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Applied Mathematical Problems in Engineering

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Abstract

There is a close relationship between engineering and mathematics, which has led to the development of new techniques in recent years. Likewise the developments in technology and computers have led to new ways of teaching mathematics for engineering students and the use of modern techniques and methods. This research aims to provide insight on how to deal with mathematical problems for engineering students. This is performed by means of a fuzzy set/Qualitative Comparative Analysis applied to conflict resolution of Public Participation Projects in support to the EU Water Framework Directive.

Keywords: Fuzzy sets; Qualitative Comparative Analysis; Public participation project; conflict resolution; decision-making

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1. Introduction

Integrated water resources management entails technical, scientific, political, legislative, and organizational aspects of water system. Water resources management suffers from continual and growing pressures, which derive from reasons such as human activity, population growth, living standards increase, land-use and climate changes, growing competition for water, and pollution from industrial, municipal, and agricultural sources. The EU Water Framework Directive (WFD) establishes a framework for the protection of all water bodies by promoting sustainable water use based on long-term protection of water resources, and enacts to achieve good qualitative and quantitative status of all water bodies by 2021. The EU WFD also states that all members shall encourage the active involvement of stakeholders in the implementation of the directive and development of watershed management plans (EC, 2000).

A way to deal with stakeholders' conflict resolution problems is by using a configurational comparative method. This is performed by means of a fuzzy set/qualitative comparative analysis, fsQCA (Ragin 2008), which overcomes some of the limitations of strictly qualitative or quantitative studies. This technique has been widely used in the literature to deal with qualitative comparative analysis (e.g., Berbegal-Mirabent and Llopis-Albert, 2015).

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2. Public participation projects in the Water Framework Directive

Stakeholders' satisfaction depends on diverse factors, such as their heterogeneous interests, educational backgrounds, employment, knowledges, resources, experiences, places of provenance, levels of participation, etc.

Stakeholders are selected by considering all groups who in some way will be affected by the implementation of measures, which includes those who have interests, claims or rights (ethical or legal) to the benefits of the measures undertaken, are likely to bear its costs or adverse impacts whatever its overall worth.

The stakeholders involved in the water decision-making of a PPP range from governments, water agencies authorities, environmental organizations, irrigation user communities, private firms, universities and research agencies, political parties, labor unions, experts, advisors, mass-media, citizens to international organizations.

Table 1 presents the factors or conditions that leads to the stakeholders' satisfaction in the decision-making process of a PPP for a watershed management, which cover environmental objectives pursued, the actual capacity of efficiently carrying out those objectives, the socio-economic development of the region, the level and mechanisms of stakeholders' participation in the PPP, and the alternative policies and measures that should be implemented in the hydrological plans.

3. Methodology

This study uses actors belonging to different watersheds and countries to assess stakeholders' preferences or degrees of acceptance regarding the diverse factors or conditions that lead to their satisfaction. Then this work deals with different watersheds realities and national legislations, and presents a general overview of the European stakeholders' satisfaction in the decision-making process of PPP for water resources management. The diversity of watersheds in terms of the management strategies they apply and their stakeholder engagement makes this work even more suitable for studying how combinations of conditions in the decision-making process can result in stakeholder satisfaction.

Eventually, we will identify what combinations of the considered conditions are necessary or sufficient to achieve the stakeholders' satisfaction in PPP.

The study is based on different European reports (EU, 2003; OECD 2015; OECD 2014), research papers dealing with these issues (e.g., Verweij et al., 2013; Srinivasan et al., 2012), online reports from webpages of European water agencies authorities, mass-media information, meetings, personal interviews, surveys, and expert judgment. Data have been collected during long-time period of years, so that a longitudinal view on the course of the stakeholders' preferences has been obtained.

Therefore, we are intended to identify which combinations of factors are sufficient to explain the outcome by means of a Qualitative Comparative Analysis (QCA) to

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overcome some of the limitations of strictly qualitative or quantitative methods, and to more systematically analyze conjunctural causal patterns

A configuration is a combination of factors -which is named as conditions in QCA terminology- that is minimally necessary and/or sufficient for obtaining a specific outcome. These configurations consist of conditions or factors that can be positive, negative, or absent. Conditions are sufficient and necessary only in combination with other conditions or which are only one alternative among others that only apply to some cases but not to others.

Contrary to QCA, which can only analyze binary variables, fsQCA overcomes this limitation by incorporating the possibility to examine varying levels of membership of cases to a particular set. First calibration procedure of outcomes and antecedent conditions into fuzzy sets is required, which categorizes meaningful groupings of cases (Ragin, 2008). Fuzzy values range from full membership (1) to full non-membership (0). A crossover point (0.5) represents neither in nor out of the set. Second the truth table is constructed, which is a matrix space with 2^k rows, where *k* is the number of antecedent conditions and represents all the logically possible combinations of causal conditions and sorts the cases according to these logically possible combinations. Each column represents a condition, and each empirical case corresponds to a configuration depending on which antecedent conditions the case meets.

Third a reduction of the the number of rows in the truth table is carried out. We have used a version of the Quine–McCluskey algorithm (Quine, 1952), although several

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algorithms can also minimize a truth table. This allows to obtain a set of combinations of causal conditions by using Boolean algebra, where each combination is minimally sufficient to produce the outcome. The row reduction depends on two criteria: a) the coverage, which indicates the empirical relevance of a solution, that is., it measures the proportion of memberships in the outcome that is explained by the complete solution; b) the consistency, which quantifies the degree to which instances sharing similar conditions display the same outcome. On the other hand, the raw coverage indicates which share of the outcome is explained by a certain alternative configuration, while the unique coverage indicates which share of the outcome is exclusively explained by a certain alternative path. Truth tables are analyzed by the fs/QCA software (Ragin 2008).

4. Results and discussion

The main aim is to determine which particular combinations of these conditions lead to stakeholders' satisfaction by examining which combinations of the conditions are necessary or sufficient to achieve it. The degree of acceptance or preference regarding the different factors is analyzed by means of using a continuous fuzzy set. It is ranged from 0 to 1, i.e., from low degree of acceptance or agreement to high degree of acceptance or agreement. We have considered 7 factors, which comprises several sub-factors as shown in Table 1. For each stakeholder and factor the aggregate final score is the arithmetic average of the fuzzy scores for each sub-factor. The calibration process has allowed

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transforming the diversity of factors used in this work into fuzzy variables, so that they match or conform to external standards.

Fuzzy scores calibration is based on different reports, research papers, online reports from webpages of European water agencies authorities, mass-media information, meetings, personal interviews, surveys, and expert judgment.

The truth table is obtained after several rounds of analyses and because there are 7 factors the dimensions are (2^7) rows and 7 columns, which entails 128 possible configurations. The matrix is checked for necessary conditions for the outcome and also for the negation of the factors indicated by the tilde (~) sign.

A condition has been considered as necessary when its consistency score exceeds the threshold value of 0.9. Results show that there are only 2 necessary conditions, which are the environmental objectives and the socio-economic development of the region.

After the minimization process using the coverage and consistency values, the combinations of causal conditions are obtained, thus providing the combinations of factors that are minimally sufficient to produce the outcome (see Table 2). In this table black circles (●) indicate the presence of a condition, white circles (○) denote its absence, and blank cells represent ambiguous conditions. Results also suggest that: a) no unifying causal path explains the outcome; b) all configurations present acceptable consistency indices (<0.80); c) high raw coverage values are obtained; d) apart from the necessary conditions, the presence of policies (both control measures and technical measures) appear in most of the configurations, which shows that the outcome strongly

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depends on the types of policies undertaken; e) the greater understanding of the problem (for instance, using a mathematical techniques like that her presented or models taking into account the key underlying biophysical processes, e.g., Llopis-Albert et al., 2014; 2015) the better management practices and consensus will be achieved among the different actors; f) better results are obtained if actors are involved at early stages, on account of they are less likely to obstruct decisions and more likely to support them; g) good outcomes in a PPP are also related to clear goals, strong control of time, organization and information.

Table 1. Variables or factors considered in the fuzzy set/Qualitative Comparative Analysis applied to PPP in support to the EU Water Framework Directive.

<table>
<tr><td colspan="2" rowspan="4">Environmental interests
–
Objectives pursued
(1)</td><td>Good quantitative status of water bodies, both surface and groundwater</td></tr>
<tr><td>Good chemical status of water bodies</td></tr>
<tr><td>Good status of water dependent ecosystems</td></tr>
<tr><td>Low environmental impacts of future land-use land-cover changes and climate changes</td></tr>
<tr><td rowspan="7">Socio-economic interests - Objectives pursued
(2)- (3)</td><td rowspan="3">Operative efficiency
(2)</td><td>Short realization time</td></tr>
<tr><td>Low implementation costs</td></tr>
<tr><td>Low maintenance, management and infrastructures construction costs</td></tr>
<tr><td rowspan="4">Socio-economic development of the region (agriculture, industry and tourism)
(3)</td><td>Maximize water for agricultural and industrial use</td></tr>
<tr><td>Maximize water for tourism and urban use</td></tr>
<tr><td>Create employment, social equity</td></tr>
<tr><td>Increase future water demands</td></tr>
<tr><td rowspan="6">Level of stakeholders' engagement in the water decision-making process

(4)</td><td rowspan="4">Perceived obstacles to the integration of stakeholder engagement in water policies and practices
(4.1)</td><td>Lack of political will and the shift of power</td></tr>
<tr><td>Lack of knowledge</td></tr>
<tr><td>Weak legal frameworks</td></tr>
<tr><td>Scant participation level</td></tr>
<tr><td rowspan="2">Perceived obstacles hindering the</td><td>Lack of clarity on the use of engagement processes</td></tr>
<tr><td>Lack of funding</td></tr>
</table>

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	effective implementation of engagement processes (4.2)	Lack of quality and accessibility of information
		Intensity and number of conflicts
		Too much or too few actors
Preferred mechanisms used for stakeholder engagement (5)		Meetings
		Workshops / conferences
		Expert panels
		Web-based communication technologies
		Water associations
		Consultations in regulatory processes
		Surveys / polls
		River basin organizations
		Others
Preferred measures and policies for sustainable water resources management (6)- (7)	Control mechanisms (6)	Control or reduction of water demand by economic instruments
		Control or reduction of pollutants by economic instruments
		Set up of user's communities as a control mechanism
		Control of water resources by application of satellite remote sensing
		More intervention of the EU Common Agricultural Policy
		Increase of water control and sanctions by water agencies
	Alternative technical actions (7)	Efficient conjunctive use of surface water and groundwater
		Use of external water resources by means of transfers
		Use of desalination plants
		Construction of new infrastructures
		Establishment of protected areas
		Greater funding for water resources research
		Others
Outcome	Stakeholders' satisfaction	Outcome: stakeholders' satisfaction

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Table 2. Sufficient configurations of factors for stakeholders' satisfaction. Black circles (●) express the presence of a condition, white circles (○) indicate its absence, and blank cells represent ambiguous conditions. In addition, frequency threshold = 1 and consistency threshold = 0.908.

Configurations (C)	Factors							Coverage		Consistency
	1	2	3	4	5	6	7	Raw	Unique	
C1	●	●	●			○	●	0.743	0.030	0.948
C2	●	○	●	●	○	○	●	0.596	0.001	0.893
C3	●	●	●		○	●		0.680	0.005	0.943
C4	●	○	●	○	●	●	●	0.623	0.006	1.000
C5	●	○	●	●	○	●	○	0.631	0.003	0.963
C6	●		●	○	●	●	○	0.513	0.011	0.959
C7	●		●	●	○	○	●	0.627	0.001	0.896
C8	●	●	●	●	○		●	0.711	0.002	0.914
Solution coverage: 0.818 and solution consistency: 0.891										

5. Conclusion

This paper provides insight into stakeholders' conflict resolution by using a fuzzy set/Qualitative Comparative Analysis (fsQCA) for determining which combinations of factors are necessary and/or sufficient for leading to stakeholders' satisfaction throughout the decision-making process of public participation in water resources management. It takes into account a wide range of factors and configurations to obtain the outcome, which allows coming up with the best management practices and policies for a certain watershed with its own particularities. This is because the methodology facilities dialogue

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during the decision-making process between theoretical ideas and empirical evidence and allows the selection and construction of cases and conditions.

From all the configurations analyzed results have shown that environmental objectives and socio-economic development of the region are necessary conditions, while for other factors results are imprecise because of stakeholders' heterogeneity and conflict interests among them. Then the outcome do not depend upon single conditions, but result from combinations.

Eventually this mathematical technique provides a transparent and multidisciplinary framework for informing and optimizing water policy decisions and goes a step further in the implementation of the WFD.

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