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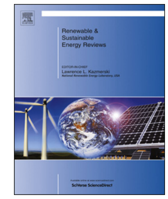

Assessing the cumulative environmental impact of hydropower construction on river systems based on energy network model

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ABSTRACT

Hydropower is the major renewable energy source for many nations and regions. Dam construction caused direct or indirect detrimental impacts on river systems by altering the water flow pattern and reshaping natural habitats. The dam-induced environmental impact assessment is critical in balancing the human demand for more accessible energy and the ecosystem conservation. In this paper, we proposed information network analysis for assessing environmental impact of hydropower construction based on energy network model of the river system. The framework is capable of evaluating multiple post-dam environmental stressors and tracking energy flows within the disturbed river system. By considering both direct and indirect interactions between system components in the network model, the environmental impacts of sedimentation, discharge change and heavy metal pollution are explicitly evaluated. Dam construction on the upper Mekong River was presented as a case study. The results suggested that the initial dam-induced impact only contributed less than 30% of the cumulative value and that the impact ranking among species, from a network perspective, significantly differed from the traditional toxicological/physiological estimation. Mollusca, benthic-feeding fish and zooplanktivorous fish in the middle trophic levels were most affected by damming, whereas the impact on species at the bottom of the food chain became less prominent in a cumulative way. The most valued species in fishery were found notably impacted and might become endangered because of dam construction. Ad-hoc management actions should be taken to enhance ecosystem conservation and sustainable hydroelectric development in China. By introducing the network approach to the cumulative environmental impact assessment, this study provided insights into a more sustainable path of hydropower construction.

Contents

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1. Introduction

Dams have been built for multiple purposes, such as irrigation for agriculture, navigation and fish framing, water supply, flood control, recreation, and hydroelectricity. About 21% of the dams are designed for power generation, which is only secondary to the application of irrigation (Fig. 1). Large dam construction for power generation has once become the symbol of human civilization progress, and the hydropower has been a major renewable energy source for many countries and regions. Until the 2010s, half of the electricity generated in one third of the countries in the world is from hydroelectricity, and 24 countries derived their electricity almost completely from hydro-dams. Four countries have dominated the hydropower landscape: China, Brazil, Canada, and the United States, which generated more than half of the world's hydroelectricity [1–3]. Over the last three decades, hydro-dams projects have been developed globally (see Fig. 1). In 2010, at 3300 billion kW h, hydroelectricity accounted for roughly 16 percent of global electricity generation, almost all produced by the world's 45,000 large dams [4]. Particularly, the hydroelectricity produced in China has increased rapidly from 20 to 600 billion kW h since 1970s, making it the largest country in terms of hydropower generation.

Though hydropower projects are considered relatively clean in terms of environmental emissions, they actually cause direct or indirect detrimental impacts on river systems by altering the water flow pattern and restructuring natural habitats [5–8]. This means these projects may be unsustainable from the environmental perspective if no protective measures are taken to conserve the ecosystems. Significant ecological changes have been reported after damming, among which sedimentation, water discharge and water quality alterations (particularly increases in some heavy metals) are detected the most significant factors in altering environmental conditions in river systems [9–11]. The construction of hydropower dams alters the structure and function of river systems. The deliberate impoundment of water is considered the major factor contributing to the significant modifications of the river's physical condition. Dams fragment river systems, causing significant effects throughout the river system (both the aquatic ecosystems and the terrestrial ecosystems) on different levels and via multiple types. These effecting levels are monomer (unit), group, assemblages and entire environment in a generic depiction, while it refers to individual, population, community and ecosystem in biological realm, and the effecting types of flow manipulations are reservoir filling, flow blockage, flow storage, and flow regulation [12]. The associated factors of these ways are hydrology, river morphology, habitat and related biota within the river system [13,14].

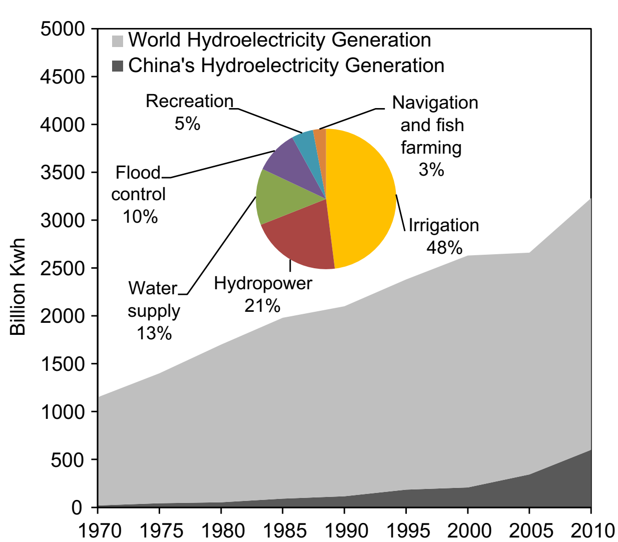

Fig. 1. Hydro-dams development of China and the world.
Source: International Commission on Large Dams (ICOLD) and Earth Policy Institute.

By addressing a wide range of anthropogenic perturbations such as energy facilities construction, ecological impact assessment (EIA) is an important tool of identifying, quantifying and evaluating the potential impacts of defined actions on systems and their components [15] EIA is capable of characterizing generated and potential outcomes in systems when human-induced stressors disturb natural processes, thus providing useful feedback for the regulation of industrial projects or civil construction [16]. A large number of EIAs have been conducted on various ecosystems frequently perturbed by human activities [17–23]. Most of these assessments were developed based on the causal relationships (i.e., cause-effect relationships) between perturbation sources and selected endpoints of interest. Frequently, standard test species or weighted bioindicators were selected and evaluated as assessment endpoints [24–26], which is heavily dependent on the values of the social groups in charge [27]. Although they have been proven useful in management practices in a wide range of scales (e.g., population, community, ecosystem and socio-ecological system [28–30]), we still have little information about what will happen to the structure and functioning inside ecosystems after disturbance due to a lack of sufficient consideration into the interactions among systems components.

On the other hand, systems ecology has been increasingly highlighted for its ability to predict the reactions of ecosystems to a rapidly changing world [31]. Modern systems ecologists suggest that all ecosystems are open networks of functional units (e.g., producers, consumers and decomposers) that interact with each other in both direct and indirect ways. A variety of modeling techniques have been developed to simulate such systemic interactions and their potential roles in responding to perturbations [32,33]. Surprisingly, few studies have sought to combine the strength of dynamical simulations with the framework of impact assessment. A salient knowledge gap exists between EIA and systems ecology.