the Floods Directive recognizes the role of Civil Protection in providing assistance to affected populations and improving preparedness and resilience. Flood risk management plans should include interventions meant to prevent and reduce damage to human health, the environment, cultural heritage and economic activities. To a broad extent, increase in resilience and mitigation of risk are one of the most important challenges that our society is facing today [5]. In this context, the successfulness of public decision processes play a key role in the implementation of risk mitigation measures and the increase in resilience of urban and rural areas. Therefore, due to the severe complexity of public decision processes, which involve different stakeholders and actors, whose stakes are high and who may have conflicting objectives, policymakers and planners require robust, transparent and coherent decision tools to support them in pursuing their arduous task.

This complexity is aggravated by stringent budget constraints and lack of financial resources, which affect public administrations and governments both at local and national level. To favor the implementation of cost-effective mitigation strategies of hydrogeological risk, policymakers and public decision-makers must take into consideration along with social costs and benefits, EU directives and regulations, territories' current residual resilience and environmental concerns [6–9]. In a dichotomous vision of human nature and behavior, it is often argued whether economic activities must be sacrificed tout court with respect to safety and avoidance of human losses, or whether there exists an acceptable risk, that can be tolerated and can be assumed as the decision variable in the process of finding a compromise solution, which accounts for human life, economy and the environment.

This paper contributes to this debate. We argue that multiple criteria approaches provide a proper theoretical and methodological framework to address the complexity of economic, physical, social, cultural and environmental factors, which characterize the design of hydrogeological risk mitigation strategies and policies.

Within academic literature, collaborative governance, which bases on the ability of multiple stakeholders and actors to share information and learn from best practices in the achievement of common societal goals, has emerged as a potential approach to the management of complex systems that involve society, economy and the environment [10, 11]. This is apparently in contrast with Arrow's impossibility theorem, according to which, when voters have three or more distinct alternatives, there is not a voting electoral system, which can convert the ranked preferences of individuals into a community-wide (complete and transitive) ranking, which satisfies the requirements of unrestricted domain, non-dictatorship, Pareto efficiency, and independence of irrelevant alternatives

[12]. The need for aggregating preferences emerges indeed in many disciplines ranging from welfare economics, where the aim is to identify an economic outcome deemed to be as acceptable and stable, to decision theory, where rational choices have to be made based on several criteria, and to electoral systems, in which a governance-related decision has to be extracted from a large number of voters' preferences. The apparently opposing positions, which inflames academic debate, can be reconciled, if we consider that, unlike traditional optimization approaches, in the presence of multiple criteria, there is not an objective definition of "best solution".

In this paper, we propose a methodological approach, which aims at increasing legitimation, accountability and transparency in public decision-making related to prioritization of hydrogeological risk mitigation strategies, and creating consensus via a participative approach and the involvement of relevant stakeholders. In this context, by creating consensus we intend finding common ground and solutions that are acceptable to all and best for the group, for which decision aiding is provided. We discuss, in fact, that the informed participation of public bodies, the private sector and civil society may be a cornerstone of efficient policy-making processes.

The remainder of the paper is organized as follows. In Sect. 2 we briefly illustrate the basics of public decision processes and decision aiding, and we discuss the role of multiple criteria decision aiding in supporting public decisions; Sect. 3 discusses a methodological approach, based on multicriteria decision aiding principles, for the prioritization of hydrogeological risk mitigation strategies; Sect. 4 concludes.

2 Public Decision Processes and Multiple Criteria Decision Aiding

Due to the growing mistrust between public opinion, experts and politicians, policymakers and public decision-makers feel the need for legitimation in their policy making and decision process. In the emergent information society [13, 14], the widespread of information and communication technologies has resulted in a rapid growth of information availability and circulation, which is somehow forcing a change in a variety of sectors, such as education, economy, health, welfare and governance, which in turn may impose a turning point in the concept of democracy. In addition, social fragmentation and the dichotomy between short-term agendas and long-term concerns contribute to making public decision processes more complex than ever. In a public decision process, due to the variety of stakeholders, there is somehow a distributed decision power and there seem to emerge different rationalities, expressed by different actors (e.g., politicians, who have short-term political agendas, and experts, who have mid-term knowledge based agendas) and different stakes (ranging from opportunistic stakes, to long-term stakes or stakes affecting large areas and populations), which are often conflicting in the allocation of heterogeneous resources (e.g., money, knowledge, land, etc.). This leads, on the one side, to conflicting opinions, actions and priorities, and on the other to conflicting information and interpretations, which mostly depend on different languages and communication patterns [15–17]. It is therefore crucial that public decision processes move from and account for core values such as accountability, legitimation, consensus and evidence. In detail, voting theory and preference modeling are extremely relevant for governance related problems and underlie theories of fair representation, participation in democracy and transparency of public decision processes

[18, 19][1]. It is fundamental as well to adopt formal models in public policy assessment, as they are grounded in a common formal language, which reduces ambiguity of communication, contributes to improving accountability and represents the basis for participative decision processes [16, 20, 21]. Nonetheless, it can be argued that formal models can generate a reduction in creative thinking, are costly to implement and not easily understandable by everyone. There is consequently a trade-off in implementing formal models between the above advantages and potential drawbacks. Once again, in order to find a compromise solution, great equilibrium and balance, together with focused vision and stated clear objectives are mandatory.

In this respect, it essential to share a common view on what is evaluation and on its role in public decision processes. In measurement theory and decision theory, evaluation means basically measuring values [15, 22, 23]. This gives rise in turn to other issues on what we mean by measure and what we mean by value (e.g., value of what, for whom, etc.).

According to measurement theory, when we measure we construct a function from a set of objects, which comes from the real world, to a set of measures, which derive from empirical observations on some attributes of the objects under investigation, by implicitly assuming that there are specific conditions under which relations among numbers can be used to express relations among objects. In this framework, objects which are indifferent, and are stated as indifferent by means of trade-offs, can be considered as of the same value. There is no doubt, that the cornerstone in measuring is related to how we construct and define the above mentioned function, starting from observations [22–24]. In addition, as different measurement scales (i.e., nominal, ordinal, ratio, interval, and absolute scales) convey different empirically significant information [25, 26], scales cannot be used indifferently and are distinguished by the transformations they can undergo without loss of empirical information. As an example, all proportional transformations on ratio scales will provide the same information, whereas all affine transformations on interval scales will provide the same information, and ordinal scales admit of any transformation as long as it is a monotonic and increasing function. Consequently, on an ordinal scale such as the Mohs scale of mineral hardness, we just know that 1 represent the softest mineral and 10 represents the hardest mineral, but there is no empirical significance to equality among intervals or ratios of those numbers [27]. Therefore, the meaningfulness of the measurement scale is a prerequisite for the meaningfulness of measures and value assessment.

It is consequently crystal clear, that based on the above considerations, evaluating is less intuitive than usually expected, and it can be considered indeed an activity within the domain of decision aiding. Decision aiding is grounded in the consensual construction of shared cognitive artifacts and can be defined as the interactions between someone involved in a decision process and a specialist able to support him/her in the decision process, of which decision aiding is part [15, 22, 23, 28–32]. The act of deciding implies that a specific decision problem is stated, a decision-maker is identified, and a specific

[1] It is worth noting that, in the Condorcet voting model, alternatives are pair-compared, preferences are stated and the corresponding graph defines the tournament. Nonetheless, it is not straightforward to identify the Condorcet winner in most of real world situations.

decision process is structured and implemented. This obviously requires cognitive efforts and responsibility.

The main objective of decision aiding is to aiding to decide, not to deciding, and it comprises four main phases: providing a comprehensive representation of the problem situation, formulating the problem, constructing or co-constructing the evaluation model and providing final recommendations to the decision maker [15, 33–35].

In the first phase, participants, stakeholders, concerns, stakes, potential resources and commitments involved are identified and described:

$$P = \langle A, O, R \rangle \tag{1}$$

where
A: actors, participants, stakeholders
O: objects, concerns, stakes
R: resources, commitments.

In the second phase, by adopting a model of rationality, actions (i.e., objects under evaluation) and points of view are identified and the problem is stated:

$$\Gamma = \langle \alpha, \nu, \Pi \rangle \tag{2}$$

where
α: actions, objects
ν: points of view
Π: problem statement.

Subsequently, the evaluation model is developed according to objectives and criteria previously set, and preferences and preference structures are modelled and aggregated via preference models, based on specific procedure, algorithms or protocols:

$$M = \left\langle \alpha', D, E, H, U, R' \right\rangle \tag{3}$$

where
α': alternatives, decision variables
D: dimensions, attributes
E: scales associated to attributes
H: criteria, preference models
U: uncertainty
R': procedures, algorithms, protocols.

In order to assess values, which depend on preferences, we need to take into account values and preferences of relevant stakeholders, individual vs social values, experts' and politicians' judgements.

Finally, in the fourth phase, final recommendations are established and a discussion on their validity and legitimation is set in place, by verifying whether information have been correctly used and are meaningful with respect to Measurement Theory, the decision process and the decision-maker.

The most relevant issues in any decision aiding process are related *de facto* to preference and preference structures. The key questions concern how to learn, model and aggregate preferences as well as how to use preference information to provide recommendations. Preferences are indeed binary relations, and a preference structure can be viewed as a collection of binary relations. The problem is therefore searching for an overall preference relation, which is representative of the different preferences. According to Social Choice Theory, preferences can be aggregated via majority voting, where each voter has equal importance and they are interviewed as many voters as necessary. By contrast, in multiple criteria decision aiding (MCDA) comparisons are based on a finite set of criteria, reflecting the preferences of one or multiple actors for whom the decision aiding process is implemented, and each criterion has a variable (relative) importance. Consequently, the nature and quantification of preference information required to formulate comprehensive comparisons is fundamental and may affect results [36–38]. This implies that information needs to be manipulated in a consistent and coherent way, in order to be useful for whom is using it and for the purpose for which the decision process has been designed.

Evaluating a performance and aggregating evaluations play a central role in evaluation and decision models. Comparing differences in evaluation is at the core of modeling and aggregating preferences to build an informed decision process [17, 22, 23, 34]. Preference models can be distinguished in two main typologies: preference models based on utility (value) functions, in which preferences are a weak order (i.e., transitive and complete preference), vs preference models, which accounts for incomparability and/or intransitivity [22, 32, 35].

When considering multi-dimensional (i.e., multiple-criteria) evaluations of actions and alternatives, specifically in public decision processes, it is likely that decision-makers call for a one-dimensional synthesis. This synthesis should reflect the value of actions and alternatives on a synthetic global evaluation scale, which in turn reflects the decision-maker's value system and his/her preferences, and it is grounded in the assumption that the decision-maker maximizes his/her utility or value, where the former is mostly referred to decision under risk, whereas the latter refers to the deterministic case [23, 24, 37]. Accordingly, alternative a is preferred to alternative b:

$$a \precsim b \ \textit{iff} \ u(a) \geq u(b) \tag{4}$$

where
$\precsim$: preference relation
u: utility
and u is a function of evaluations based on n criteria g_k, i.e. $\{g_k(a),\ k = 1,\ldots..n\}$.
If function u is linear, we obtain an additive utility (value) model:

$$u(a) = \sum\nolimits_{k=1}^{n} u_k(g_k(a)) \tag{5}$$

where
u_k: single-attribute value function.
In case of a linear combination of g_k, (5) results into a weighted sum model:

$$u(a) = \sum\nolimits_{k=1}^{n} w_k(g_k(a)) \tag{6}$$

where
w_k: weight (i.e., relative importance) of criterion k.

Although the additive value model is one of the most widely adopted in real world situations, it is worth noting that there are conditions under which the preferences of a decision-maker cannot be described by an additive value function model. These conditions are those in which compensation among criteria is not accepted. It is therefore of primary importance to verify whether the decision-maker's value system (i.e., preference system) can be described by an additive model. If not, other models should be implemented, e.g., multiplicative or non-independent models, which accounts more specifically for imprecisions [39, 40].

The additive multi-attribute value model is indeed satisfactory, when stakeholders actively participate in the decision process and accept its formulation. It provides in fact a direct and easy-to-understand interpretation of results in terms of decision: the best alternative is the one, which exhibits the highest model value [23, 24, 37].

3 Prioritization of Hydrogeological Risk Mitigation Strategies

Public decision-making in mitigation of hydrogeological risk is a challenging and complex task, which is evermore submitted to verification, monitoring and transparency.

As above discussed, decision aiding provides both a theoretical and methodological framework that can be implemented to different contexts of decision-making, and a formal preference theory [32, 38, 41]. Within the context of decision aiding, in this section we propose a methodological approach meant to increase legitimation, accountability and transparency in prioritization of hydrogeological risk mitigation strategies, and to embed some participatory decision-making elements, such as consensus.

The occurrence of natural disasters, such as river flooding, represents a worldwide challenge, due to more frequent extreme weather events and storm surges, which have made territories more vulnerable to floods and have produced severe economic impacts [42]. River discharges have increased as a consequence of climate change, urban sprawl and lack of maintenance of riverbeds and hydraulic infrastructures, which in turn caused more frequent levee failures and, consequently, further increased risk of flooding [43].

In this respect, the Veneto Region has suffered from many flooding events in the past and in recent years. The event that occurred in 1966 is the most worldwide known. Although it affected the entire Veneto Region, the images of the high water event (acqua alta), which occurred in Venice on November 4 1966, when an exceptional occurrence of high tides, rain-swallen rivers and a strong scirocco-wind caused the canals to rise to a height of 194 cm (measured with respect to the reference sea level at Punta della Salute), impressed and shocked the world. More recently, it is worth mentioning the occurrence of two extreme events in 2010 and 2018, respectively. Between the end of October 2010 and the beginning of November 2010, the effects of extreme meteorological conditions involved 130 municipalities, more than 500,000 inhabitants and caused the flooding of 140 km^2 of rural and urban areas in the provinces of Vicenza, Padova, Verona and landsides in the provinces of Treviso and Belluno. In addition, in 2018 the so-called Vaia storm (namely a hurricane) caused significant damages to forests (more than 8 million cubic meters of standing trees), buildings and infrastructures and impacted severely and unprecedentedly protection against landslides, avalanches and floods, as well as biodiversity. The consequences of Vaia storm affected not only natural resources and the environment, but also the local and regional economy and local communities, caused two deaths and the isolation of entire communities for weeks [44]. Key lessons have been learnt from these two events in terms of both territorial planning and management and policy interventions, in order to mitigate hydrogeological risk and increase the territory resilience. In 2011 the Veneto Region approved a comprehensive master plan of interventions ("Piano delle azioni e degli interventi di mitigazione del rischio idraulico e geologico"-Deliberazione della Giunta Regionale n. 1643 del 11 ottobre 2011) for a total amount of €2,731,972,000 of public works and infrastructures, considered as structural measures, and €5,422,600 of non-structural measures (e.g., efficient flood forecast-warning systems, flood risk assessment, etc.). In addition, in 2019 the Veneto Region approved an additional plan of interventions for a total amount of about €928,000,000 ("DPCM 27 febbraio 2019" and "DPCM 4 aprile 2019").

Due to high upfront and investment costs and to the chronic lack of public financial resources, these masterplans are implemented by sequential phases and their implementation requires a clear and informed identification of priorities, which should account not only for technical issues and concerns, but also for economic, social and environmental ones. In this context, in which high stakes and stochastic future implications are involved, multicriteria approaches provide formal decision-making models to assess a finite set of criteria, perform evaluation of alternatives based on each single criterion, and finally aggregate these evaluations to rank alternatives with respect to the specific objective of identifying priority of intervention [7, 45–50].

In detail, we discuss the potential of a novel application of the Analytic Hierarchy Process [51–53] in the solution of this ranking problem and in the improvement of public decision-making in terms of legitimation, accountability and transparency. The Analytic Hierarchy Process (AHP) is indeed a well-established multi-criteria approach, based on experts' judgements. It has been largely adopted by scholars and practitioners to systematize a wealth of decision problems, and proved to be effective when quantitative information on the effects of action is limited [6, 48, 54–57].

The AHP allows for ordering a finite number of actions A_i, with respect to a finite number k of attributes/criteria a_j ($j = 1, \ldots, k$), each of which is assigned a judgment score qualifying its performance according to Saaty's semantic scale [58]. The AHP implement a weighted sum model and is grounded in the construction of a hierarchy, where the main goal of the decision problem (i.e., the prioritization of risk mitigation strategies) is placed at the top of the hierarchy, whereas criteria and sub-criteria are positioned at lower levels, and alternatives/actions are at the bottom level. We deem that to structure the specific decision problem under investigation and provide a valid support to the decision-maker, it should be developed and implemented an absolute AHP model, in which each independent alternative at a time is ranked in terms of rating of intensities with respect to each criterion/sub-criterion. In an absolute model, the hierarchy is decomposed as usual into criteria and sub-criteria, which are further decomposed to the bottom level, which accounts indeed for intensities through ratings [59, 60].

According to [61], rating categories can be established for each criterion and the typology (i.e., qualitative or quantitative) and number of ratings can vary contingent on different criteria/sub-criteria, which are evaluated by an "intensity", identified by a numerical variation range. Subsequently, available information can be used to assess relative importance of criteria and sub-criteria through pairwise comparisons performed by the interviewed panel of experts, and priorities (i.e., weights) are determined according the eigenvalue approach. Absolute measurement AHP compares pairwise indicator categories (i.e., high, low, etc.) to an ideal preference synthesis, as alternatives are compared to standard levels and are measured on an absolute scale.

In the context of prioritization of hydrogeological risk mitigation strategies, it is of paramount importance the representativeness of the group of experts, which should include representatives of the three main perspectives involved in a public decision process: knowledge, government and business. It is worth noting that group decision-making benefits from capturing as much diversity of thinking as possible, in order to reach consensus on the final ranking in a systematic and transparent way [62]. Via focus groups and dynamic discussion, consensus on criteria, sub-criteria and ratings can be created, experts' judgements obtained and the hierarchy can be validated.

Thanks to the absolute AHP model peculiar characteristics, once the hierarchy of criteria has been set and weights have been determined, the model can be implemented on any set of alternatives, which does not need to be defined a priori, as in relative AHP models, but can evolve over time. This guarantees the possibility of including straightforward additional alternatives or accounting for changes in single-criterion valuations of alternatives, contingent to variations in boundary conditions of the decision environment, which may stochastically evolve over time (e.g., due to climate change effects, variations in terrain slope stability, etc.). Furthermore, such a model could be easily coupled to existing monitoring systems and prediction models, thus providing some dynamics in public decision processes and contributing to the fulfillment of Directive 2007/60/EC requirements in terms of flood risk management and flood prevention, protection and mitigation.

4 Conclusions

The mitigation of hydrogeological risk is a challenging and complex task, which includes the reduction of damages to human health, the environment, cultural heritage and economic activities. Public decision-making in this context is evermore submitted to verification, monitoring and transparency and, as any other decision process, calls for legitimation due to the growing mistrust between public opinion, experts and politicians.

Investments in structural and non-structural measures to reduce hydrogeological risk and increase territories resilience involve large investment and upfront costs. Due to the dramatic and ever-growing lack of public financial resources, these investments are necessarily implemented by sequential phases, thus requiring an informed identification of priorities, which should account for technical, economic, social and environmental issues and concerns. In this respect, multicriteria approaches provide valuable formal models to identify a priority ranking and improve the legitimation, accountability and transparency of public decision-making. Specifically, in this paper we discussed the potential of an absolute AHP model *ad hoc* developed to support public decision-makers in the ranking process, when quantitative information on the effects of actions may be limited. Thanks to the specific characteristics of absolute AHP measurement, once the hierarchy of criteria has been set and weights have been determined, the model can be implemented on any set of alternatives, which can evolve over time, thus accounting for changes in single-criterion valuation of alternatives, contingent to variations in boundary conditions of the decision environment.

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