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Multi-criteria decision-making on assessment of proposed tidal barrage schemes in terms of environmental impacts

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ABSTRACT

For tidal range power plants to be sustainable, the environmental impacts caused by the implement of various tidal barrage schemes must be assessed before construction. However, several problems exist in the current researches: firstly, evaluation criteria of the tidal barrage schemes environmental impact assessment (EIA) are not adequate; secondly, uncertainty of criteria information fails to be processed properly; thirdly, correlation among criteria is unreasonably measured. Hence the contributions of this paper are as follows: firstly, an evaluation criteria system is established from three dimensions of hydrodynamic, biological and morphological aspects. Secondly, cloud model is applied to describe the uncertainty of criteria information. Thirdly, Choquet integral with respect to λ-fuzzy measure is introduced to measure the correlation among criteria. On the above bases, a multi-criteria decision-making decision framework for tidal barrage scheme EIA is established to select the optimal scheme. Finally, a case study demonstrates the effectiveness of the proposed framework.

1. Introduction

In order to confront the serious energy crisis and growing greenhouse effect, vigorously develop renewable energy is the current urgent task of whole mankind. Tidal range energy, as a renewable source, is coming into consideration recently because of its long term predictability and large potential (Sleiti, 2017). It is a form of hydropower that converts the energy obtained from tides into electricity. Constructing a tidal barrage across an estuary to extract tidal range power is a very mature way, which is developed as early as the 1960s. However, it is well-known that the tidal barrage construction is expected to entail some detrimental environmental impacts. In the planning stage of a tidal range power plant construction, more than one feasible barrage schemes will be proposed, and the environmental impacts of various barrage schemes are largely different. So, before building a tidal range power plant, the environmental impacts caused by the implement of various tidal barrage schemes must be assessed and compared fully. And the most environmentally friendly scheme should be concerned about. There are three major operating schemes for a tidal barrage, including ebb generation, flood generation and two-way generation (Kadiri et al., 2012). The environemental impacts caused by barrage vary according to the adopted operating schemes. Between the three operating schemes, two-way generation has the least impact on the hydrodynamic regime of the estuary (Xia et al., 2010b). In this paper, it is assumed that the various tidal barrage schemes all adopt the two-way generation operating scheme mainly owing to the convenience of comparison.

Assessing the possible environmental impacts of various tidal barrage schemes is a difficult and complex task since the estuary environment is a complex system consisting of hydrodynamic, biological and morphological aspects. Fortunately, a lot of studies have focused on this topic. And various numerical models are the most used method. Angeloudis et al. (2016) examined the potential of simplified 0-D modelling techniques for operation optimization. Ahmadian et al. (2014) made a comparison of hydro-environmental impacts for ebb-only and two-way generation for a Severn Barrage by implementing a linked 1-D/2-D hydro-environmental model. Xia et al. (2010c) assessed the impact of different tidal renewable energy projects on the hydrodynamic processes in the Severn Estuary using 2D hydrodynamic model. Zhou et al. (2016) presented a 3-D numerical model named MODFLOW to study the tidal effects on groundwater dynamics of a multi-layered estuary aquifer system. Apart from these multi-dimensional hydro-environmental tools, Kidd et al. (2015) evaluated potential environmental impacts following a tidal barrage installation by using a first order morphological response morphological model (FORM). There is no doubt that these modellings have made a great contribution to the environmental impacts of tidal barrage scheme. However, these modellings may seem not applicable to make an all-round

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environmental impact assessment. The reasons are as follows: firstly, these modellings only focused on a single or limited aspects of the environmental impacts and it is very complex to use multiple modellings simultaneously; secondly, it is clear that some environmental impacts induced by tidal barrages cannot be adequately assessed by numerical modellings, such as the likely impact of a barrage on shorebird populations (Mitchell and Probert, 2011); thirdly, decision makers (DMs) prefer to obtain a general assessment result in some cases, but these modellings cannot aggregate the individual criteria values into an overall value. By comparison, some methods which can comprehensively assess the tidal barrage environmental impacts are studied. A choice experiment (CE) method was employed by Lee and Yoo (2009) to measure the economic cost that results from the environmental damage caused by the construction of tidal power plant. It is a suitable method for valuing environmental goods with multiple criteria. Additionally, an Environmental Benefits Assessment (EBA) method was proposed by Hooper et al. (2014) to provide a systematic approach to evaluate the impact of local-scale developments on environmental benefits. Nevertheless, some irrationalities still exist in the two methods. For the CE method, there are some restrictions on criteria: the criteria should be independent or nearly independent of one another and there should only be a few criteria. And for the EBA method, there are several gaps in the data, and poor confidence in the accuracy of much of the data that was available. In view of this, we try to solve the issue of tidal barrage scheme EIA using the multi-criteria decision-making (MCDM) techniques since they can deal with a number of dependent criteria and possess strong data processing capability. As a well-known branch of decision-making, MCDM aims to find the most suitable solutions from a set of alternatives under multiple criteria conditions. While the MCDM has not yet been applied to tidal barrage scheme EIA, it has been successfully applied in the site selection tidal range power plants in our previous work (Wu et al., 2016b).

To successfully introduce the MCDM techniques into the problem of tidal barrage scheme EIA, the two issues of evaluation criteria identification and decision-making methods must be concerned. However, some problems related to the two issues will decrease the quality of tidal barrage scheme EIA. Firstly, evaluation criteria of the tidal barrage scheme EIA are not adequate. The inadequacy manifests in two aspects. On the one hand, most researches mainly focused on the environmental impact in term of single hydrodynamic aspect. In fact, the environmental impacts caused by tidal barrage embody in many aspects, such as biological aspect and morphological aspect; on the other hand, although a few researches reviewed the environmental impacts systematically, the amount of associated criteria is simply inadequate. Obviously, both of the defects will lead to the irrationality of the tidal barrage scheme EIA. Secondly, the uncertainty of criteria information fails to be processed properly. DMs often fail to give accurate criteria values since the dynamics and complexity are accompanied by the estuary environment. Linguistic variables are applicable in such uncertain environment since they are easy to express, and are close to the thinking mode of human mind, such as “fair”, “good” or “between fair and good”. Although fuzzy set theory can be used to describe the fuzziness of linguistic variables to some extent, but fails to include the randomness (Wu et al., 2016a). Actually, in all kinds of uncertainty, randomness and fuzziness are the most important and fundamental (Li et al., 2004). Obviously, processing the uncertainty of information improperly will reduce the accuracy of tidal barrage scheme EIA. Thirdly, correlation among criteria is unreasonably measured. There are more or less correlations among criteria of tidal barrage scheme EIA. In spite of striving to remove the correlative criteria, it still cannot ensure the criteria are absolutely independent to each other. However, most of MCDM methods have implicit assumption that the criteria are independent to each other, which are not agree with practice situation. Although the method of analytic network process (ANP), one of the MCDM methods, can deal with the correlative criteria, the judgment matrix in ANP may not meet with consistent, and the computing processes are complex and hardly can be solved by hand. Thus, measuring correlation among criteria unreasonably will weaken the scientificity of the tidal barrage scheme EIA.

Therefore, in this paper, a decision framework for selecting the most environmentally friendly barrage scheme is established. Firstly, a comprehensive evaluation criteria system is established in light of relative literatures, which consists of 12 criteria in hydrodynamic, biological and morphological aspect. The merit of this evaluation criteria system is that it decomposes the objective of tidal barrage scheme EIA to each criterion to ensure that all the impacts can be taken into account. Then, considering that the fuzziness and randomness are indispensable elements of the uncertainty, these criteria values represented initially in the form of interval linguistic variables are quantified using the cloud model. After that, a clear correlation relationship between criteria is hackled, and the Choquet integral with respect to λ-fuzzy measure is introduced to measure the correlation among criteria reasonably. It is noticed that the combination of the cloud model and the Choquet integral with respect to λ-fuzzy measure has not been studied yet.

The rest of the paper is organized as follows. The next section reviews the current evaluation criteria and inadequacies of the existing decision-making methods. Section 3 analyzes the significant criteria for tidal barrage scheme EIA as well as correlation relationship among them. Section 4 introduces the fundamental conceptions of cloud model and Choquet integral with respect to λ-fuzzy measure. Section 5 establishes the decision framework for the tidal barrage scheme EIA. Section 6 presents an illustrative a case study of the Severn estuary together with comparisons with some existing methods. Section 7 draws the conclusions.

2. Literature review

2.1. Evaluation criteria

Despite evidence of acute detrimental environmental impacts, there is a paucity of analyses assessing the environmental impacts of barrages in the peer reviewed literature. Only 13 relative literatures between 2009 and 2016 are collected. And their study object, environmental impact are listed and the aspect which these environmental impacts belong to is also generalized, which is shown in Table 1.

As can be seen from the table, the existing evaluation criteria of tidal barrage scheme EIA are not comprehensive. The defect fails to reflect the inherent characteristics of environmental impacts caused by tidal barrage, and further leads to the irrationality of the tidal barrage scheme EIA. Therefore, establishing a reasonable and comprehensive evaluation criteria system for tidal barrage scheme EIA is necessary and urgent.

2.2. Decision-making method

Quantitative criteria and qualitative criteria are involved simultaneously in the tidal barrage scheme EIA. For the former, most of them cannot be measured precisely by crisp numbers owing to the restriction of measuring and forecasting technology and dynamic characteristics of environment, and for the latter, quantifying them by employing the numerical scales will also cause the information losing. In this context, the application of linguistic variables proposed by Zadeh (1974) is recommended to work where crisp numbers fail to describe the criteria values (Pedrycz and Chen, 2011). The merits of linguistic variables are that they are easy to express and are close to the thinking mode of DMs. Actually, linguistic variables are already being used in EIA. For example, Zulueta et al. (2016) proposed a linguistic fusion approach for heterogeneous environmental impact significance assessment. Furthermore, it is meaningful to extend the linguistic variables into interval linguistic variables which consist of two linguistic variables since the preferences of DMs cannot match any of linguistic variable in some