Journal of Environmental Management 196 (2017) 48–55

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Review

Use of multicriteria analysis (MCA) for sustainable hydropower planning and management

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ARTICLE INFO

Article history:
Received 21 September 2016
Received in revised form
22 February 2017
Accepted 26 February 2017

Keywords:
Multicriteria analysis
Sustainable hydropower
Renewable energy
Water resources management
Decision-making process
Stakeholders involvement

ABSTRACT

Multicriteria analysis (MCA) is a decision-making tool applied to a wide range of environmental management problems, including renewable energy planning and management. An interesting field of application of MCA is the evaluation and analysis of the conflicting aspects of hydropower (HP) exploitation, affecting the three pillars of sustainability and involving several different stakeholders. The present study was aimed at reviewing the state of the art of MCA applications to sustainable hydropower production and related decision-making problems, based on a detailed analysis of the scientific papers published over the last 15 years on this topic. The papers were analysed and compared, focusing on the specific features of the MCA methods applied in the described case studies, highlighting the general aspects of the MCA application (purpose, spatial scale, software used, stakeholders, etc.) and the specific operational/technical features of the selected MCA technique (methodology, criteria, evaluation, approach, sensitivity, etc.). Some specific limitations of the analysed case studies were identified and a set of "quality indexes" of an exhaustive MCA application were suggested as potential improvements for more effectively support decision-making processes in sustainable HP planning and management problems.

Contents

1. Introduction

Hydropower (HP) is one of the most important renewable energy sources (RES), having the highest electricity production share (66.4% in 2008 in EU-27) (Šantl and Steinman, 2015) among RES and contributing approximately with the 16% to the global electricity production (IHA, 2015). Moreover, the trend for new HP plants is increasing, especially in regions with a relevant hydropower potential. For example in the Alps there is a highly strategic interest in the exploitation of this potential with the aim of

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http://dx.doi.org/10.1016/j.jenvman.2017.02.067
0301-4797/

providing a future-proof energy supply and clear advantages for the global CO_2 balance and the generation of several socio-economic benefits. However, despite its advantages, HP implementation causes several impacts on the affected watercourses, such as changes in river morphology and flow alterations (river impoundment, flow reduction, hydro-peaking, etc.), with a consequent loss of habitats (Alpine Convention, 2011b) and biodiversity of aquatic biota (Vezza et al., 2014a). Negative impacts of hydropower generation are not only associated with large dams, reservoirs and related hydropower facilities, but also with small hydropower plants (SHP) originating cumulative effects impacting several river stretches (Vezza et al., 2014b).

In recent years, the increased awareness by public opinion and governments about sustainable hydropower development started to involve with almost equal importance all the three interdependent pillars of sustainability, i.e. economic development, environmental protection and social justice (Kumar and Katoch, 2015), and local community is now being recognized as a key stakeholder (Diduck et al., 2013).

In order to face the problem of conflicting objectives due to multiple purposes and stakeholders, the use of a method that adds structure, auditability, transparency and rigour to the decision making process (Šantl and Steinman, 2015), like multicriteria analysis (MCA), is strongly required.

MCA is a decision-making tool used to carry out a comparative assessment of different alternatives, on the basis of a set of evaluation criteria, taking into account the opinions of the different actors concerned. It allows involved stakeholders to assign a score to each alternative, in order to quantify its performance in relation to the selected criteria. The method consists of five main steps: alternatives selection, criteria selection, utility function choice, weight allocation and final ranking. At the end of the analysis, a vector of the performances is produced, which represents the final ranking of the alternatives: the one characterized by the highest score is considered the best alternative for the problem in question (Mammoliti Mochet et al., 2012).

Due to its intrinsic features, MCA is then recognized as an important tool in addressing issues related to environmental management, since it enables to evaluate and analyse conflicting aspects from multiple perspectives, with a general overall goal of determining a preference order among a number of available options (Steele et al., 2009).

In particular, for the planning, management or policy assessment of renewable energy projects, including hydropower, several multicriteria decision analysis (MCDA) methods have been developed over the last few decades. Sustainable water management requires a proper understanding of the context by the policy decision maker and MCA can bring in a rigorous structure to decision models for the integrated management of water resources (Šantl and Steinman, 2015) and the multiplicity of metrics and the complexity of energy planning and projects can be easily handled during the decision-making process (Carriço et al., 2014). Therefore, MCA can be considered a very useful tool especially in regions where HP developments are significantly increasing, since it allows the incorporation of socio-environmental considerations into hydropower project assessments; with MCA decision makers can identify a sustainable balance between economic growth, facilitated by hydropower, and socio-environmental targets, linked to sustainable energy production (Morimoto, 2013).

The strong need and, on the other hand, the difficulty of integrating ecological, socio-economic and hydropower companies objectives in a sustainable manner have been recognized by the EU. Some guidelines, in fact, were elaborated to provide a methodological approach to support decision-making processes on regional and strategic levels (Alpine Convention, 2011a; Swiss Confederation, 2011). However, a concrete and shared MCA method for the evaluation of watercourses hydropower exploitation is still missing (Šantl and Steinman, 2015).

Under the above scenario, the objective of this paper is to analyse the main features of the different existing MCA methods, reviewing the state of the art of MCA applications to sustainable hydropower production and related decision-making and operational management problems. The analysis was based on a critical review of scientific papers related to the field of interest (MCA applications to hydropower), selected among the academic articles present in *Scopus* and *Web of Science* databases and published over the last 15 years.

The review was aimed at (i) analysing in detail the nature of MCA application to the HP sector, (ii) focusing on the most important technical features applied in several specific case studies proposed by different authors and (iii) identifying some limitations that still characterise current evaluations. On the basis of this critical review, a set of "quality indexes" of an exhaustive MCA application to a real case study were identified and some proposals were made to improve future applicative research.

2. Materials and methods

The selection of papers to be analysed was carried out using *Scopus* and *Web of Science* databases of peer-reviewed literature and completed in October 2015 focusing on scientific works published over the last 15 years. The articles were selected first searching the following keywords and their combinations: "multicriteria", "MCA", "AHP", "renewable energies", "hydropower", "HP", "hydroelectricity", and then reading the abstract of the papers returned by the databases. In this way it was possible to select only the scientific papers that really described the application of one or more multicriteria approaches to hydropower use, thus excluding, for example, the ones in which hydropower was compared to other renewable energy sources in order to find the best type of plant or energy production method in a specific context. Articles whose full paper resulted unavailable in the above databases or from other online sources were excluded from the sample.

The full papers of the selected sample were critically analysed with a two phases approach: in a first phase general aspects of the MCA application were analysed, while afterwards specific operational/technical features of the selected MCA technique were investigated.

In the analysis the following general parameters of the MCA application were considered in order to understand where and at which spatial scale MCA is applied and to identify tools, purposes and actors involved:

-The country in which the case study was set;
- The spatial scale, i.e. the extension of the area of application (for example national, regional or more specific scale);
- The description of the case study, differentiating real case studies (single site or multi-sites) from theoretical/illustrative examples;
- The software used to implement the method;
- The nature and the context of the decisional problem, i.e. the purpose for which MCA was used;
- The actors involved in the decision-making process, e.g. experts or stakeholders.

The analysis of these parameters was aimed at understanding where MCA is mainly applied and at which spatial scale, identifying tools, purposes and actors involved.

In order to draw an exhaustive and detailed picture of the main technical characteristics of the MCA applications in the sample, the