energies

MDPI

Article

Environment Management of Hydropower Development: A Case Study

Yakun Zhang [1], Wenzhe Tang [1,*], Colin F. Duffield [2], Lihai Zhang [2] and Felix Kin Peng Hui [2]

1 State Key Laboratory of Hydroscience and Engineering, Institute of Project Management and Construction Technology, Tsinghua University, Beijing 100084, China; zyk18@mails.tsinghua.edu.cn
2 Department of Infrastructure Engineering, The University of Melbourne, Melbourne, VIC 3010, Australia; colinfd@unimelb.edu.au (C.F.D.); lihzhang@unimelb.edu.au (L.Z.); kin.hui@unimelb.edu.au (F.K.P.H.)
* Correspondence: twz@mail.tsinghua.edu.cn

Abstract: Environment management is one of the key aspects of hydropower development in acquiring sustainable energy. However, there has been limited research demonstrating the overall aspects of environment management of hydropower development with support of sound empirical evidence. In present study, the status of environment management in hydropower development was comprehensively investigated by conducting a case study based on the data collected from a field survey. The results show that, as environment management is largely subject to legal requirements, the environment management system needs to be established by integrating the legal requirements and needs of project implementation. This could potentially reduce the influence of legal restrictions on hydropower development. The main hydropower project environment management processes include identifying key environmental factors, implementation, monitoring, and performance measurement, which deal with environmental issues such as terrestrial and aquatic ecology protection, wastewater treatment, solid waste disposal, and acoustic-environment protection. Project participants should establish partnering relationships to cooperatively deal with environmental impacts of hydropower project development, in which public participation and sufficient resources input into environmental protection are essential for project success. The results of this study provide a sound basis for participants to deal with the key issues of environmental protection such as meeting legal requirements, training for improving environment management process, cost control, and cooperative environment management. The results of this study could help practitioners to tackle the interactions among project delivery, environmental protection, and engagement of local communities in an optimized way with the aim of maximizing effectiveness of the resources of all participants.

Keywords: hydropower; environment management system; environment management processes; partnering; case study

Citation: Zhang, Y.; Tang, W.; Duffield, C.F.; Zhang, L.; Hui, F.K.P. Environment Management of Hydropower Development: A Case Study. *Energies* **2021**, *14*, 2029. https://doi.org/10.3390/en14072029

Academic Editor: Nikolaos P. Theodossiou

Received: 18 March 2021
Accepted: 4 April 2021
Published: 6 April 2021

1. Introduction

The use of renewable energies is an effective way to reduce carbon emissions [1]. In order to alleviate the potential impacts of climate changes caused by fossil fuels [2] the development of hydropower has become a trend worldwide. As hydropower projects can contribute significantly to environment sustainability, hydropower development should enable the reduction of fossil energy usage [3]. China is rich in hydro-energy resources and has 14% of the world's electricity generated by hydropower plants [4]. China plans to increase the share of non-fossil energy from 15.0% in 2020 to 20.0% by 2030 [5], and the realization of this goal largely relies on hydropower development [6].

However, hydropower development may have impacts on the project-located environment as well as local communities [7–10]. Hydropower development involves project implementation and environmental and social objectives [9–12], and balancing these objectives is challenging for the environment management of hydropower project delivery [13].

Dealing with environmental issues in hydropower project delivery involves complex interactions among clients, designers, builders, consultants, suppliers, local communities, and authorities [14]. The lack of cooperation between project participants is the key barrier to implementing effective environment management [7,10,12,15,16].

Therefore, the objective of this research is to understand the critical success factors of the environment management system, process, and cooperative approaches in dealing with hydropower project environment management, which help participants cooperatively solve environmental problems by maximizing effectiveness of the resources of all participants. This paper presents findings on the key aspects of environment management in hydropower development, with the support of a case study of the Yangfanggou hydropower project.

2. Literature Review on Environment Management of Hydropower Development

In addition to the advantages of hydropower development, such as energy supply [17,18], employment generation, and the improvement of water quality, hydropower projects may cause changes in aquatic communities, the loss of flora and fauna genetic patrimony, local climatic changes, the destabilization of slopes, and the relocation of residents [19]. Rivers could be impaired without appropriately considering components of ecosystems [20].

Hydrologic condition and riparian changes in the river basin are critical in dealing with the environment management of hydropower projects [21,22]. Dams have a strong impact on the fluvial environment by altering downstream flows [23]. Allan et al. demonstrated that the biological diversity of rivers is significantly influenced by landform and the surrounding land use [24]. Damming rivers can also cause riparian changes such as inducing geological hazards [15], soil erosion [25], changes in local climate [26], and influence on historical sites and cultural heritages [16].

Influence on aquatic and terrestrial ecosystems is a key environmental issue of hydropower development [27,28]. River damming creates significant impacts on river environments worldwide [29], and the influence on river ecosystems has increased by building water structures in recent years [30]. Whereas the influence of reservoir inundation is immediate, ecological impacts on downstream could be long-term problems [29]. The undesirable impacts should be mitigated to ensure the ecosystems are not harmed [30,31]. Kuriqi et al. pointed out that setting appropriate environmental flows is important to riverine ecosystem conservation. For instance, a minor reduction of hydropower generation may significantly increase environmental flows for meeting ecosystem needs [32–35]. To understand the ecological impacts of hydrological changes, Gao et al. indicated the need to monitor fish assemblages before and after hydropower project construction. Ad-hoc management measures should be adopted to protect riverine ecosystems for sustainable hydropower development [36].

The social impacts of hydropower development are significant and largely arise from the impoundment of reservoirs [37]. Tilt et al. identified the social impacts of large-scale hydropower projects, including impacts on migration resettlement, infrastructure development, local economy, employment structure, cultural life, and social relations [38]. Tang et al. pointed out that migrants' skills could be ineffective in the resettled communities, and losing the original social relations could aggravate migrants' economic marginalization due to the decrease of their social capitals [22]. Varan et al. revealed that, in addition to the impact on local cultural heritage, the resettlements could cause unwanted place-based memories [39]. Due to extensive aspects related to dealing with social issues, Cretan et al. pointed out that hydropower project construction needs to consider not only social and economic relations but also the influence of political power [40].

The environment management of hydropower development includes planning, organization, implementation, and control [41]. By studying the Himalaya Dams in India, Grumbine and Pandit demonstrated that the improvement of planning and implementation of environmental protection is crucial to the development of hydropower projects [42]. Kuby et al. indicated that dam construction requires an advance assessment of the river system to weigh the economic and ecological objectives [26]. Soito et al. also pointed out that the social and environmental impacts of the entire basin should be assessed in advance with public participation [25].

Mitigating the above environmental impacts involves all of the stakeholders involved in the hydropower project, including clients, contractors, designers, consultants, local residents, and authorities [7,16]. Rosso et al. pointed out that use of hydropower and river ecosystem conservation are two contrasting aspects which may generate conflicts among project participants [43]. As environment management activities are closely interrelated, the establishment of partnering relationships among project participants to cooperatively mitigate the environmental impacts of hydropower development is essential [9,44]. Liu et al. indicated that hydropower development should be a win-win energy development approach, and cooperation among stakeholders could assist to realize the integration of sustainable development and mitigation of environmental impacts [45]. For instance, Wang et al. studied the relationship between public responses and social impacts of project development and indicated the importance of people-oriented environment management [10], which requires the participation of local communities in improving environment management performance. Project participants should explicitly evaluate the risks and balance the ecological, economic, and social goals [46].

To tackle the increase of environment-related disputes, project participants should jointly establish environment management systems and processes and cooperatively solve environmental problems. This would allow participants to clearly understand their responsibilities and have the motivations and necessary resources to achieve environmental protection objectives [41,47,48]. Sternberg indicated that hydropower development should also make environmental technical improvements to minimize environmental influence [49].

Despite the approaches addressed by the above researchers, there is a lack of empirical evidence on systematically analyzing environment management of project participants. Accordingly, we conducted a case study of the Yangfanggou hydropower project from the perspective of project participants. Case studies demonstrate real-life phenomena using multiple data collection methods, which is important to help understand how and why real-world things happen [50]. Understanding the status of the environment management system, process, and cooperative approaches can help overcome the challenge of how to maximize the utilization of hydropower while maintaining riverine ecosystems. The empirical research questions for the case study are:

1. What is the status of environment management system in the hydropower project?
2. What is the status of environment management process in the hydropower project?
3. What is the status of cooperative environment management in the hydropower project?
4. What are the appropriate strategies to improve environment management of hydropower development?

3. Research Methods

3.1. Choosing Research Case of Yangfanggou Hydropower Project

Several hydropower projects have been developed in southwest China [41], a region in which 70.8% of hydropower resources are located [51]. The Yalong River, located in Western Sichuan Province, is an important branch of the Yangtze River where 21 cascade hydropower projects have been planned and built. Located in the middle reaches of the Yalong River, the Yangfanggou hydropower project is a large-scale hydropower station in China with a total installed capacity of 1500 MW, and the estimated total budget is about RMB 20 billion (USD 2.96 billion), with environmental protection being a key aspect of the Yangfanggou hydropower project's delivery. The project participants, including the client, designer, builder, and consultant, are prestigious in the hydropower industry. The Yangfanggou hydropower project can well represent the environment management of hydropower development in the Yalong River as well as in China. Thus, the Yangfanggou hydropower project was chosen as the case for an in-depth study on environment management.

3.2. *A Triangulated Approach of Data Collection*

A triangulated approach permits both qualitative and quantitative data collection to test a study proposition [52]. The case study of Yangfanggou hydropower project uses questionnaire survey as the principal survey method, complementing with interviews, project documents collection and direct observation. Questions of the questionnaire were designed on the basis of the reviewed studies combining with the author's experience and understanding of environment management in hydropower development.

The relevant themes worthy of investigation include the environment management system, processes, and cooperative management among participants. The variables of the environment management system were measured by 4 indicators (see Table 1), which enabled us to learn aspects regarding the hydropower project environment management system's completeness, renewal, compliance to legal requirements, and matching project needs. The variables of the environment management process were measured by 6 indicators (see Table 2) regarding the identification of key environmental factors, integration of environment management into the project implementation process, training, monitoring, performance measurement, and cost management. The variables of cooperative environment management were measured by 15 indicators (see Table 3), which enabled us to learn how project participants collaboratively delt with environmental issues regarding mutual goals, input of resources, allocation of responsibilities, linkages between stakeholders, joint resolution of environmental problems, and environment information management.

Table 1. Environment management system.

Indicators	Overall		Client		Contractor		Consultant	
	M.	**R.**	**M.**	**R.**	**M.**	**R.**	**M.**	**R.**
Compliance to legal requirements	4.51	1	4.60	1	4.38	1	4.62	1
Matching project needs	4.35	2	4.58	2	4.18	2	4.38	2
Environment management system renewal	4.19	3	4.22	3	4.00	4	4.23	3
Environment management system completeness	4.14	4	4.20	4	4.15	3	4.15	4
Average	**4.30**	—	**4.40**	—	**4.18**	—	**4.35**	—

Note: M. = mean; R. = rank.

Table 2. Environment management processes.

Indicators	Overall		Client		Contractor		Consultant	
	M.	**R.**	**M.**	**R.**	**M.**	**R.**	**M.**	**R.**
Environment management training process	4.15	1	4.00	2	4.31	1	4.38	1
Process of identifying key environmental factors	4.14	2	4.13	1	4.03	5	4.15	3
Environment management process monitoring	4.12	3	3.93	3	4.08	4	4.23	2
Integrating environment management into project implementation process	4.09 [a]	4	3.73	5	4.00	6	4.08	5
Environmental performance measuring process	4.09	5	3.85	4	4.15	3	4.08	6
Environmental cost management process	4.07 [a]	6	3.67	6	4.23	2	4.11	4
Average	**4.11**	—	**3.89**	—	**4.13**	—	**4.17**	—

Note: M. = mean; R. = rank. [a] One-way analysis of variance (ANOVA) is significant at the 0.05 level.

Table 3. Cooperative environment management.

Indicators	Overall		Client		Contractor		Consultant	
	M.	**R.**	**M.**	**R.**	**M.**	**R.**	**M.**	**R.**
All project participants have mutual goals	4.33	1	4.20	1	4.35	2	4.38	3
Timely review and continuously improvement	4.28	2	4.00	3	4.23	5	4.35	4
Inputting sufficient resources	4.21	3	3.95	4	4.08	11	4.15	9
Clear responsibilities in environment management	4.19	4	4.07	2	4.21	6	4.62	1
Good cooperation with government	4.16 [a]	5	3.73	12	4.16	8	4.23	7
Participants have rich knowledge and experience in environment management	4.15	6	3.80	8	4.00	13	3.92	15
Environment information management infrastructure is effective	4.12	7	3.89	5	4.31	3	4.31	5
Environment management process among participants are well connected	4.07	8	3.73	13	4.15	9	4.15	10
Environment management systems among participants are well matched	4.06	9	3.80	9	4.25	4	4.28	6
Participants actively cooperate to solve environmental problems	4.05	10	3.67	14	3.77	15	4.05	12
Periodic training for environment management	4.00 [a]	11	3.78	10	4.08	12	4.46	2
Environment management plays an important role in overall project management	3.98 [a]	12	3.75	11	4.38	1	4.20	8
Coordination among participants is efficient	3.95	13	3.67	15	4.12	10	3.94	14
Environment information is efficiently circulated	3.91	14	3.87	6	4.18	7	4.08	11
Good cooperation with local residents	3.79	15	3.82	7	4.00	14	4.00	13
Average	**4.08**	—	**3.85**	—	**4.15**	—	**4.21**	—

Note: M. = mean; R. = rank. [a] ANOVA is significant at the 0.05 level.

The questions were formatted in a 5-point Likert scale, which facilitates different statistical techniques to be used for analysis. Interviews, direct observations, and engineering document reviews were also used to collect more in-depth data for the study. A total of 93 questionnaires were distributed to management staff of project participants, with a distribution of 26 (the client), 38 (general contractor), and 29 (the consultant). Each respondent at least 5 years of experience in hydropower development. The fieldwork survey approach enabled all sent questionnaires to be collected.

After the completion of questionnaire survey, the respondents with high rank positions were interviewed in a group meeting. A total of 61 respondents were interviewed, with a distribution of 17 (the client), 25 (general contractor), and 19 (the consultant). Direct observation of construction sites and reviewing the project implementation reports deepened the researchers' understanding of environment-related hydropower project delivery activities.

The data collected from questionnaires were analyzed using the Statistical Package for Social Science. Techniques used for this research included estimation of the sample population mean, rank cases, and one-way analysis of variance (ANOVA), with the results being tested by significance. The level of significance in this paper follows the usual hurdle of statistical significance of 0.05. The data collected from interviews, direct observations, and project document reviews were used to validate and explain the questionnaire survey results.

4. Survey Results and Analyses

4.1. Environment Management System

The environment management system was evaluated on a scale of 1–5 by respondents, where 1 = very poor and 5 = very good. The results are shown in Table 1.

The one-way ANOVA analysis indicates that project participants reported no significant difference on the evaluation outcome of environment management system. As shown in Table 1, the overall rating had a high score of 4.30, showing that all participants established mature environment management systems. "Compliance to laws" obtained the highest rating of 4.51, and this is attributed to the fact that environment management is largely subject to laws and regulations. The requirements of laws and regulations were strictly incorporated into environment management systems by each participant. Other indicators also had high ratings ranging from 4.35 to 4.14. Interviews confirmed that the scope of environment management system included all of the work required with the renewal of the system in a timely manner, and the environment management manual well matched the needs of project delivery.

4.2. Environment Management Processes

The environment management processes were evaluated on a scale of 1–5 by respondents, where 1 = very poor and 5 = very good. The results are shown in Table 2.

As seen in Table 2, the average score of environment management process was 4.11, showing that environment management processes performed well in general. The project environment management processes included identifying key factors, implementation, monitoring, and performance measurement.

To identify the key factors of terrestrial-ecology protection, field investigations were carried out before construction and rare species of plants were conserved or transplanted. To mitigate the aquatic-ecology impacts of the dam, the client invested in building the fish breading base (see Figure 1), and the contractor hired experienced experts to operate the base during the project implementation stage. Every year, the base can breed different kinds of fish, totaling up to 500,000 fish, which are released to the river to conserve the fish species.

Figure 1. Fish breading base of the Yangfanggou hydropower project.

Wastewater-reuse facilities were set up in an aggregate system in construction site areas, with the processing capability of 910 m^3/h. The treated wastewater could then be used for greening vegetation to save water and avoid water pollution. In terms of acoustic-environment protection, excavations of groundworks and slopes were arranged in the daytime, and low-noise equipment was chosen in producing concrete to avoid influence the local communities.

The environmental management approaches should be incorporated into the training process for improving participants' understanding and execution. As shown in Table 2, "environment management training process" obtained the highest rating of 4.15, and this is attributed to the project's great effort in environment training. The training contents included: (1) Environmental protection knowledge and responsibility; (2) inspection and evaluation of environmental protection process; (3) improvement of working environment; (4) integrated management of occupational health, safety and environment (HSE). The interviewed experts indicated that, due to many workers having a low level of education and instability existing in the workforce, it is indispensable to improve the technique skills of the workers in environmental protection.

The one-way ANOVA result shows that the client and the contractor had different perceptions on the "environmental cost management process." There is an environmental management budget, and the contractor spent it labor payoffs, inspections, and onsite waste treatment facilities. Although the contractor was satisfied with the use of money on environment management, the client wanted the contractor to do more, which is attributed to the lack of clear specifications on environmental protection. There is a need to establish standardized environment management criteria by which methods and outcomes can be measured and evaluated. Accordingly, the general contract should clearly specify how to use the budget to meet the environmental protection requirements.

4.3. Cooperative Environment Management

Environment management in hydropower development involves different participants' cooperation. The cooperative environment management of the Yangfanggou hydropower project was assessed on a scale of 1–5 by respondents, where 1 = strongly disagree and 5 = strongly agree. The results are shown in Table 3.

As seen in Table 3, the average score of the 15 indicators was 4.08, indicating that the cooperation among participants in environment management of the project was generally well. Interviews confirmed that all project participants had the mutual goal of environment management and had input sufficient resources in jointly solving environmental problems. For example, the client set incentives to motivate the contractor's workers to meet the requirements of environment management in the construction processes.

However, "coordination among participants is efficient" and "environment information is efficiently circulated" obtained relatively low scores (see Table 3), owing to the complex factors involved in hydropower project environment management and the reciprocal interactions among multiple participants. This suggests that information technologies, such as the timely collecting, saving, and transferring big data for improving management efficiency, should be well developed and used to support environment management process.

Notably, "good cooperation with local residents" had the lowest score of 3.79, indicating the challenge in dealing with environmental issues involving local residents. It is necessary to carefully consider the environmental impacts of hydropower project construction to ensure good air quality, avoid water pollution, and reduce the influence of diverting watercourses on local residents' livelihoods.

5. Discussions

5.1. Strategies for Environment Management of Hydropower Development

(1) Establishing environment management system by integrating legal requirements and project needs

The results of this study demonstrate that, to meet the legal requirements, project participants should clearly know the relevant specifications of environment protection regulations and laws, and hydropower project environment management system needs to be renewed in a timely manner. This is attributed to the fact that environmental impact assessment law needs to be continuously reformed to maintain riverine ecosystems and create the social resilience associated with hydropower development [8]. The research outcomes suggest that the hydropower project's environmental impacts should be thoroughly studied and understood in early stage of project planning and design. This is in line with the view that stresses assessing the social and environmental impacts of entire basin in advance [25].

This case study illustrates that the environment management system should be established by integrating the legal requirements and needs of project implementation, which help reduce the influence of legal restrictions on hydropower project delivery. This is imperative, especially for provisions of environment law addressing the impacts of an individual project in the context of the whole river basin [42,53]. However, due to the complexity of hydropower project development, relevant environmental protection requirements can be from the power, transportation, and water sectors. Inconsistencies among these requirements should be carefully considered in preparing the environment management system.

(2) Improving cost management of environmental protection

The survey results (see Table 2) show that there is misalignment between the client and the contractor on environmental cost management, owing to a lack of clear specifications on the execution of environmental protection. Shaktawat et al. also pointed out that hydropower project construction requires a huge investment, with uncertainties involving considerable costs [54]. The finding of Wang et al. illustrated that hydropower project cost has the closest relationship with environmental impacts [15]. Hydropower investments have been subject to intense criticism over environmental issues and common experience with cost uncertainty. Awojobi et al. suggested that learning from historical information could help reduce the uncertainty in the cost of hydropower project construction worldwide [55].

Both the client and the contractor should not only prepare a budget for environment management but also clearly specify the criteria, scope, and responsibility of environmental protection. Then, there is a need to control environment management costs using the following approaches: (1) Optimizing planning to improve the efficiency of resource input in environment management; (2) promoting green construction technologies to reduce environmental impacts in project implementation; (3) ensuring the effectiveness in execution; and (4) using information technologies to monitor and analyze environment management performance for continuous improvement.

(3) Enhancing the capability of workers in environmental protection by training

The survey results indicate that hydropower project delivery involves a large number of workers with a low level of education. This is consistent with the finding that approximately 70% of the contractors' workers had inadequate technical skills in hydropower project delivery, and this happens because workers are normally from rural areas with low education levels [22]. Wang et al. demonstrated that capability of workers is significantly correlated with hydropower project performance, including environment management [15].

It is essential to improve technique skills of the workers by training on environmental protection knowledge and responsibility. Environmental protection process should be inspected and evaluated to ensure the workers' performance meeting requirements and to find causes of problems for continuous improvement. These approaches can not only assist mitigate the project's environmental impacts, but also help integrated management of occupational health, safety and environment in construction, thereby creating healthier and safer working conditions to protect the workers.

(4) Enhancing project participants' cooperative environment management

This case study shows that hydropower project environment management processes involve complex interactions among the client, designers, builders, consultants, suppliers, local communities, and authorities. This provides sound support to the propositions on adopting a win-win energy development approach and cooperatively mitigating environmental impacts to reduce environment-related disputes [9,12,47,56]. Project participants should establish well-connected interorganizational environment management processes, with clearly delineated responsibilities which facilitate jointly dealing with environmental issues in construction. Incentives can be used to provide contractors with the necessary motivation and resources for better environment management performance.

The survey results demonstrate that good cooperation with local residents is the most challenging issue in environment management (see Table 3). This is attributed to the significance of the social impacts of hydropower development, and dealing with them involves extensive factors and complex interactions. It is indispensable to adequately study and understand the interactions among hydropower development and environmental and social processes. In the early stage of project planning and design, public opinions should be widely collected. In the construction stage, feedback from local residents should also be incorporated into environment management processes in a timely manner to mitigate the hydropower project's environmental impacts on local communities.

However, achieving good coordination among participants and efficient environment information circulation are challenging (see Table 3). Information technologies should be applied to support both inter- and intraorganizational environment management processes. The information technologies should have the functions of monitoring the environmental status, collecting and analyzing big data, approving construction plans, and decision-making, which help improve environment management efficiency.

5.2. Contributions to the Body of Knowledge

The findings of the study have both theoretical and practical contributions to the existing body of knowledge. First, this study identified the critical success factors of the environment management system, processes, and cooperative approaches in dealing with the environmental issues of hydropower development. Second, the survey results demonstrate the status of environment management in hydropower development, revealing the key issues of environment management such as meeting legal requirements, training for improving participants' understanding and execution, cost control, and cooperation among participants. Third, the practical strategies found in this study can help practitioners to optimally deal with the interactions among project delivery, environmental protection, and local communities by maximizing the effectiveness of the resources of all participants.

5.3. Limitations and Future Research Directions

The main limitation of this study lies in the fact that data were only collected from one hydropower project in China, and more hydropower projects worldwide should be further studied. In the future, the relationships between the key factors of environment management should be studied to help theoretically understand the links between the environment management system, processes, and cooperation of participants. In addition, the use of incentives, environmental cost management, green construction, and application of information technologies should be the emphasis of future research to improve the effectiveness and efficiency of environment management.

6. Conclusions

Environment management is a key aspect of hydropower development, but there is a lack of empirical studies demonstrating the overall aspects of environment management of hydropower project delivery. A case study on hydropower project environment management was conducted on the basis of the data collected from a field survey, with the findings as follows.

As environment management is largely subjected to legal requirements, incorporating the relevant requirements of laws and regulations into environment management systems is essential for participants to deliver the hydropower project. The environment management system should be established by integrating the legal requirements and needs of project implementation, which can help to reduce the influence of legal restrictions on hydropower development.

The main hydropower project environment management processes include identifying key environmental factors, implementation, monitoring, and performance measurement, which deal with environmental issues such as terrestrial and aquatic ecology protection, wastewater treatment, solid waste disposal, and acoustic-environment protection. The environmental management processes should include training to improve participants' understanding and execution. Due to a preponderance of workers with a low level of education and high turnover in the workforce, it is indispensable to improve the technique skills of the workers in environment management.

There is misalignment between the client and the contractor on environmental cost management. There is a need to clearly specify the criteria, scope, and responsibility of environmental protection, which will help reach the client and contractor reach an agreement on the environment management budget that optimally allocates the resources necessary to accomplish the objectives. In project implementation, environment management costs can be controlled by approaches such as optimizing the planning, applying green construction technologies, enhancing the capabilities of managers and workers, and using information technologies, which assist improving environment management effectiveness and efficiency.

Project participants should establish partnering relationships to cooperatively deal with the environmental impacts of hydropower project development, in which public participation and sufficient resource input into environmental protection are essential. In cooperative environment management, interorganizational environment management processes should be well matched and connected, and the processes should be supported by information technologies on environment status monitoring, data collecting, and analyzing, checking, approving, and decision-making with high efficiency.

Author Contributions: Conceptualization, W.T.; Writing—original draft preparation, Y.Z.; Writing—review and editing, C.F.D., L.Z. and F.K.P.H.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (NSFC), grant number 51579135, 51779124 and 51379104.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Many thanks are offered to the National Natural Science Foundation of China (Grant Nos. 51579135, 51779124, 51379104). The authors also thank the respondents for their contributions during the survey.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Schiermeier, Q.; Tollefson, J.; Scully, T.; Witze, A.; Morton, O. Electricity without carbon. *Nature* **2008**, *454*, 816–823. [CrossRef] [PubMed]
2. Hellweg, S.; Mila i Canals, L. Emerging approaches, challenges and opportunities in life cycle assessment. *Science* **2014**, *344*, 1109–1113. [CrossRef]
3. Cartelle Barros, J.J.; Lara Coira, M.; de la Cruz Lopez, M.P.; del Cano Gochi, A. Assessing the global sustainability of different electricity generation systems. *Energy* **2015**, *89*, 473–489. [CrossRef]
4. Hu, Y.; Cheng, H. The urgency of assessing the greenhouse gas budgets of hydroelectric reservoirs in China. *Nat. Clim. Chang.* **2013**, *3*, 708–712. [CrossRef]
5. National Development and Reform Commission (NDRC) of People's Republic of China. The 14th Five-year Plan for Economic and Social Development of the People's Republic of China. Available online: https://www.ndrc.gov.cn/fggz/fzzlgh/gjfzgh/202103/P020210323405614585384.pdf (accessed on 23 March 2021).
6. Bawa, K.S.; Koh, L.P.; Lee, T.M.; Liu, J.; Ramakrishnan, P.S.; Yu, D.W.; Zhang, Y.-P.; Raven, P.H. China, India, and the Environment. *Science* **2010**, *327*, 1457–1459. [CrossRef] [PubMed]
7. Du, L.; Tang, W.; Liu, C.; Wang, S.; Wang, T.; Shen, W.; Huang, M.; Zhou, Y. Enhancing engineer-procure-construct project performance by partnering in international markets: Perspective from Chinese construction companies. *Int. J. Proj. Manag.* **2016**, *34*, 30–43. [CrossRef]

8. Tang, W.; Shen, W.; Lei, Z.; Wang, S.; Duffield, C.F.; Wei, Y.; Hui, F.K.P. Holistic hydropower scheme for China. *Nature* **2016**, *532*, 37. [CrossRef]
9. Tang, W.Z.; Duffield, C.F.; Young, D.M. Partnering mechanism in construction: An empirical study on the Chinese construction industry. *J. Constr. Eng. Manag.* **2006**, *132*, 217–229. [CrossRef]
10. Wang, S.; Tang, W.; Qi, D.; Li, J.; Wang, E.; Lin, Z.; Duffield, C.F. Understanding the Role of Built Environment Resilience to Natural Disasters: Lessons Learned from the Wenchuan Earthquake. *J. Perform. Constr. Facil.* **2017**, *31*, 04017058. [CrossRef]
11. Chang, X.; Liu, X.; Zhou, W. Hydropower in China at present and its further development. *Energy* **2010**, *35*, 4400–4406. [CrossRef]
12. Shen, W.; Tang, W.; Wang, S.; Duffield, C.F.; Hui, F.K.P.; You, R. Enhancing Trust-Based Interface Management in International Engineering-Procurement-Construction Projects. *J. Constr. Eng. Manag.* **2017**, *143*, 04017061. [CrossRef]
13. Diakoulaki, D.; Karangelis, F. Multi-criteria decision analysis and cost-benefit analysis of alternative scenarios for the power generation sector in Greece. *Renew. Sustain. Energy Rev.* **2007**, *11*, 716–727. [CrossRef]
14. Darmawi; Bernas, S.M.; Imanuddin, M.S.; Sipahutar, R. Renewable energy and hydropower utilization tendency worldwide. *Renew. Sustain. Energy Rev.* **2013**, *17*, 213–215. [CrossRef]
15. Wang, S.; Tang, W.; Li, Y. Relationship between Owners' Capabilities and Project Performance on Development of Hydropower Projects in China. *J. Constr. Eng. Manag.* **2013**, *139*, 1168–1178. [CrossRef]
16. Wang, S.; Shen, W.; Tang, W.; Wang, Y.; Duffield, C.F.; Hui, F.K.P. Understanding the social network of stakeholders in hydropower project development: An owners' view. *Renew. Energy* **2019**, *132*, 326–334. [CrossRef]
17. Cheng, L.; Opperman, J.J.; Tickner, D.; Speed, R.; Guo, Q.; Chen, D. Managing the Three Gorges Dam to Implement Environmental Flows in the Yangtze River. *Front. Environ. Sci.* **2018**, *6*, 64. [CrossRef]
18. Von Sperling, E. Hydropower in Brazil: Overview of positive and negative environmental aspects. In *Terragreen 2012: Clean Energy Solutions for Sustainable Environment, Proceedings of the Clean Energy Solutions for Sustainable Environment, Beirut, Lebanon, 16–18 February 2012*; Salame, C., Aillerie, M., Khoury, G., Eds.; Elsevier: Amsterdam, The Netherlands, 2012; pp. 110–118.
19. Ansar, A.; Flyvbjerg, B.; Budzier, A.; Lunn, D. Should we build more large dams? The actual costs of hydropower megaproject development. *Energy Policy* **2014**, *69*, 43–56. [CrossRef]
20. Brandt, S.A. Classification of geomorphological effects downstream of dams. *Catena* **2000**, *40*, 375–401. [CrossRef]
21. Chen, S.; Chen, B.; Fath, B.D. Assessing the cumulative environmental impact of hydropower construction on river systems based on energy network model. *Renew. Sustain. Energy Rev.* **2015**, *42*, 78–92. [CrossRef]
22. Tang, W.; Li, Z.; Qiang, M.; Wang, S.; Lu, Y. Risk management of hydropower development in China. *Energy* **2013**, *60*, 316–324. [CrossRef]
23. Bridge, G.; Jonas, A.E.G. Governing nature: The reregulation of resource access, production, and consumption. *Environ. Plan. A Econ. Space* **2002**, *34*, 759–766. [CrossRef]
24. Allan, J.D. Landscapes and riverscapes: The influence of land use on stream ecosystems. *Annu. Rev. Ecol. Evol. Syst.* **2004**, *35*, 257–284. [CrossRef]
25. Da Silva Soito, J.L.; Vasconcelos Freitas, M.A. Amazon and the expansion of hydropower in Brazil: Vulnerability, impacts and possibilities for adaptation to global climate change. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3165–3177. [CrossRef]
26. Kuby, M.J.; Fagan, W.F.; ReVelle, C.S.; Graf, W.L. A multiobjective optimization model for dam removal: An example trading off salmon passage with hydropower and water storage in the Willamette basin. *Adv. Water Resour.* **2005**, *28*, 845–855. [CrossRef]
27. Aguiar, F.C.; Martins, M.J.; Silva, P.C.; Fernandes, M.R. Riverscapes downstream of hydropower dams: Effects of altered flows and historical land-use change. *Landsc. Urban Plan.* **2016**, *153*, 83–98. [CrossRef]
28. Anderson, D.; Moggridge, H.; Warren, P.; Shucksmith, J. The impacts of "run-of-river' hydropower on the physical and ecological condition of rivers. *Water Environ. J.* **2015**, *29*, 268–276. [CrossRef]
29. Braatne, J.H.; Rood, S.B.; Goater, L.A.; Blair, C.L. Analyzing the impacts of dams on riparian ecosystems: A review of research strategies and their relevance to the Snake River through Hells Canyon. *Environ. Manag.* **2008**, *41*, 267–281. [CrossRef]
30. Ali, R.; Kuriqi, A.; Abubaker, S.; Kisi, O. Hydrologic Alteration at the Upper and Middle Part of the Yangtze River, China: Towards Sustainable Water Resource Management Under Increasing Water Exploitation. *Sustainability* **2019**, *11*, 5176. [CrossRef]
31. Fang, J.; Wang, Z.; Zhao, S.; Li, Y.; Tang, Z.; Yu, D.; Ni, L.; Liu, H.; Xie, P.; Da, L.; et al. Biodiversity changes in the lakes of the Central Yangtze. *Front. Ecol. Environ.* **2006**, *4*, 369–377. [CrossRef]
32. Kuriqi, A.; Pinheiro, A.N.; Sordo-Ward, A.; Garrote, L. Flow regime aspects in determining environmental flows and maximising energy production at run-of-river hydropower plants. *Appl. Energy* **2019**, *256*, 113980. [CrossRef]
33. Kuriqi, A.; Pinheiro, A.N.; Sordo-Ward, A.; Garrote, L. Influence of hydrologically based environmental flow methods on flow alteration and energy production in a run-of-river hydropower plant. *J. Clean. Prod.* **2019**, *232*, 1028–1042. [CrossRef]
34. Kuriqi, A.; Pinheiro, A.N.; Sordo-Ward, A.; Garrote, L. Water-energy-ecosystem nexus: Balancing competing interests at a run-of-river hydropower plant coupling a hydrologic-ecohydraulic approach. *Energy Convers. Manag.* **2020**, *223*, 113267. [CrossRef]
35. Tharme, R.E. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. *River Res. Appl.* **2003**, *19*, 397–441. [CrossRef]
36. Gao, X.; Fujiwara, M.; Winemiller, K.O.; Lin, P.; Li, M.; Liu, H. Regime shift in fish assemblage structure in the Yangtze River following construction of the Three Gorges Dam. *Sci. Rep.* **2019**, *9*, 4212. [CrossRef] [PubMed]
37. Egre, D.; Milewski, J.C. The diversity of hydropower projects. *Energy Policy* **2002**, *30*, 1225–1230. [CrossRef]

38. Tilt, B.; Braun, Y.; He, D. Social impacts of large dam projects: A comparison of international case studies and implications for best practice. *J. Environ. Manag.* **2009**, *90*, S249–S257. [CrossRef]
39. Varan, C.; Cretan, R. Place and the spatial politics of intergenerational remembrance of the Iron Gates displacements in Romania, 1966–1972. *Area* **2018**, *50*, 509–519. [CrossRef]
40. Cretan, R.; Vesalon, L. The Political Economy of Hydropower in the Communist Space: Iron Gates Revisited. *Tijdschr. Voor Econo. Soc. Geogr.* **2017**, *108*, 688–701. [CrossRef]
41. He, W.; Tang, W.; Wei, Y.; Duffield, C.F.; Lei, Z. Evaluation of Cooperation during Project Delivery: Empirical Study on the Hydropower Industry in Southwest China. *J. Constr. Eng. Manag.* **2016**, *142*, 04015068. [CrossRef]
42. Grumbine, R.E.; Pandit, M.K. Threats from India's Himalaya Dams. *Science* **2013**, *339*, 36–37. [CrossRef] [PubMed]
43. Rosso, M.; Bottero, M.; Pomarico, S.; La Ferlita, S.; Comino, E. Integrating multicriteria evaluation and stakeholders analysis for assessing hydropower projects. *Energy Policy* **2014**, *67*, 870–881. [CrossRef]
44. Wang, T.; Tang, W.; Qi, D.; Du, L. Enhancing design management in international EPC projects based on partnering. *J. Tsinghua Univ. Sci. Technol.* **2016**, *56*, 360–364.
45. Liu, Y.; Ma, J.; Wang, H.; Yan, D.; Lv, Y.; Deng, W. Multi-dimensional assessment of socioeconomic impacts of hydropower development—A case in the Upper Chuan River. *Sci. China Technol. Sci.* **2015**, *58*, 1272–1279. [CrossRef]
46. Gjermundsen, T.; Jenssen, L.; Mauring, K. *Economic Risk- and Sensitivity Analyses for Hydro-Power Projects*; International Energy Agency: Paris, France, 2000.
47. Eom, C.S.J.; Paek, J.H. Risk Index Model for Minimizing Environmental Disputes in Construction. *J. Constr. Eng. Manag.* **2009**, *135*, 34–41. [CrossRef]
48. Jiang, H.; Qiang, M.; Lin, P. Assessment of online public opinions on large infrastructure projects: A case study of the Three Gorges Project in China. *Environ. Impact Assess. Rev.* **2016**, *61*, 38–51. [CrossRef]
49. Sternberg, R. Hydropower: Dimensions of social and environmental coexistence. *Renew. Sustain. Energy Rev.* **2008**, *12*, 1588–1621. [CrossRef]
50. Noor, K.B.M. Case Study: A Strategic Research Methodology. *Am. J. Appl. Sci.* **2008**, *5*, 1602–1604. [CrossRef]
51. Fang, Y.; Wang, M.; Deng, W.; Xu, K. Exploitation scale of hydropower based on instream flow requirements: A case from southwest China. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2290–2297. [CrossRef]
52. Love, P.E.D.; Holt, G.D.; Li, H. Triangulation in construction management research. *Eng. Constr. Archit. Manag.* **2002**, *9*, 294–303.
53. Frey, G.W.; Linke, D.M. Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. *Energy Policy* **2002**, *30*, 1261–1265. [CrossRef]
54. Shaktawat, A.; Vadhera, S. Risk management of hydropower projects for sustainable development: A review. *Environ. Dev. Sustain.* **2021**, *23*, 45–76. [CrossRef]
55. Awojobi, O.; Jenkins, G.P. Managing the cost overrun risks of hydroelectric dams: An application of reference class forecasting techniques. *Renew. Sustain. Energy Rev.* **2016**, *63*, 19–32. [CrossRef]
56. Wang, Y.; Han, Q.; de Vries, B.; Zuo, J. How the public reacts to social impacts in construction projects? A structural equation modeling study. *Int. J. Proj. Manag.* **2016**, *34*, 1433–1448. [CrossRef]