The ecological damage compensation for hydropower development based on trade-offs in river ecosystem services

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Abstract. Hydropower development is a kind of trade-offs in river ecosystem services, while increasing provision services but reduce some regulation or supporting services. However, some ecosystem services we lost are difficult to recover and thus affect the regulated river and riparian ecosystems inevitably. In this context, an ecological compensation framework for damaged river in hydropower development was proposed based on the trade-off in river ecosystem services. And the accounting system for affected rivers was established based on river eco-service alteration, for the hydropower services cannot replace the lost services. Using the ecosystem services valuation methods, the trade-offs of river ecosystem services were quantified and illustrated by some hydropower projects in Lancang River, Yalung River and Min Chiang in China. According to the survey data, the annual compensation standard of per unit installed capacity in above cases may range from 27 to 206 RMB Yuan.

1. Introduction

Hydropower development in China has shown its huge development potential in last decades, for its low carbon emission and the increasing energy demand. However, hydropower projects construction would bring a series of negative impacts to nature ecosystems, and the affected river could be the most vulnerable and complex one.

In the view of watershed ecosystem services, Wang et al [1] proposed an evaluation models for hydropower development, and estimated the impacts using ecosystem services valuation methods. Some studies also pointed that the non-market value of environment was under evaluated during hydropower projects cost-benefit assessment [2]. Moreover, considering the cumulative impacts due to hydropower dam construction, the researchers have extended their focus into the riparian ecosystem and the whole regional ecosystem, the studies included the riparian vegetation effects analysis, the prediction of river ecological integrity, the impact of the earthquake frequency in the reservoir area, as well as the changing of the regional ecological carrying capacity were all contributed to assess a hydropower [3, 4]. Moreover, some developed countries had launched dam removing because of environmental considerations and the economic cost [5]. The MA acknowledges us that people have to make difficult trade-offs to maximize human well-beings when utilizing the nature environment and resources [6]. In this context, hydropower is a finite resource. When we exploit this service from the regulated river, some other ecological service would be decreased or damaged. That creates an increasing call for an ecological compensation for the habitats that damaged from the hydropower development [7, 8].
The ecological compensation was an effective environmental management method, which can promote ecological protection by internalized environmental externalities [9]. Although the ecological compensation policies are deficient in hydropower development, the researches at home and abroad have always continued. An ecological compensation standard for river basin water environment was calculated based on total pollutants control [10]; an ecological compensation for inundated habitats was made due to carbon stock balance [11]; moreover, the payment for ecosystem (PES) scheme was designed in Cambodia between hydropower operators and forest managers [12]. From the respective of the trade-offs in river ecosystem services during hydropower development, this research make efforts to propose an ecological damage compensation framework for the regulated river and riparian ecosystem. It aims to provide effective suggestions for some office and policy-makers.

2. Framework and methods

2.1. Framework

In this paper, we proposed an ecological damage compensation framework for the regulated rivers during hydropower development (Figure 1). In this framework, the ecological impacts due to hydro projects were analyzed based on the related river ecosystem services’ trade-off. According to the four categories of ecosystem services changing, the benefited and impaired which caused by the environmental externality in hydropower development can be recognized.

![Figure 1 A framework of ecological compensation for the affected river in hydropower development](image)

2.2. Methods

The variation of affected river ecosystem services by hydropower would be calculated through ecosystem service valuation methods (Table 1). Thus, the trade-off services can be quantified which can be as a basis for the standard of the ecological compensation.
Table 1 The river ecosystem services valuation methods

| Ecosystem service type | Service item         | Method                 |
|------------------------|----------------------|------------------------|
| Providing service      | Hydroelectricity     | Market value method    |
|                        | Water supply         | Market value method    |
| Regulation service     | Flood control        | Shadow price method    |
|                        | Fluvial transportation| Project restoration method |
|                        | Soil conservation    | Project restoration method |
|                        | Environment purify   | Project restoration method |
| Supporting service     | Habitat supporting   | Project restoration method |
| Culture service        | Cultural             | Contingent valuation method |

3. Results and analysis

3.1. Stakeholder analysis

According to the river ecosystem services’ alteration, the possible related stakeholders in hydropower development would be recognized, as shown in Table 2.

Table 2 The possible stakeholders in hydropower project

| Ecosystem service type | Stakeholders     |
|------------------------|------------------|
| The added              |                  |
| Hydroelectric generation| Hydropower developers |
| Water supply           | Water users     |
| Flood control          | Downstream residents |
| Other provision services| Other beneficiaries |
| The lost               |                  |
| Biodiversity           | River and Riparian ecosystem |
| Fluvial transportation | Environment benefits losers |
| Soil conservation      |                  |
| Environmental decontamination |          |
| Water regulation       |                  |

3.2. Trade-off analysis

We selected three representative rivers in China with hydropower development and calculated the annual variation of each river ecosystem service value caused by per unit installed capacity. The results were shown in Table 3 and Figure 2.

Table 3 The annual variation of river ecosystem service value caused by per unit installed capacity (RMB Yuan/Kw)*

| Regulated river Ecosystem service type | Lancang River | Yalung River | Min Chiang |
|----------------------------------------|---------------|--------------|------------|
| The added                              |               |              |            |
| Hydroelectric generation               | 714           | 723          | 828        |
| Water supply                           | 0.57          | /            | 37.78      |
| Flood control                          | 0.32          | 4.88         | 23.14      |
| The lost                               |               |              |            |
| Biodiversity                           | 13.90         | 2.47         | 36.26      |
| Fluvial transportation                 | 188           | 7.85         | 49.12      |
| Soil conservation                      | 3.01          | 12.39        | 61.35      |
| Environmental decontamination          | 0.67          | 4.50         | 11.34      |

Note: the parameters for calculation came from Ref. [13-15].
It seems that the trade-offs in river ecosystem services during hydropower development are advantageous and profitable, for the added ecosystem service value is higher than the lost. However, the concern cannot just stay at the increased ‘value’. On the one hand, the river ecosystem service loss would be a conservative estimate; on the other hand, the added services cannot substitute for the lost from the perspective of ecological functions. In this concern, the ecological compensation for the damaged river ecosystem should be established and the compensation standard could be estimated based on the river ecosystem services value loss. Take the cases in this study as an example, the annual compensation standard could be ranged from 27 to 206 RMB Yuan/KW due to the degree of river ecosystem services loss.

![Figure 2. The river ecosystem services value alteration generated by hydropower development](image)

3.3. Eco-compensation mode analysis
The different compensation objects should be compensated in different modes. For the affected human, the provided ecological compensation should meet their actual requirements. Thus, various compensation ways could be combined, such as policy compensation, fund compensation, and material compensation may be selected for their benefits loss. For the habitat loss, project compensation method, such as afforestation projects could be built in watershed, which offset the lost ecosystem services. The damaged aquatic river could be also compensated by off-site compensation mode, which means that the beneficiaries could take some measures to improve other pollutant water bodies in local watershed, to realize regional water system ecological balance.

4. Conclusion
In this paper, we proposed a hydropower development ecological compensation framework to promote water resource sustainable exploitation. According to the trade-off analysis, the compensation objects were identified, and standard was calculated based on the loss of affected river ecosystem services by hydropower development. With the case study of Lancang River, Yalung River and Min Chiang hydropower development, the annual compensation standard could be ranged from 27 to 206 RMB Yuan/KW due to the degree of river ecosystem services loss.

This study was a preliminary attempt for hydropower development trade-off analysis in the view of affected river ecosystem services. Due to the data acquisition restrictions, the specific standard setting and how to carry out the ecological compensation need further studies.

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