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Review of ecological compensation in hydropower development

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ABSTRACT

Ecological compensation could coordinate the development of energy, the economy, and the environment by internalizing environmental externalities and adjusting for the relationships with stakeholders' benefits. Thus, because hydropower is a clean and renewable form of energy, it is urgent that an ecological compensation mechanism be established for hydropower to promote its sustainable development. In this context, this paper has reviewed previous compensation research to explore the particular role that ecological compensation has had in the sustainable development of hydropower. The paper discusses and perfects the ecological compensation mechanism establishment in hydropower development, discussing its connotation, stakeholders, modes, and development of standards. We found that the current ecological compensation mechanism in hydropower development was not complete; the accuracy, applicability and reasonability of each mode of ecological compensation in hydropower development required additional study. Based on these findings, in this review paper, a complete ecological compensation mechanism framework was constructed to avoid the partial compensation on large hydropower projects. With this new compensation mechanism framework, the displaced people, inundated habitats, and regulated rivers were identified as the recipients, whereas the beneficiaries from the hydropower development were identified as the payers. The findings also indicated that the market-led and government-led compensation should be integrated when designing natural habitat restoration, resettlement compensation, and payment for ecosystem services (PES) in hydropower development. Additionally, a cascade ecological compensation development mode was proposed for hydropower development according to the practical situation in China to illustrate the gradual perfection of the ecological compensation mechanism establishment.

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1. Introduction

The potentially serious environmental and social impacts that result from hydropower project development are attracting greater attention. Although hydropower development has always been traditionally considered a green energy resource, some reports have differentiated between “small hydro” as being renewable and sustainable, whereas “large hydro” is not [1]. Zhang and Xu also illustrated that the low-carbon status of large hydropower projects was overestimated [2]. A recent wave of public opposition to hydropower projects has emerged, particularly to schemes that involve reservoirs impounded by large dams. As some evidence has shown, dams impair river ecosystems by altering their flow regimes both in terms of the hydrology and geomorphology, such as the water temperature, flood extent and nutrient loads, and thus degrade feeding and breeding habitats along the river [3]. Other research has shown that stocks of Atlantic salmon on the Penobscot River declined dramatically following the construction of hydropower dams in the early 20th century [4]. Likewise, the migratory fish resource at risk from mainstream dam development on the Mekong River was estimated at 0.7–1.6 million tons per year [5]. Furthermore, the socioeconomic impacts generated by dam construction are numerous and outstanding, with respect to the displacement of a large number of indigenous people from their homeland, the extensive destruction of agricultural and forest lands, damages to historical and mineral resources, and the loss of archeological, scenic and tourist sites [6–8].

Because of the increasing adverse impacts, ecological compensation was proposed as an effective management tool to alleviate the identified contradictions among energy, the environment and socio-economics. By constructing a model area with similar ecological functions or qualities that are impaired by human activities, the ecological compensation mechanism was designed to directly improve the ecologically damaged area [9]. It was also applied to solve ecological problems in an indirect way through the payment for ecosystem or environmental services (PES), which was identified as being a market solution to adjust stakeholder interests towards protecting the environment [10]. In the field of ecological compensation for hydropower development, a broad range of hydropower interests and stakeholders began decades ago to seek approaches to hydropower development and management from different perspectives. To maximize the benefits to society and minimize the environmental and social impacts to local communities, many policies, projects and schemes were designed and thus a mechanism for ecological compensation in hydropower development began to gradually form. The World Commission on Dams and the International Hydropower Association produced policy principles and the hydropower industry developed sustainability guidelines to minimize the negative impacts [11,12]. Furthermore, several federal laws were designed in the United States to impose environmental constraints on hydropower operations, such as the Grand Canyon Protection Act, the Central Valley Project Improvement Act and the Electric Consumers Protection Act [13]. Concurrently, ecological compensation structures such as artificial gravel banks and different types of manufactured habitats were installed along the banks of reservoirs [14], all of which could be ecologically defined as ecological

compensation mechanisms. Although these measures mitigated the negative consequences, this remediation was found to be costly and was not suitable in all cases. Given the growing awareness of environmental protection as part of hydropower development, trade-offs were negotiated between hydropower companies and the landowners in watersheds with regards to environmental protection [15], which is referred to as ecological compensation in environmental economics.

2. Purpose of study

Although various ecological compensation measures have been taken to provide environmental protection in past decades, an ecological compensation mechanism for hydropower development has not been formally established. Because there is no definitive statement for the range and duty of hydropower stakeholders, the implemented compensation measures were not efficient enough. Moreover, the challenge in quantifying the various and extensive impacts from hydropower projects causes development of an ecological compensation standard to be more difficult. Thus, some queries will be raised in its development, such as does hydropower development need an ecological compensation mechanism or not? What type of ecological compensation should be applied in this field? Who should participate in the ecological compensation? How much should be compensated for impacts to the ecological environment? How could ecological compensation be reasonably and effectively practiced?

To solve these pending problems in ecological compensation and provide guidance for policymakers, this paper focuses on the following four aspects. It seeks answers to the issues concerning ecological compensation of hydropower development in terms of connotation, stakeholders, modes, and standards development. Finally, this paper also proposes further trends and solutions to ecological compensation based on the above review.

3. What is ecological compensation in hydropower development?

The term ‘compensation’ has different definitions in different contexts. Compensation measures always appear in the last step of an environmental impact assessment (EIA) and natural resource damage assessment (NRDA). It refers to the mitigation measures used to minimize environmental impacts during a project’s construction and operation, restoration of the site and to compensate for residual impacts [16,17]. Many potential impacts including ecological, economic, and social among others may require compensation. Cuperus [18] defined ecological compensation as the substitution of ecological functions or qualities that are impaired by human development. Ecological compensation plays one of the main sustainability roles within the overall compensation practice [19]. At present, ecological compensation has developed into an effective measure to balance efficiency and equity during economic development and environmental protection [20,21].

An eco-environmental externality is the theoretical basis of ecological compensation [22]. Through ecological compensation, the eco-environmental cost from resource development and the

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