RESEARCH PAPER

Check for updates

CC BY

THE 3Ps (PROFITS, PROBLEMS & PLANNING) OF DAMS AS INEVITABLE DEVELOPMENTAL SOURCE: A REVIEW

Nidhi Jasrotia[1], Ripudaman Singh[2*]
[1] Department of Geography, Lovely Professional University, Punjab, 144011, India
[2] AISS, Amity University, Noida, Uttar Pradesh, 201313, India
***Corresponding author:** ripudaman1@hotmail.com, rsingh29@amity.edu
Received: November 13th, 2022 / Accepted: May 29th 2024 / Published: July 1st 2024
https://DOI-10.24057/2071-9388-2024-2661

ABSTRACT. Since the beginning of river valley civilizations, humans have sought to harness the potential of flowing waters. The monumental structures of dams have been instrumental in damming these flowing waters and providing a wide range of benefits to society, including irrigation, drinking water, and generating clean energy. The present paper reviews in detail the hydropower reservoirs (dams) and presents a broader depiction of the 3Ps associated with their profits, problems, and planning. A literature review pertaining to dam construction and their impacts has been undertaken to analyze various approaches involving studies on socio-economic and environmental indicators and sustainability/risk factors related to dams. Various online search engines have been used to identify the desired studies and research for review. The first section of the paper gives a detailed account of the contribution (i.e., profits) made by dams to the economic development of humanity. The second part presents the negative social and environmental impacts (i.e., problems) of dams. As the paper proceeds, numerous tools/models analyzed during the literature review are presented that can be used to mitigate the negative fallouts of these dams (i.e., planning). However, it has been found that all these methods provide fragmented information with no certainty regarding which essential aspects require more emphasis while planning for these superstructures. Thus, a basic uniform frame is suggested, showcasing the fundamental and most critical aspects to be considered while planning a dam structure, which are described according to the three phases of dam construction, i.e., pre-construction, construction, and post-construction phases. While presenting the 3Ps (profits, problems and planning) of dams and analyzing their pitfalls, the 3Is (innovative keys) are recommended, emphasizing innovative technologies, innovative planning, and innovative solutions, which are needed in making these dams more optimal, judicious, and sustainable.

KEYWORDS: environment, hydropower, innovative, planning, reservoirs, sustainable

CITATION: Jasrotia Nidhi, Singh Ripudaman (2024). The 3Ps (Profits, Problems & Planning) Of Dams As Inevitable Developmental Source: A Review. Geography, Environment, Sustainability, 2(17), 119-130
https://DOI-10.24057/2071-9388-2024-2661

ACKNOWLEDGEMENTS: No funding has been received for this study. The authors are thankful for the constructive feedback from peers and colleagues. The anonymous reviewers' comments and advices are gratefully acknowledged.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

Earth is known as the blue planet (Byatt et al. 2001) as its surface has around 71% of water and 29% of land. Out of all water, oceans constitute around 96.5% of the remaining fresh water in the form of rivers, lakes, ice caps, glaciers, underground aquifers, and so on. However, the irony is that water resources are unevenly distributed over the land. These spatial variations in water distribution are the reasons why people in many parts of the globe still do not have enough water for drinking, sanitation, and irrigation. At some places, there are floods, while other regions experience droughts. To overcome the problem of regional variations in water availability, humans relied on dams not only in modern times but also in antiquity (Castelan 2002). Going back into history, the first dam was constructed in Jordan around 4000 BCE, and Sadd El-Kafara dam construction dates back to 2600 BCE in Egypt (Schhnitter 1994). In modern times, the Spanish were the leaders in dam construction around 1600 CE (Tullos et al. 2009). At present, there are around 800,000 dams constructed and operating on the earth, of which 50,000 are large dams (Kornijowl 2009). The International Commission on Large Dams (2022) describes dams with a height greater than 15 m as falling into the category of large dams. Whatever the size, whether small, large, or medium, all dams are the need of the hour all over the world, where the top three most populous countries, i.e., China, India, and the USA, are also the top-ranking countries with the largest number of dams (World Register of Dams 2020a), viz., China, which has 23,841 dams, followed by the USA (9263) and India (4407) (Fig. 1).

These hydropower reservoirs become inevitable, especially in developing countries, as they find no better option than dams to meet the demands of water supply, electricity, changing and urbanizing lifestyles of burgeoning populations, along with the mounting pressure to mitigate carbon emissions in the scenario of climatic change (Biswas 2012).

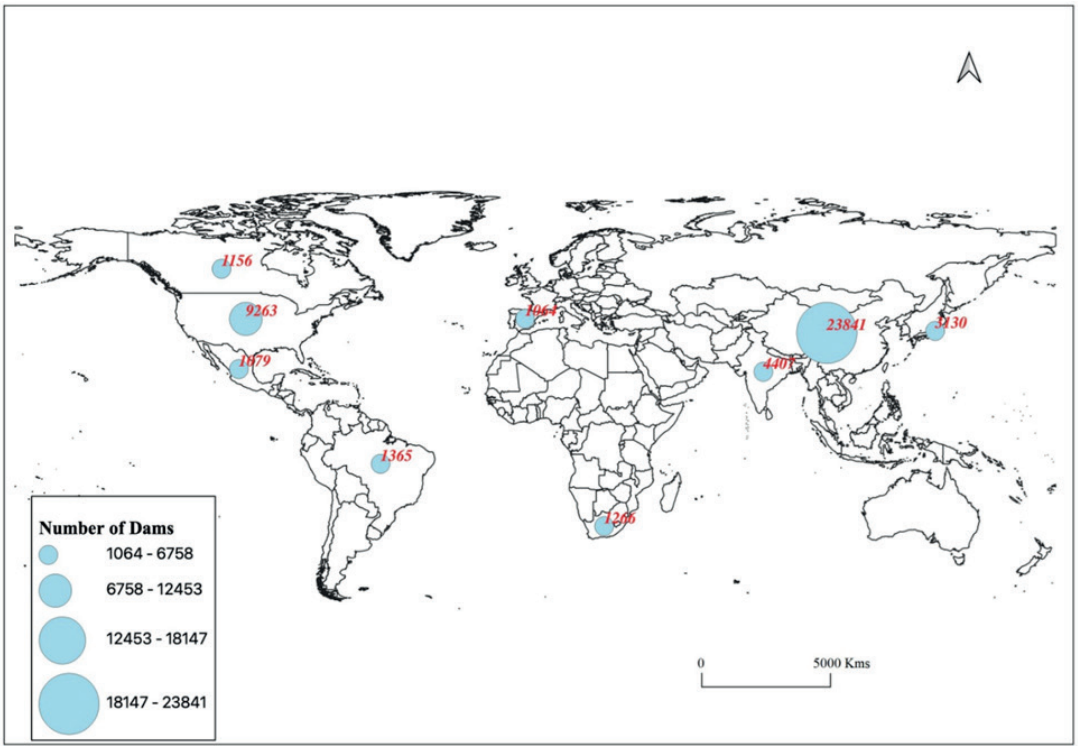

Fig. 1. Top Nine Countries with Largest Number of Dams in the World

Need for Dams. To mitigate and overcome the problems faced by emerging and developing countries and to address the growing needs of power, water, irrigation, food production, etc., dams play a vital role. Table 1 summarizes some facts that answer the question, why are these dams needed or and why do we need dams?

Considering these facts, countries all over the world are shifting their dependence from fossil fuels to more renewable and clean sources of energy (Fig. 2) (International energy agency, market report July 2021www.iea.org.electricity). Among the renewables, hydropower dominates, with more than half a share of power generation (International Hydropower Association 2020). In the year 2016, hydropower contributed 16-17% of the world's power, which was 70% of all renewable sources of energy (Alam et al. 2017).

MATERIALS AND METHODS

We conducted a literature review based on peer-reviewed journal articles pertaining to the construction of the dam's reservoir and their socio-economic and ecological impacts, both positive and negative. Further, we reviewed the articles pertaining to various approaches involving studies on social indicators, environmental indicators, sustainability indicators, and risk factors. For deriving the desired studies and literature, we used the online search engines Research Gate, Scopus, and Google Scholar and the National Digital Library of India, using the search terms viz., large dams, impacts of dams, hydropower, and dam construction-specific impacts on socio-economics and the environment (Fig. 3). A combination of all these could result in a limited number of selected studies. In total, 82 research papers have been reviewed, out of which 26 were reviewed for problems associated with major dams constructed in the world, 25 were reviewed for positive impacts of large dam construction, and 25 were reviewed for different approaches used to study various impacts of dams, respectively. The remaining papers were reviewed to analyze the innovative solutions recommended in the findings.

For exclusion criteria, we did not include papers related to run-of-river, small hydropower projects, or dam removal impacts, stipulating that impacts of dams and reservoirs must be based at least partially on large dams' construction. Fig. 3 depicts the flow diagram that shows the search engines used to select the studies for review using select terms and exclusion criteria.

Table 1. Summary of facts: why do we need dams?

Facts regarding dams	Measures and numbers
Aggregate storage capacity	7714 km^3 (World Register of Dams 2020b)
Hydropower	2.3 trillion kilowatt hours of electricity each year (World Register of dams 2020c)
Number of people dying of hunger	25000 /day (United Nations 2022)
Number of hungry people in the world	828 million people sleep hungry every night globally (World Food Program 2022)
Number of people without access to clean Cooking	2.6 billion people globally (IRENA 2021)
Number of people without access to drinking Water	1.5 billion people globally (IRENA 2021)
Number of people without electricity	759 million people globally (IRENA 2021)

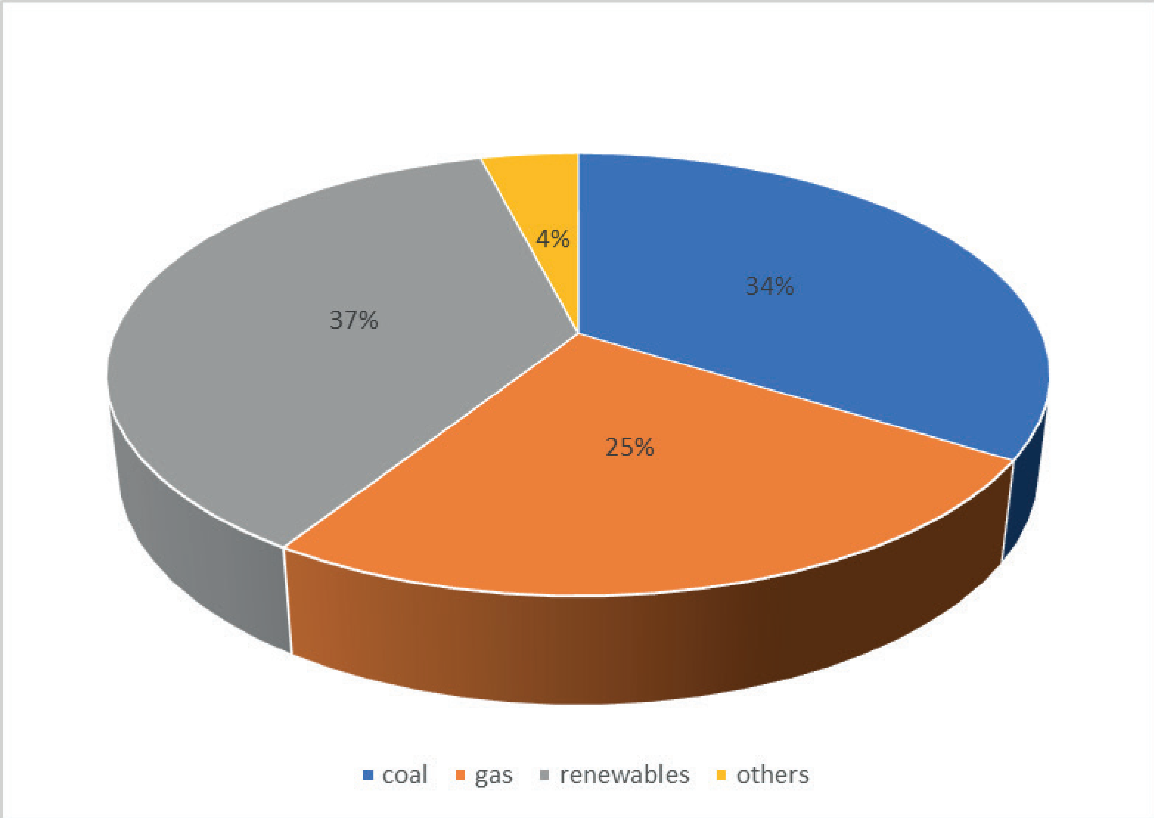

Fig. 2. Global share of fossil fuels and low carbon renewables in electricity generation, 2020

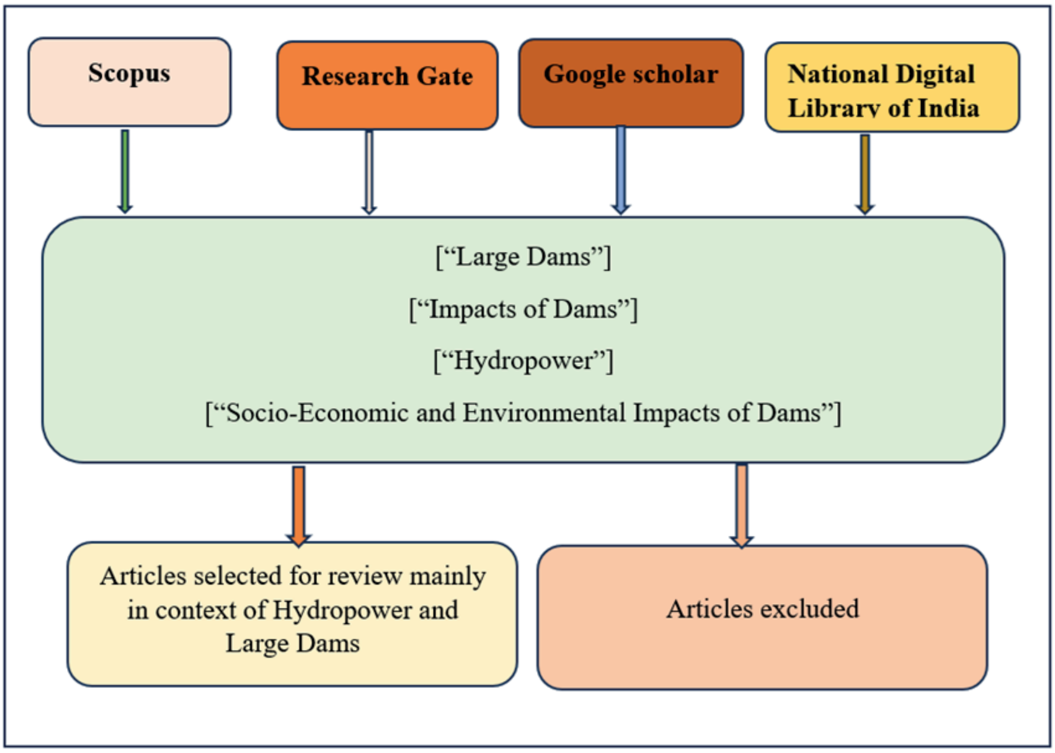

Fig. 3. Methodology for selection of articles on Large Dams

RESULTS AND DISCUSSION

The present paper analyzes the 3Ps associated with the profits, problems, and planning aspects of dams in a comprehensive and detailed manner. Firstly, the major profits of dams are discussed, followed by the problems that dams bring with them, and finally, the most significant planning perspective is scrutinized, which can maintain a balance between profits and problems of dams to make the dams more environmentally friendly and sustainable.

Profits (of Dams): without the exploitation of rivers, the world would be a much different place with cycles of droughts, floods, and famines (Altinbilek 2002). The International Energy Agency (2021) has found that energy produced by hydroelectric installations throughout the world provides approximately 1/5th of the world`s total electrical energy. As per the Hydropower Status Report (2022) for the year 2021, the total hydropower installed capacity reached 1360 GW, with the top six countries being China, Brazil, the USA, Canada, Russia, and India (Fig. 4) (International Hydropower Association 2022). The

International Renewable Energy Agency (IRENA 2021) reported that the world's existing hydropower capacity needs to grow by around 60% by 2050 to reach 2150 GW to help limit the rise in global temperature to well below 2°C. Considering their overall utility, dams are known for their multipurpose roles and benefits. Primarily, dams are constructed for four major profits, as listed below:

- to meet the increasing demand of water (Eiriksdottir et al. 2017);
- to provide electrical energy to expanding urban and industrial centers (Altinbilek 2002);
- to irrigate the agricultural regions (Brown 2009);
- to control floods and divert the excessive river waters to arid regions (Brown 2009).

The World Commission on Dams categorizes the purposes of dams in nine categories (Table 2). According to the study conducted by the United States Committee on Large Dams (USCOLD) (1997), the living conditions of people today are certainly improved by the construction of dams. For managing the finite water resources in a sustainable manner and to fulfil the potable and industrial water demand and the ever-increasing energy demand, dams are indeed considered to be an effective tool in this regard (Altinbilek 2002).

The large amount of water that can be stored in reservoirs makes dams more useful as they can generate power instantly according to the varied electricity demand, which is otherwise not possible with other sources of power generation, such as thermal and nuclear sources (Egrea & Milewskib 2002). Dams are considered large social investments as they have a great role in the future prospects of both urban and rural populations, especially

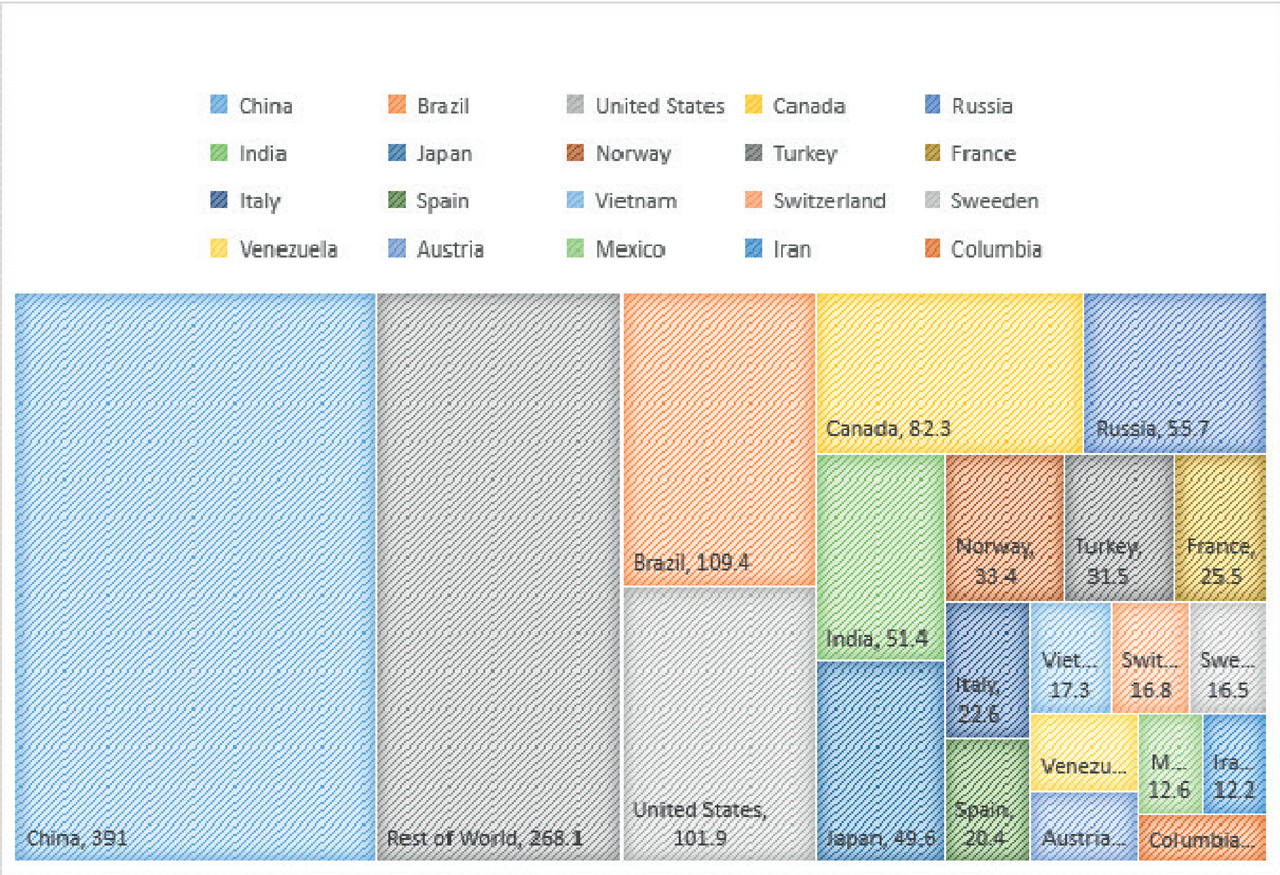

Fig. 4. Countrywise hydropower installed capacity, 2021: 1360GW

Table 2. Categorization of Dams based on Purposes

Code	Description	Dams with sole purpose	Multiple-purpose dams
C	Flood control	2539	4911
F	Fish farming	42	1487
H	Hydropower	6115	4135
I	Irrigation	13580	6278
N	Navigation	96	579
R	Recreation	1361	3035
S	Water supply	3376	4587
T	Tailing	103	12
X	Others	1579	1385

in developing countries (Dixon et al. 1989). Dams control flood hazards and support flood plain agriculture (Poff & Hart 2002). IPCC (2007), in its report, predicted that due to the increased frequency of precipitation events, the areas affected by droughts and floods will be augmented, the effects of which can be controlled by dams (Tullos et al. 2009).

Dams contribute much more than the above-explained benefits, such as low carbon emissions and adding very few impurities to the air (Jumani et al. 2017). Thus, hydropower can be a major bridge to the urgently needed transition to sustainable energy (Goodland 1995). Dams raise the socio-economic status of people by providing modern infrastructure and employment to them (Brown et al. 2009). For example, Bui Dam in Ghana led to improvements in road networks, drinking water, health, and education (Mortey 2017). Dams also provide recreational and navigational facilities as well as income to society (Brown et al. 2009).

The benefits and contributions of some of the major dams in the world are summarized in Table 3 and Fig. 5. Clean and affordable energy and zero hunger are two of the 17 Sustainable Development Goals adopted in 2015 by 193 countries to end extreme poverty, reduce inequality, and protect the planet through its Agenda 2030 (United Nation 2021).

Certainly, the path to reach these goals goes through hydropower if the problems associated with dams are reviewed and eradicated using proper planning and policies. There is a dire need to shed some light on the problematic side of dams, which is being done in the following section.

Problems (associated with dams): World Commission on Dams (2000) reports that "shortfalls in technical, financial and economic performance have occurred and are compounded by significant social and environmental impacts of dams, the costs of which are often disproportionately borne by poor, indigenous people and other vulnerable groups". Dixon et al. (1989), found that dams have direct benefits, but there are many associated environmental and social effects, most of which are likely to be costs. Globally, the major issues arising due to dam construction can be grouped as socio-economic impacts of dams (Rao 1989; Pinho et al. 2007; Sharma and Thakur 2017) and environmental impacts (Richter et al. 2010; Pinho et al. 2017). These negative impacts often lead to undue cost/schedule overruns of dams (Fig. 6).

Table 3. Benefits of some major dams in the world

Country (Dam)	Benefits
Mexico (Chicoasén Dam)	42% for agriculture, 39% for hydropower, 9% for water supply,10% for water supply (Castelan 2002).
Turkey (Ataturk)	irrigates 882,000 ha land which is about 56% of the total irrigated land, generate 8900 GWh/year energy and contributes about 3.8 billion US$/year to its economy (Altinbilek 2002).
Switzerland (Grande Dixence Dam)	59.6% of electricity comes from hydropower (Kellner 2019).
India (Sardar Sarovar)	Irrigates 18.45 lac ha land in Gujarat, provide drinking water to 173 Urban centers and 9490 villages, flood protection to 4 lac population of Gujarat, has two power houses of 1200 MW & 250 MW each (Sardar Sarovar Narmada Nigam Ltd. 2021).
China (Three Gorges)	It protects about 15 million residents and 3.7 million acres in the Lower Yangtze floodplain (Earth observatory 2007).
Brazil (Tucurui)	Supplies power to 13 million people (La Rovere and Mendes 2000).

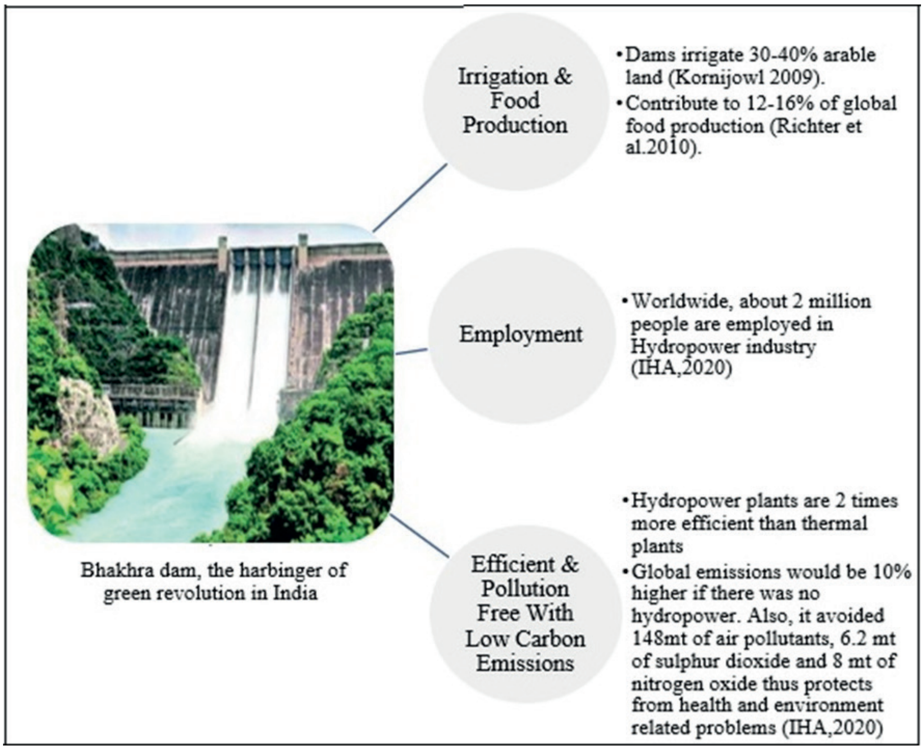

Fig. 5. Worldwide contributions of Dams

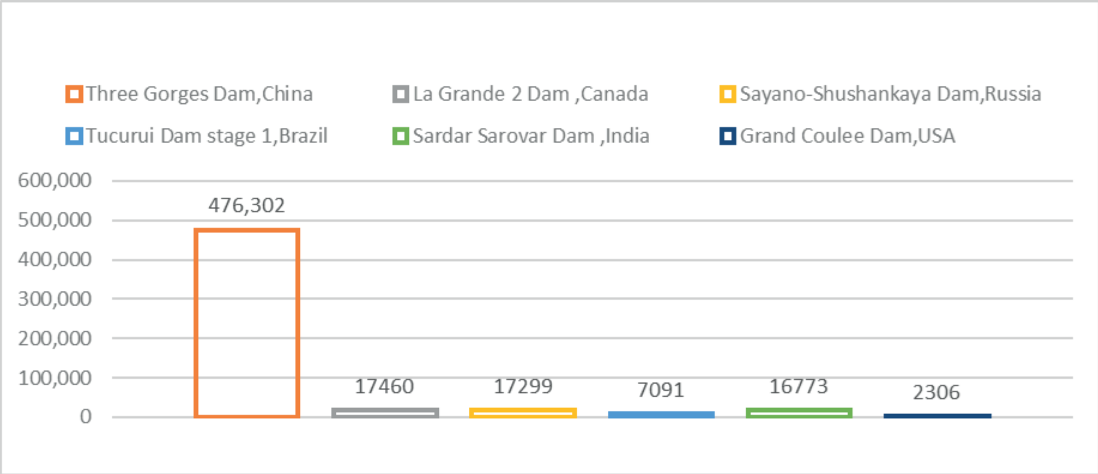

Fig. 6. Cost overruns of hydroprojects in million US dollar
(Shaktawat & Vadhera 2021)

Impoundment and presence of reservoirs in dam construction are the major causes of negative socio-economic as well as environmental impacts of dams (Egrea and Milewskib 2002; Sokolov et al. 2020). Also, global climatic changes and the growing demand for electricity intensify the negative impact of dams (Tullos et al. 2009). The intensity and magnitude of socio-economic impacts are vast in time and space and are explained below:

• Involuntary displacement and resettlement are the most dreadful of the socio-economic impacts (Mcnally et al. 2008; Gutman, 1994) leading to adulteration in social networks (Brown 2009). For example, over 10 million people were displaced by dam construction between 1950-1990 in China alone, and many more in other Asian developing countries (Kiik 2023). Similarly, in Poland, during the filling of Czorsztyn Reservoir, over 300 households were drowned in the village Maniowy (Kornijowl 2009). Gorshkov et al. (2013) discussed the problems of ponds and dam reservoirs in Russia.

• Profound direct and indirect negative impacts on the livelihood of displaced populations are found (Aung et al. 2021). Moreover, locals are cheated in the name of employment and electrification (Jumani et al. 2017). Forest and agricultural land are inundated (Mcnally et al. 2008), resulting in food insecurity (Richter et al. 2010), increased water conflicts (Rao 1989; Moller 2005), changes in resource allocation and resource use patterns (Gutman 1994). Sikka (2020) analyzed the large displacements caused by the Sardar Sarovar Dam in India. Chandy et al. (2012) found that due to dam construction in Sikkim, India, changes in land use and occupation of people could adversely impact their livelihoods. Also, there is immigration to host places, and thus relocation results in higher densities and greater struggles over resource access (Tullos et al. 2009) by altering the land-man ratio. Worldwide, about 1249 large dams have been constructed in protected areas, which adversely affect the health of protected areas; thus, dam construction within or near protected areas should be avoided (Thieme et al. 2020). The World Commission on Dams, in its seminal report, noted that dams are spatially significant, locally disruptive, and come along with lasting and often irreversible effects (Tullos et al. 2009). The World Register of Dams (2020d), illustrates the magnitude of displaced people through some of the largest dams (Fig. 7). The negative impacts of dams are summarized in Table 4. These problems can be tackled with the numerous tools/methods mentioned below in the planning section.

Planning (of dams). As numerous sectors such as water, food, and energy supply get affected by water resource projects, the framework of optimal designs for proper operation and maintenance of these projects and existing water resource–related curricula need to be improved and updated (Singh 2023). The sustainability of a dam depends on

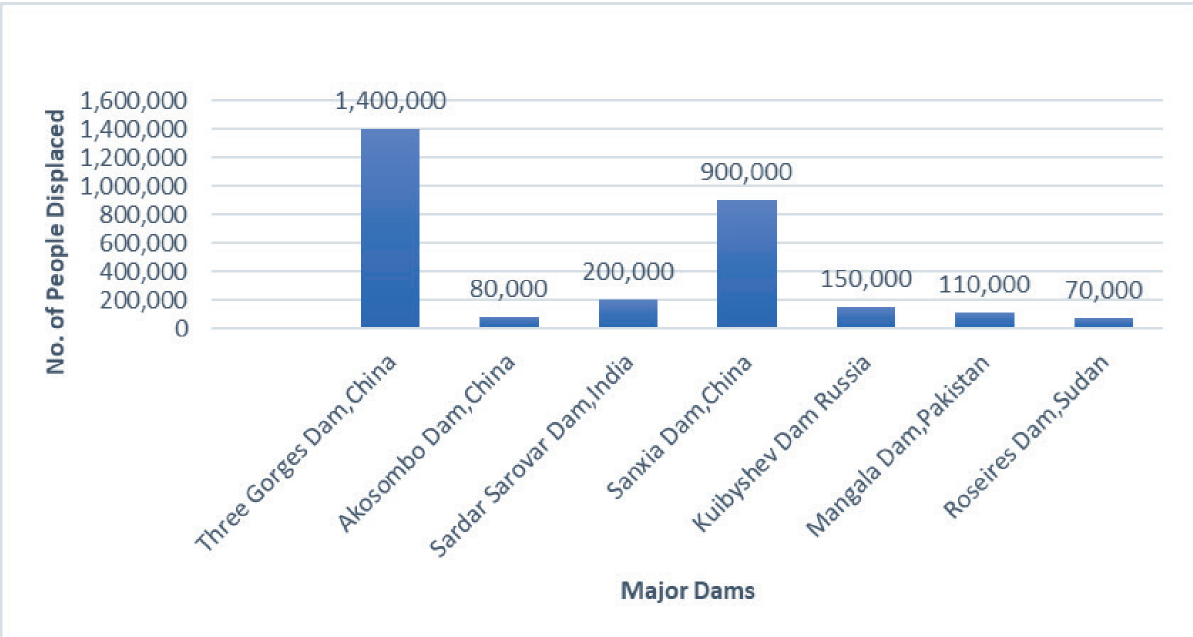

Fig. 7. Resettled persons due to major dam construction
(Shaktawat & Vadhera 2021; World Register of Dams, 2020d)

the policy, its planning, and its proper implementation. A well-crafted plan integrates policymakers, the scientific community, and the people who will share the costs and benefits. Public involvement in planning and decision-making processes is an important aspect (Gogoi 2023). A lack of involvement from any one of these three factors often results in the construction of controversial dams. Considering the negative impacts of dams and reservoirs, many countries in the west (including USA and European countries) have initiated dam and reservoir removal projects as well (Habel 2020).

Water resource management through dam construction is such a dynamic process as it involves the entangled web of society, environment, climate change, and sustainability. These four aspects are so interrelated that a minor imbalance in one can derail the entire development process initiated through dams. An innovative hydropower development model is one that can coordinate environmental protection and resettlement while boosting economic and social development and is needed the most (Sun et al. 2020). Such an innovative model is the precursor to the 'innovative technology' required for making sustainable dams. In the last 20 years, as dam construction has picked up mainly in developing countries, there has been an urgent need to address the issues related to the various impacts of dams. After the WCD (2002) report, new areas of research in the context of dams have emerged, namely climate change and dams, downstream impacts of dams, and gender-based studies in dam impacts (Schulz & Adams 2019). We recommend the 3Is (innovative keys) which emphasize the need for innovative technologies, innovative planning, and innovative solutions to enhance the optimization, judiciousness, and sustainability of dams. To begin with, getting acquainted with innovative technologies, some of the approaches/models for planning and sustainability assessment of dams (Tables 4-7) are summarized and presented here.

Table 4. Studies/approaches involving risk factor

Tools/Model	Indicators Used	Main Findings
Fuzzy Topsis (Agarwal & Kansal 2020)	Risk Index based initial cost interval assessment by using Multi criteria decision making methodology	The result of case study matches the actual values of project
Fuzzy Logic (Kucukali 2011)	Fuzzy rating tool to calculate Risk Index (R)	Site geology and Environment issues were the most important risks
Fuzzy Hybridized with ANN and genetic Algorithm (Shaktawat & Vadehra 2021)	Sensitivity analysis to evaluate Risk factor is a primary method	Study found that construction phase is the most critical and Life cycle risk assessment is required for sustainable growth
Risk Framework (Cleary et al. 2015)	Consequences of failure modes of Earth dams	Earth dams are more vulnerable to failures due to Overtopping, Piping and Landslip failures
Hydro Informatic (Approach Maan et al. 2020)	Estimation of design flash flood	Flood hydrographs are more important in flood-risk management.

Table 5. Studies/approaches involving environmental indicators

Tools/Model	Indicators Used	Main Findings
Greenhouse Gases Risk Assessment Tool (GRAT) (Kumar et al. 2019)	Life cycle GHG emissions of reservoirs using age of reservoirs, annual mean temperature, annual mean precipitation and runoffs	Three Gorges reservoir was found under high risk of CH_4.
Dam Environment Vulnerability Index (DEVI) (Latrubesse et al. 2017)	The Basin Integrity Index, The Fluvial Dynamics Index, the Dam Impact Index	The study found that the Maderia River watershed in Amazon River basin is the most vulnerable with high value of DEVI (80-100).
Artificial Neural Network (ANN) (Xu et al. 2019)	Quantification of plant biodiversity indicators related to Hydropower ANN was used to maintain a balance between hydropower and biodiversity targets by developing an optimization model	Recommended to use Pareto-Optimal solutions to optimize the human as well as ecosystem Objectives.
Life Cycle Impact Assessment (LCIA) (Gracey et al. 2016)	Quantification of environmental Impacts of hydropower on Biodiversity.	Study found that main impacts being, freshwater habitat alteration, water quality degradation, land use impact.
Multi - criteria scoring tool to assess the environmental risks of SHPs (Kucukali 2014)	Environmental flow, water quality, fish passage and protection, watershed protection, threatened and endangered species, selected on basis of EBRD*	The hydropower plant under case study failed in all criteria of EBRD.
Hierarchical Framework (Burke et al. 2009)	Quantification of First order, 2nd order and 3rd order impacts of multiple dams within the study area.	Recommended alternative River management Strategies using Hierarchical framework over space and time.
Environmental Impact Assessment (EIA), a Comparative analysis (Abdul-Sattar 2007)	Legislative and implementation deficiencies in developed and developing countries.	Case study in Pakistan shows deficiencies even after the implementation of EIA

Table 6. Studies/approaches involving social indicators

Tools/Model	Indicators Used	Main Findings
Social impact Assessment of three large Hydro Projects *Egre & Senecal 2003*	Resettlement issues and Resettlement Action Plan	Pre-project SIA is useful if resettlement plans' implementation is based on its findings
Social Life Cycle Assessment (SLCA) *Aung et al. 2021*	Multiple social stressors, Different impact Categories within Potentially disturbed communities	Shweli Dam has more negative impacts than benefits to locals.
Integrative Dam Assessment Model (IDAM) *Brown et al. 2009*	Objective and subjective Cost/benefit analysis using 27 impacts of dams	Policy makers can use it to find alternatives and priorities in dam construction
Comparison of SIA in two dams *Tilt et al. 2009*	Migration and resettlement, changes in rural economy, employment, infrastructure, cultural aspects, health and gender relations	Policy makers can know which interventions to be taken and how by identifying the dams' impacts
Hydraulic Modelling *Wyrick et al .2009*	Social impacts of dam removals	The study recommends Interaction between all stake holders
Matrix Framework-A Review *Kirchherr & Charles 2016*	Unification of existing frameworks for social impacts into a single Framework	A holistic way to assess the complex and multi-dimensional social impacts of dams
Resettlement and Livelihood adaptation-A Case study *Sayatham & Sudhardiman 2015*	Farming households with different assets and resources	Insufficient agricultural land is the major obstacle in livelihood adaptation after dam construction
Four stages planning for Resettlement *Scudder 2005*	Socio-economic status of displaced people	Handing over a Sustainable Resettlement to 2^{nd} generation

Table 7. Studies/approaches involving sustainability criteria

Tools/Model	Indicators Used	Main Findings
Hydropower Sustainability Assessment Protocol *Hartmann et al. 2019*	Good and best practices at each stage of lifecycle of a hydropower project for 24 topics	Teesta-v project meets proven best practice on 6 out of 20 topics. It exceeds basic good practice on 9 topics and meets basic good practice on 5 topics
PROMETHEE & Analytical Network Process *Wu et al. 2017*	Firstly, HELTS* is used to rank social sustainability of each alternative. Then Analytical Network Process is used to measure Correlation between indicators	Public recognition is discovered as key indicator by Comparative analysis
Multi-Criteria Analysis *Morimoto 2013*	Quantitative relationship between economic, environmental and social indicators	Economic indicator has biggest impact (.324) followed by environment impact (.0102)
Emergy Analysis *Zhang et al. 2014*	Environment loading and Sustainability of energy Systems	Environment loading ratio is acceptable when 2.04.
Causal Diagrams to show Impact Pathways *Voegeli et al. 2019*	Series of 10 casual Diagrams each showing specific topic	Stakeholders' perspective with proper understanding of pathways to know the main reason of conflicts.
Sustainability Assessment -A Review *Nautiyal & Goel 2020*	Hydropower, development, society, environment, economy is interlinked	Sustainability prediction of HPPs is incomplete without considering all biophysical impacts.

Undoubtedly, there are numerous models/approaches being developed from time to time for assessing the impacts of dams based on different aspects; however, it has been found that whenever dam impact assessment is done, it is focused on only a single aspect, and there is a lack of a unified basic frame that can give a comprehensive understanding to policymakers (Schultz & Adams 2019), so that whatever method or tool they are applying to plan a proposed dam construction should be focused on some fundamental aspects to make dams more judicious and optimal development devices (Shafa et al. 2023). To fill this gap, phase-wise essential aspects for the planning of dam construction are being suggested here as 'innovative planning' (Table 8). Taking these planning phases as a uniform code for all dam construction, any method can be used to assess these aspects, on the basis of which policies, decision-making, and planning can be done accordingly.

Also, it is necessary to involve planners and policymakers, keeping in view the interdisciplinary approach. Apart from the above-mentioned aspects, there is a need for some 'innovative solutions' for redressing the negative impacts of dams, which are discussed as follows:

• To use dams' infrastructure for installing the solar panels, this way enhances energy production (Rauf et al. 2020; Vella 2021).

• To focus on developing new technologies to capture methane from hydroelectric reservoirs before it enters the atmosphere and convert it into energy (Hirsch 2007).

• As methane is a much more potent greenhouse gas than CO_2, you can control methane emissions by planting trees like pines, spruce, etc. that can absorb methane emissions (Yoneda 2013).

• To control reservoir siltation, detailed statistical analysis of the morphometric parameters at the micro-

Table 8. Phases of dam construction planning

Phase -I	Phase-II	Phase-III
Pre-construction Planning 1. Socio-economic equality and inclusion 2. Awareness among all the stakeholders about their roles in making dams sustainable 3. Site geology 4. Cost/schedule over runs 5. Environment safety and conservation 6. Climate change, hungry water and gender impacts of dams and vice-versa 7.Potential of dam reservoir for GHG emissions burden	Construction Planning 1.Dam failure risks and safety measures assessment 2.Assessing the burden of infrastructure on local as well as outsourced resources	Post-construction Planning 1.Re-checking and evaluating what has been achieved and what is the lacking? 2. Measures and solutions to mitigate the remaining problems

watershed scale is essential (Singh & Singh 2020) and the most severe impacts of sedimentation can be prevented if sedimentation management begins within a decade of reservoir construction (Anari et al. 2023).

• To use dam water for hydroponics, there is a benefit to the locals (Sharma et al. 2019).

• To use 'optimization model' for allocating reservoir water efficiently for irrigation to different cropping zones (Alfaisl et al. 2023).

• To use various 'Non-Revenue Water (the amount of water produced and lost before it reaches customers) Reduction Strategies' (Farouk et al. 2023). In this way, water theft and other water losses (losses due to leaks, bursts, overflow from water mains, service connections) in developing and developed countries can be reduced.

CONCLUSION

Dams have numerous profits along with various problems associated with them, for which these inevitable developmental tools attract criticism. However, one thing that needs to be mentioned here is that hydropower and dams cannot be ignored at all. Out of eight lac dams constructed in the world, more than 50,000 are large dams, which have an impact on more people. Although western countries have moved into the phase of decommissioning and the removal of dams, most developing countries are rapidly constructing more and more dams to tap their water resources. China and India, which have around 40% of the world population, are also home to more than 50% of the largest dams in the world. So efficient and sustainable dams are needed more to serve humanity and achieve sustainable development. Furthermore, without such dams, our shared sustainable future is incomplete. So, its high time to realize the truth: only counting the problems associated with dams is not going to work. More collaborative efforts from science, policy, governance, and people's inclusion are required to advance the 3Is of 'Innovative Technologies, Innovative Planning, and Innovative Solutions', aiming to enhance the efficiency of existing dams and create more optimal and sustainable future dams.

REFERENCES

Abdul-Sattar N. (2007). Comparative analysis of the EIA system of developed and developing countries: Cases of hydroelectric power plants. Gothenburg: Environmental System Analysis, Chalmers University of Technology. Available at: https://publications.lib.chalmers.se/records/fulltext/43366.pdf [Accessed 30 Mar. 2022].

Agarwal S.S. and Kansal, M.L. (2020). Risk based initial cost assessment while planning a hydropower project. Energy Strategy Reviews, 31, 100517, 1-12, DOI: 10.1016/j.esr.2020.100517.

Alam F., Alam Q., Reza S., Khurshid-ul-Alam S. M., Saleque K. and Chowdhury H. (2017). A review of hydropower projects in Nepal. Energy Procedia, 110, 581-585, DOI: 10.1016/j.egypro.2017.03.188.

Alfaisal F.M., Alam S., Alharbi R.S., Kaur K., Khan M. A., Athar M.F., and Rahin S. A. (2023). Application of an Optimization Model for Water Supply Chain Using Storage Reservoir Operation for Efficient Irrigation System. Discrete Dynamics in Nature and Society, 2023, 7932653, 1-13, DOI: 10.1155/2023/7932653.

Altinbilek D. (2002). The role of dams in development. Water Science & Technology, 45(8), 169-180, DOI: 10.2166/wst.2002.0172.

Anari R., Gaston T. L., Randle T. J., and Hotchkiss R. H. (2023). New Economic Paradigm for Sustainable Reservoir Sediment Management. Journal of Water Resources Planning and Management, 149(2), 04022078-1-13, DOI: 10.1061/(ASCE)WR.1943-5452.0001614.

Aung T.S. et al. (2021). Social impacts of large-scale hydropower project in Mynamar: A social life cycle assessment of Shweli hydropower dam. The International Journal of Cycle Assessment, 26, 417-433. DOI: 10.1007/s11367-021-01868-3.

Biswas A.K. (2012). Impacts of Large Dams. In: C. Tortajada, A. Dogan and A.K. Biswas eds., Impacts of Large Dams: A global assessment. New York: Springer, 1-18. Available at: http://ndl.ethernet.edu.et/bitstream/123456789/7406/1/Impacts%20of%20Large%20Dams%20A%20Global%20Assessment.pdf [Accessed Apr. 2022].

Brown P.H., Tullos D., Tilt B., Magee D. and Wolf A. T. (2009). Modelling the costs and benefits of dam construction from multidisciplinary perspective. Journal of Environmental Management, 2009 Jul, 90, S303-S311, DOI: 10.1016/j.jenvman.2008.07.025.

Burke M., Jorde K., and Buffington J.M. (2009). Application of a hierarchical framework for assessing environmental impacts of dam operation: changes in streamflow, bed mobility and recruitment of riparian trees in a western North American river. Journal of Environmental Management, 2009 Jul, 90 S3, S224-S236 DOI: 10.1016/j.jenvman.2008.07.022.

Byatt A., Fathergill A., Holmes, M. and Allenborough D. (2001). The Blue Planet, a natural history of the Oceans. New York: DK Publishing.

Castelan E. (2002). Role of large dams in the socio-economic development of Mexico. International Journal of Water Resources Development, 18(1), 163-177, DOI: 10.1080/07900620220121729.

Chandy T. et al. (2012). Impacts of hydropower development on rural livelihood sustainability in Sikkim, India: Community perceptions. Mountain Research and Development, 32(2), 117-125, DOI: 10.1659/MRD-JOURNAL-D-11-00103.1.

Cleary P. W. et al. (2015). A scenario-based risk framework for determining consequences of different failure modes of Earth dams. Natural Hazards, 75(2), 1489-1530, DOI: 10.1007/s11069-014-1379-x.

Dixon J.A., Talbot L.M. and Lemoigne, J.M. (1989). Dams and the Environment: Considerations in World Bank Projects. World Bank Technical Paper Number 110. Washington, D.C.: The World Bank. Available at: https://documents1.worldbank.org/curated/en/300561468782146320/pdf/multi-page.pdf [Accessed 30 Mar. 2022].

Earth Observatory. (2007, 15 July). Three Gorges Dam, China. [online], Maryland: NASA Earth Observatory. Available at: https://earthobservatory.nasa.gov/images/7769/three-gorges-dam-china [Accessed Apr. 2022].

Egrea D. and Milewskib J. C. (2002). The diversity of hydropower projects. Energy Policy, 30(14), 1225-1230, DOI: 10.1016/S0301-4215(02)00083-6.

Egre D. and Senecal P. (2003). Social impact assessment of large dams throughout the world: Lessons learned over two decades. Impact Assessment and Project Appraisal, 21(3), 215-224, DOI: 10.3152/147154603781766310.

Eiriksdottir S.E., Oelkers H.E. and Hardardottir, J. (2017). The impact of damming or riverine fluxes to the ocean: a case study from Eastern Iceland. Water Research, 113, 124-138, DOI: 10.1016/j.watres.2016.12.029.

Farouk A.M., Rahman R.A. and Romali N.S. (2023). Non-revenue water reduction strategies: a systematic review. Smart and Sustainable Built Environment, 12(1), 181-199, DOI: 10.1108/SASBE-04-2021-0071.

Gogoi T. (2023). Anti-Dam Discourse: Stakeholder Engagement and Decision-Making. In: P. Singh et al., eds., The Route Towards Global Sustainability: Challenges and Management Practices. Cham: Springer International Publishing, 379-393, DOI: 10.1007/978-3-031-10437-4_19.

Goodland R. (1995). How to distinguish better hydros from worse: the sectoral approach to environmental analysis of Hydroprojects. Washington D.C.: Environment Department, The World Bank. Available at: https://documents1.worldbank.org/curated/ru/864871555087210530/pdf/Environmental-Sustainability-Ranking-of-Hydroprojects-How-to-Distinguish-Better-Hydros-from-Worse.pdf [Accessed Apr. 2022].

Gorshkov S., Touchart L., Mochalova O., Ozerskiy A. and Evseeva, L. (2013). From Ponds to Man-made Seas in Russia. Geography Environment Sustainability, 6(4), 65-76, DOI: 10.24057/2071-9388-2013-6-4-65-76.

Gracey E.O. and Verones F. (2016). Impacts from hydropower production on biodiversity in a LCA framework- review and recommendations. The International Journal of Life Cycle Assessment, 21(3), 412-428, DOI: 10.1007/s11367-016-1039-3.

Gutman P.S. (1994). Involuntary resettlement in hydropower projects. Annual Review of Energy and Environment, 19, 189-210, DOI: 10.1146/annurev.eg.19.110194.001201.

Habel M., Mechkin K., Podgorska K., et al. (2020). Dam and reservoir removal projects: a mix of socio-ecological trends and cost-cutting attitudes. Scientific Reports, 10, 19210, 1-16, DOI: 10.1038/s41598-020-76158-3.

Hartmann J., Locher, H. and Khandkal Z. (2019). Hydropower sustainability assessment protocol-Teesta V Power Station, India, Official Assessment NHPC limited. [online] www.hydrosustainability.org Available at: https://static1.squarespace.com/static/5c1978d3ee1759dc44fbd8ba/t/5d8c752237aac41d409a4923/1569486263861/Teesta-V+Assessment+Report_Sept+19+2019_final.pdf [Accessed 30 Jun. 2022].

Hirsch T. (10 may, 2007). Project aims to extract dam methane. [online] BBC News. Available at: http://news.bbc.co.uk/2/hi/science/nature/6638705.stm [Accessed 31 Mar. 2022].

International Energy Agency (2021, July). Electricity Market Report. International Energy Agency, [online]. Available at: https://www.iea.org/reports/electricity-market-report-july-2021 [Accessed 10 Aug. 2021].

International Commission on Large Dams. (2022). Position Paper. [online] International Commission on Large Dams. Available at: www.icold-cigb.org [Accessed 31 Dec. 2022].

International Hydropower Association (2020). Facts about Hydropower. [online] International Hydropower Association. Available at: https://www.hydropower.org/iha/discover-facts-about-hydropower [Accessed 15 Dec. 2020].

International Hydropower Association (2022). Hydropower Status Report: 2021. [online] International Hydropower Association. Available at: https://assets-global.website-files.com/64f9d0036cb97160cc26feba/64f9d0036cb97160cc2711ef_IHA20212405-status-report-02_LR.pdf [Accessed 12 Dec. 2022].

International Renewable Energy Agency (2021). IRENA Members commit to top up global hydropower fleet. [online] International Renewable Energy Agency. Available at: https://www.irena.org/newsroom/articles/2021/May/IRENA-Members-Commit-to-Top-Up-Global-Hydropower-Fleet [Accessed 15 Jul. 2022].

Jumani S., Rao S., Machado S. and Prakash A. (2017). Big concerns with small projects: Evaluating the socio-ecological impacts of small hydropower projects in India. Ambio, 46, 500-511, DOI: 10.1007/s13280-016-0855-9.

Kellner E. (2019). Social Acceptance of a multipurpose reservoir in a recently deglaciated landscape in the Swiss Alps. Sustainability, 11(14), 3819, 1-22, DOI: 10.3390/su11143819.

Kiik L. (2023). Inter-national conspiracy? Speculating on the Myistone Dam controversy in China, Burma, Kachin, and a displaced village. Geopolitics, 28(1), 72-98, DOI: 10.1080/14650045.2020.1808886.

Kirchher J. and Charles K.J. (2016). The social impacts of dams: A new framework for scholarly analysis. Environmental Impact Assessment Review, 60, 99-114, DOI: 10.1016/j.eiar.2016.02.005.

Kornijowl R. (2009). Controversies around dam reservoirs: Benefits, Costs and future. Ecohydrology and Hydrobiology, 9(2-4), 141-148, DOI: 10.2478/v10104-010-0001-4.

Kucukali S. (2011). Risk assessment of river type hydropower plants using fuzzy logic approach. Energy Policy, 39(10), 6683-6688, DOI: 10.1016/j.enpol.2011.06.067.

Kucukali S. (2014). Environmental risk assessment of small hydropower (SHP) plants: A case study for Tefen SHP plant on Filyos river. Energy for Sustainable Development, 19(1), 102-110, DOI: 10.1016/j.esd.2013.12.010.

Kumar A., Yang T. and Sharma M.P. (2019). Long Term Prediction of greenhouse gas risk to the Chinese hydropower reservoirs. Science of Total Environment, 646, 300-308, DOI: 10.1016/j.scitotenv.2018.07.314.

Latrubesse E.M. et al. (2017). Damming the rivers of the Amazon Basin. Nature, 546, 363-369, DOI: 10.1038/nature22333.

La Rovere E.L. and Mendes F.E. (2000). Tucuruí Hydropower Complex Brazil, Final Report: November 2000. Cape Town: World Commission on Dams. Available at: https://archive.internationalrivers.org/sites/default/files/attached-files/csbrmain.pdf [Accessed 17 Dec. 2021].

Maan G.S., Patra J.P. and Singh R. (2020). A Hydro-Informatic Approach for Estimation of Design Flash Flood in Bargi Dam Cross-Section of Narmada River, India. Geography Environment Sustainability, 13(2), 104-114, DOI: 10.24057/2071-9388-2019-178.

McCully P. (2001). Silenced rivers: the ecology and politics of large dams. London: Zed Books. Available at: https://theswissbay.ch/pdf/Books/Survival/Farming%2C%20Animalraising%2C%20Homesteading/Farming%2Bgardening/water%20management/Silenced%20Rivers%20Complete%20.pdf [Accessed 15 Dec. 2021].

McNally A., Magee D. and Wolf A.T. (2008). Hydropower and sustainability: Resilience and Vulnerability in China's power sheds. Journal of Environmental Management, 90 (S3), S286-S293, DOI: 10.1016/j.jenvman.2008.07.029.

Moller L.C. (2005). Transboundary Water conflicts over hydropower and Irrigation: Can Multilateral Development Banks Help? CREDIT Research Paper No. 05/09. Nottingham: Centre for Research in Economic Development and International Trade, University of Nottingham. Available at: https://www.nottingham.ac.uk/credit/documents/papers/05-09.pdf [Accessed 20 Jul. 2021].

Moran E.F., Lopez M.C., Moore N., Muller N. and Hyndman D.W. (2018). Sustainable hydropower in the 21st century. Proceedings of National Academy of Sciences of United States of America, 115(47), 11891-11898, DOI: 10.1073/pnas.1809426115.

Mortey E.M., Ofosu E.A., Kolodko D.V. and Kabobah A.T. (2017). Sustainability assessment of the Bui hydropower System. Environments, 4(2), 1-25, DOI: 10.3390/environments4020025.

Morimoto R. (2013). Incorporating socio-environmental considerations into project assessment models using multi-criteria analysis: A case study of Sri Lankan hydropower projects. Energy policy, 59, 643-653, DOI: 10.1016/j.enpol.2013.04.020.

Nautiyal H. and Goel V. (2020). Sustainability assessment of hydropower projects. Journal of Cleaner Production, 265(1), 121661, DOI: 10.1016/j.jclepro.2020.121661.

Pinho P., Maia R. and Monterroso A. (2007). The quality of Portuguese environmental impact studies: The case of small hydropower projects. Environmental Impact Assessment Review, 27(3), 189-205, DOI: 10.1016/j.eiar.2006.10.005.

Poff N.L. and Hart D. (2002). How dams vary and why it matters for the emerging science of dam removal? [online], Bioscience, 52 (8), 659-688. Available at: https://pofflab.colostate.edu/wp-content/uploads/2019/08/Poff_2002_howdamsvaryandwhyitmatters.pdf [Accessed 10 Dec. 2022].

Rao R.V. (1989). Large and small dams. International Journal of Water Resources Development, 5(2), 135-142, DOI: 10.1080/07900628908722425.

Rauf H., Gull M.S. and Arshad N. (2020). Complementing hydroelectric power with floating solar PV for daytime peak electricity demand. Renewable Energy, 162, 1227-1242, DOI: 10.1016/j.renene.2020.08.017.

Richter B.D., Postel S., Revenga C., Scudder T., Lehner B., Churchill A. and Chow M. (2010). Lost in development's shadow: The downstream human consequences of dams. [online], Water Alternatives, 3(2), 14-42. Available at: https://www.water-alternatives.org/index.php/volume3/v3issue2/80-a3-2-3/file [Accessed 25 Nov. 2022].

Sardar Sarovar Narmada Nigam Ltd. (2021, 23 August). Benefits of Projects. [online], www.sardarsarovardam.org Available at: https://www.sardarsarovardam.org/benefits-of-project.aspx [Accessed 10 Dec. 2022].

Sayatham M. and Suhardiman D. (2015). Hydropower resettlement and livelihood adaptation: The Nam Mang 3 project in Laos. Water Resources and Rural Development, 5, 17-30, DOI: 10.1016/j.wrr.2015.01.001.

Schultz C., and Adams W.M. (2019). Debating dams: The World Commission on Dams 20 years on. Wiley Interdisciplinary Reviews: Water, 6(5), e1396, DOI: 10.1002/wat2.1369.

Scudder T.T. (2005). Future of Large Dams: Dealing with Social, Environmental, Institutional and Political Costs. London: Earthscan, Routledge, DOI: 10.4324/9781849773904.

Shafa N.S., Babzadeh H., Aghayari F., and Saremi A. (2023). Multi-objective planning for optimal exploitation of surface and groundwater resources through development of an optimized cropping pattern and artificial recharge system. Ain Shams Engineering Journal, 14(2), 101847, DOI: 10.1016/j.asej.2022.101847.

Shaktawat A. and Vadhera S. (2021). Risk management of hydropower projects for sustainable development- a review. Environment, Development and Sustainability, 23, 45-76, DOI: 10.1007/s10668-020-00607-2.

Sharma A.K. and Thakur N.S. (2017). Assessing the impact of small hydropower projects in Jammu and Kashmir: A study from north-western Himalayan region of India. Renewable and Sustainable Energy Reviews, 80, 679-693, DOI: 10.1016/j.rser.2017.05.285.

Sharma N., Acharya S., Kumar K., Chaurasia O.P. and Singh N. (2019). Hydroponics as an advanced technique for vegetable production-an overview. Journal of Soil and Water Conservation, 17(4), 364-371, DOI: 10.5958/2455-7145.2018.00056.5.

Singh, R. (2023). Water Resources Planning Under (Deep) Uncertainty. [online], Oxford Research Encyclopaedia of Environmental Science, www.oxfordre.com. Available at: https://doi.org/10.1093/acrefore/9780199389414.013.628 [Accessed 15 Mar. 2023].

Singh S., and Singh R. (2020). Geo-spatial topology based morphometric analysis for soil and water conservation in Dholbaha watershed of Kandi region. Journal of Physics: Conference Series, 1531 (2020) 012087, 1-14, DOI: 10.1088/1742-6596/1531/1/012087.

Sikka G. (2020). Moving beyond Economic Analysis: Assessing the socio-cultural impacts of displacement and resettlement by Sardar Sarovar Project, India. Geography Environment Sustainability, 13(3), 90-101, DOI: 10.24057/2071-9388-2019-165.

Sokolov D.I., Erina O.N., Tereshina M.A. and Puklakov V.V. (2020). Impact of Mozhaysk Dam on the Moscow River Sediment Transport. Geography Environment Sustainability, 13(4), 24-31, DOI: 10.24057/2071-9388-2019-150.

Sun L, Dongxiao N., Wang K. and Xu X. (2020). Sustainable development pathways of hydropower in China: Interdisciplinary qualitative analysis and scenario-based system dynamics quantitative modelling. Journal of Cleaner Production, 287, 125528, DOI: 10.1016/j.jclepro.2020.125528.

Thieme M.L., Khrystenko D., Qin S., Golden Kroner R.E., Lehner B., Pack S., ... and Mascia, M.B. (2020). Dams and protected areas: Quantifying the spatial and temporal extent of global dam construction within protected areas. Conservation Letters, 13(4), e12719, 1-8. DOI: 10.1111/conl.12719.

Tilt B., Barun Y. and He D. (2009). Social impacts of large dam projects: a comparison of international case studies and implications for best practice. Journal of Environmental Management, 90(Supplement 3), S249-S257, DOI: 10.1016/j.jenvman.2008.07.030.

Tullos D., Tilt B. and Liermann C.R. (2009). Introduction to the special issue: Understanding and linking the biophysical, socioeconomic and geopolitical effects of dams. Journal of Environmental Management, 90(Supplement 3), S203-S207, DOI: 10.1016/j.jenvman.2008.08.018.

United Nations (2021). Sustainable Development. New York: Department of Economic and Social Affairs, United Nations. Available at: https://sdgs.un.org/goals [Accessed 23 Jan. 2022].

United Nations (2022). Losing 25,000 to Hunger Every Day. [online], UN Chronicle. Available at: https://www.un.org/en/chronicle/article/losing-25000-hunger-every-day [Accessed 25 Dec. 2022].

Vella H. (12 January, 2021). Inside the world's largest dam - based floating solar power project. [online], Power Technology. Available at: https://www.power-technology.com/features/inside-the-worlds-largest-dam-based-floating-solar-power-project/ [Accessed 15 Mar. 2022].

Voegeli G., Hediger W. and Romerio F. (2019). Sustainability assessment of hydropower: Using Causal diagram to seize the importance of impact pathways. Environmental Impact Assessment Review, 77, 69-84, DOI: 10.1016/j.eiar.2019.03.005.

World Commission on Dams. (2000). Dams and Development; a new framework for decision-making: The Report of World Commission on dams. London: Earthscan Publications Ltd. Available at: https://archive.internationalrivers.org/sites/default/files/attached-files/world_commission_on_dams_final_report.pdf [Accessed 20 Nov. 2022].

World Food Program. (2022). Global Food Crisis- 2022: A year of unprecedented hunger. [online], World Food Program. Available at: https://www.wfp.org/global-hunger-crisis [Accessed 31 Dec. 2022].

World Register of Dams. (2020a). Number of dams by member countries. [online], International Commission on Large Dams. Available at: https://www.icold-cigb.org/article/GB/world_register/general_synthesis/number-of-dams-by-country-members [Accessed 31 Dec. 2020].

World Register of Dams. (2020b). General Synthesis. [online], International Commission on Large Dams. Available at: https://www.icold-cigb.org/GB/world_register/general_synthesis.asp [Accessed 31 Dec. 2020].

World Register of Dams. (2020c). Role of dams. [online], International Commission on Large Dams. Available at: https://www.icold-cigb.org/GB/dams/role_of_dams.asp [Accessed 31 Dec. 2020].

World Register of Dams (2020d). Classification by resettled persons. [online], International Commission on Large Dams. Available at: https://www.icold-cigb.org/article/GB/world_register/general_synthesis/classification-by-resettled-persons [Accessed 31 Dec. 2020].

Wu Y., Wang Y., Chen K., Xu C. and Li L. (2017). Social sustainability assessment of small hydropower with hesitant PROMETHEE method. Sustainable Cities and Society, 35, 522-537, DOI: 10.1016/j.scs.2017.08.034.

Wyrick J.R., Rischman B.A., Burke C.A., McGee C. and Williams C. (2009). Using Hydraulic modelling to address social impacts of small dam removals in southern New Jersey. Journal of Environmental Management, 90(Supplement 3), S270-S278, DOI: 10.1016/j.jenvman.2008.07.027.

Xu C., Xu Z. and Yang Z. (2019). Reservoir operation optimization for balancing hydropower generation and biodiversity conservation in a downstream wetland. Journal of Cleaner Production, 245, 118885, DOI: 10.1016/j.jclepro.2019.118885.

Yoneda Y. (18 December, 2013). Study shows Christmas trees suck up super potent greenhouse gas. [online], INHABITAT. Available at: https://inhabitat.com/new-study-shows-christmas-trees-suck-up-super-potent-greenhouse-gas/ [Accessed 30 Dec. 2022].

Zhang L., Pang M. and Wang C. (2014). Emergy Analysis of a small hydropower plant in South-western China. Ecological Indicators, 38, 81-88, DOI: 10.1016/j.ecolind.2013.09.037.