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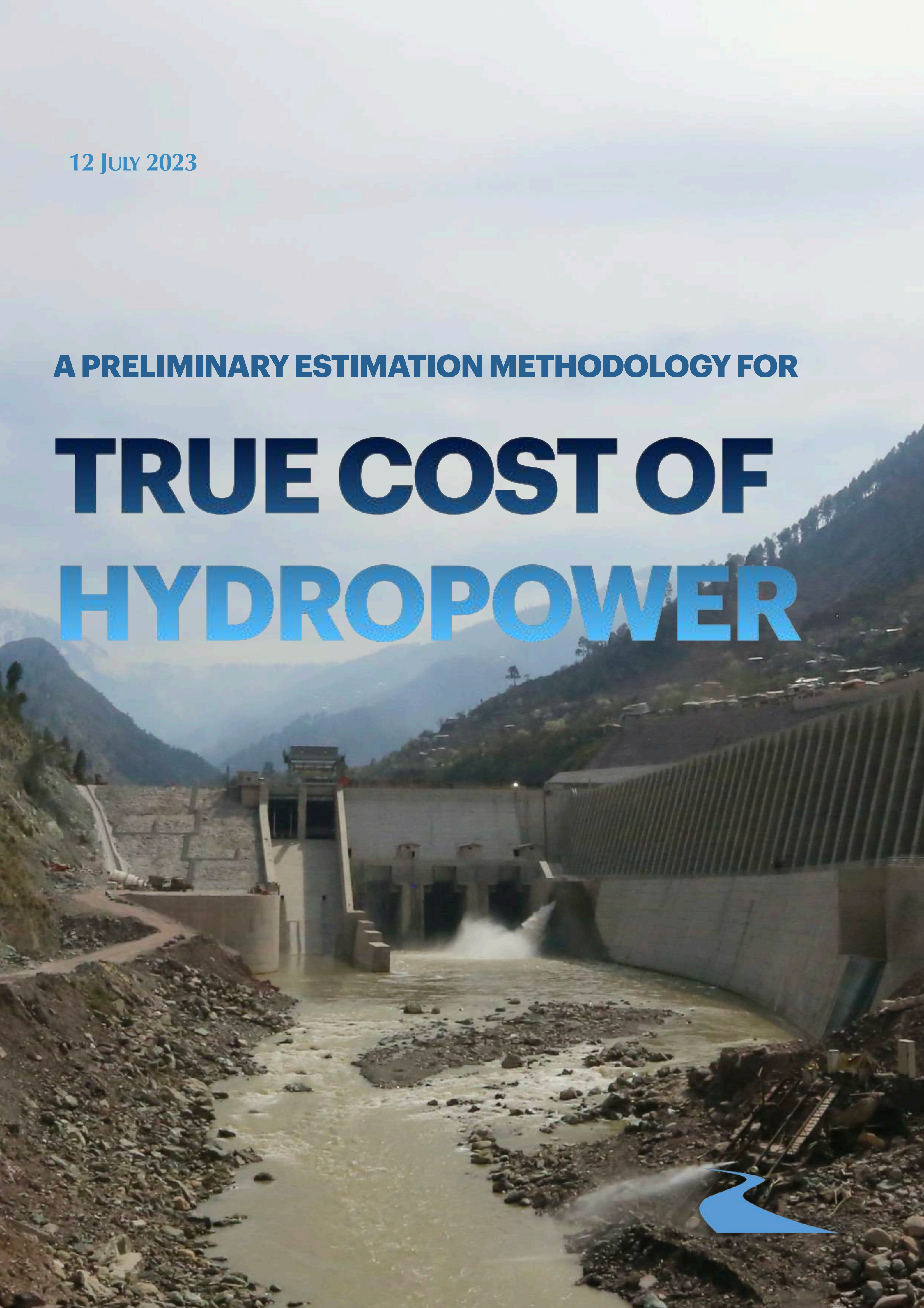
A PRELIMINARY ESTIMATION METHODOLOGY FOR

TRUE COST OF HYDROPOWER



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Deliverable 01

A Preliminary Estimation Methodology for True Cost of Large Hydropower Projects

By

*Hassan Abbas, Asghar Hussain & Wajhi U H Naqvi**

This report feeds into the broader perspective of Energy Transition in South Asia. Collaboration partners in developing this report include: Alliance for Climate Justice and Clean Energy (ACJCE), Policy Research Institute for Equitable Development (PRIED) and Alternative Law Collective (ALC). This Hydro-costing methodology was prepared as a precursor to the project specific case studies of two large hydropower facilities in the Indian Basin of Pakistan - one, hydropower with water storage, and two, hydropower as run-of-the-river.

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Cover Photo: Conjugate dam structure (rock filled and concrete) in Neelum River for Neelum Jhelum Hydropower Project (NJHP). Photo © Abbas

Document Control Sheet

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Title:	**A preliminary estimation methodology for True Cost of Hydropower**
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Synopsis:	Pakistan intends to build 10 large dams in the next decade for water storage and “clean” energy. But environmental and social consequences of large dams are well documented in extant literature. It is, therefore, important of the decision makers to be able to weigh alternatives for both clean energy and water management before deciding upon the multibillion dollar investment on large dams.This report contributes to the debate on the viability of new large dams in Pakistan vis-a-vis their alternatives.

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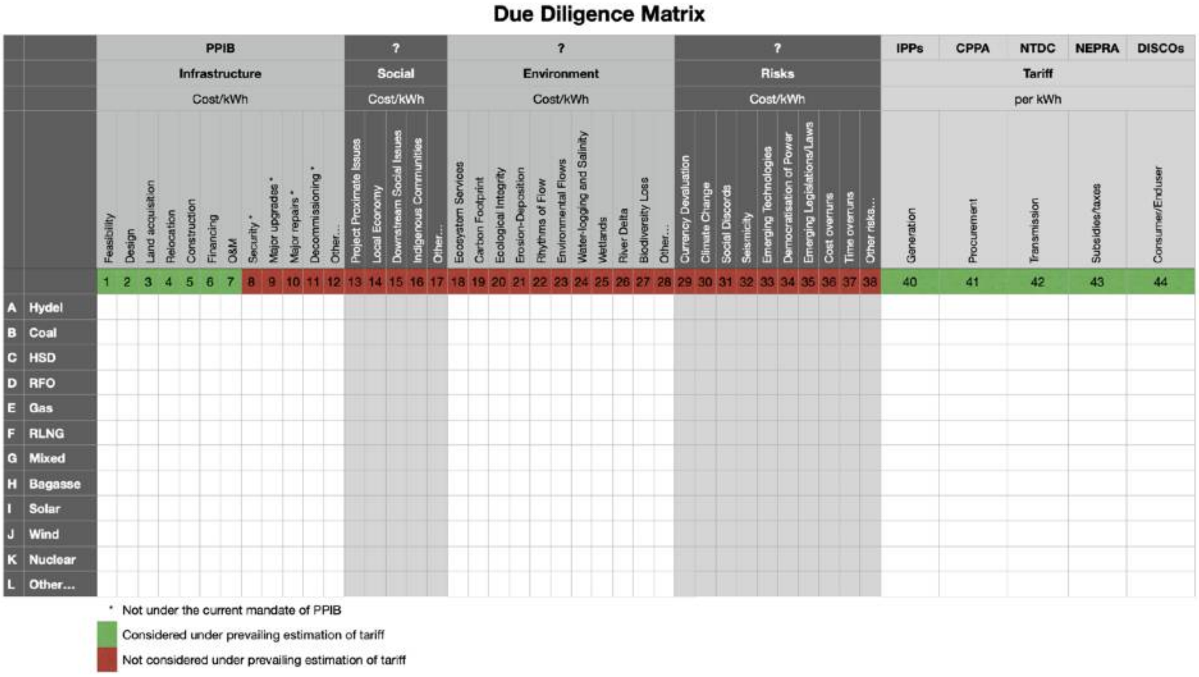
Executive Summary

This report was primarily aimed at devising a methodology which could help in estimating true cost of a large hydropower project and its comparison with the alternative sources of energy.

The other aim of the report was to devise a way where complicated information and cost estimations from hydro and their alternatives could be readily presented to the policy makers and decision makers where they could easily get down to the crux of the matter and make decisions.

The report and the consequent methodology was to be based on desktop studies and extant literature. After going though extensive literature on costs/benefits of large hydro power projects, social, environmental and economic aspects, an indicative list of factors influencing the true cost of large hydropower was derived.

The influencing factors were listed and organised in a matrix format where these could be evaluated for hydropower projects as well as their alternatives. The matrix thus formed was termed Due Diligence Matrix or DDM, as shown below:



Due Diligence Matrix

		PPIB												?					?											?										IPPs	CPPA	NTDC	NEPRA	DISCOs
		Infrastructure												Social					Environment											Risks										Tariff				
		Cost/kWh												Cost/kWh					Cost/kWh											Cost/kWh										per kWh				
		Feasibility	Design	Land acquisition	Relocation	Construction	Financing	O&M	Security *	Major upgrades *	Major repairs *	Decommissioning *	Other...	Project Proximate Issues	Local Economy	Downstream Social Issues	Indigenous Communities	Other...	Ecosystem Services	Carbon Footprint	Ecological Integrity	Erosion-Deposition	Rhythms of Flow	Environmental Flows	Water-logging and Salinity	Wetlands	River Delta	Biodiversity Loss	Other...	Currency Devaluation	Climate Change	Social Discords	Seismicity	Emerging Technologies	Democratisation of Power	Emerging Legislations/Laws	Cost overruns	Time overruns	Other risks...	Generation	Procurement	Transmission	Subsidies/taxes	Consumer/Enduser
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	40	41	42	43	44
A	Hydel																																											
B	Coal																																											
C	HSD																																											
D	RFO																																											
E	Gas																																											
F	RLNG																																											
G	Mixed																																											
H	Bagasse																																											
I	Solar																																											
J	Wind																																											
K	Nuclear																																											
L	Other...																																											

* Not under the current mandate of PPIB

🟩 Considered under prevailing estimation of tariff

🟥 Not considered under prevailing estimation of tariff

Figure ES1: Due Diligence Matrix for Decision Support

The factors listed in DDM, which are not exhaustive, are numbered from 1 through 44. The power generation alternatives, not exhaustive yet again, are listed from A through L. Any listed factor, affecting any generation system, can be evaluated to populate the corresponding cell in DDM . For example, impacts of hydropower on river delta will be assessed and noted in cell A26. Similarly, all cells that apply to a particular power source will be assessed and populated in the matrix. Finally, when all power sources have been evaluated for their respective factors, a holistic comparison will emerge through DDM in a single glance. DDM is the decision support tool that has evolved out of this study.

The challenge, however, is how to evaluate each required factor and populate the matrix.

Since impacts and externalities of hydropower could expand over the river basin - from source to delta., a GIS+BIM indexing methodology is presented to integrate various variables in the river basin in an interactive framework. The indexing uses geospatial data from land-use to population distribution, relates it to energy demand, and then estimates different indices which could help compare alternative modes of energy to fulfil the same energy demand within the same geospatial settings. An example of GIS+BIM indexing method is given in the illustration below which shows hypothetical examples of evaluating energy demand, energy potential and energy costs, etc.

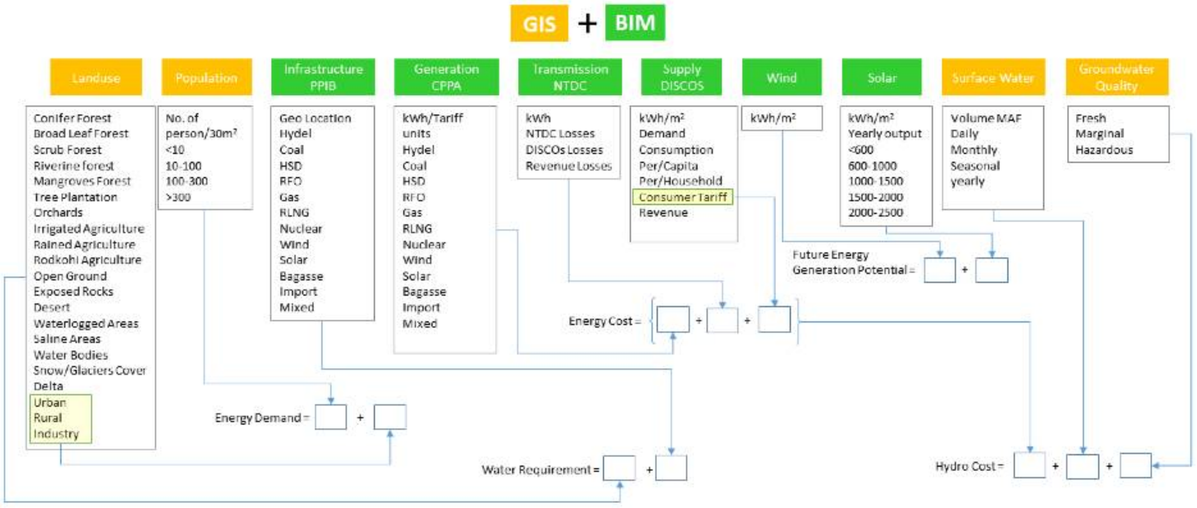


Figure ES2: GIS+BIM illustrative indexing module

These cannot be a set methodology to evaluate the cost of every factor affecting or being impacted by energy generation and distribution. Each cell in the DDM needs to have its own bespoke methodology for evaluation. Tools like Indexing can help and provide a framework. By taking into consideration every tool, data, and method avail, each required cell in the DDM can be populated. Despite best efforts, the values evaluated against each factor will have a range of uncertainty attached to it. By setting boundary conditions, assumptions, data and governing equations, factors can be stochastically analysed and presented as maximum, minimum or most likely values for each factor. The aim is not to generate exact dollar numbers in DDM, but a range of values which brings the various internal and external costs of a large hydro project in perspective with its alternatives.

Acronyms and Abbreviations

BCM	Billion Cubic Meter
CPI	Climate Policy Initiative
CPPA	Central Power Purchase Agency
CPPA-G	Central Power Purchase Agency Guarantee Limited
CRU	Climate Research Unit
Cusec	Cubic feet per second
DDM	Due Diligence Matrix
DIDR	Dam-induced displacement and resettlement
DISCO	Distribution Company
EHV	Extra high voltage
ESMAP	World Bank's Energy Sector Management Assistance Program
FESCO	Faisalabad Electric Supply Company
FFC	Federal Flood Commission
GAO	Government Accountability Office [of the USA]
GEPCO	Gujranwala Electric Supply Company
GoP	Government of Pakistan
GSP	Geological Survey of Pakistan
GW	Gigawatt
GWA	Global Wind Atlas
GWEC	Global Wind Energy Council
GWh	Gigawatt-hour
HESCO	Hyderabad Electric Supply Company
IBRD	International Bank for Reconstruction and Development
IEA	International Energy Agency
IESCO	Islamabad Electric Supply Company
IGCEP	Indicative Generation Capacity Expansion Plan
IPPs	Independent Power Producers

IRENA	International Renewable Energy Agency
IRN	International Rivers Network
IRSA	Indus River System Authority
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
KESC	Karachi Electric Supply Company
kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt peak
LCA	Lifecycle assessment
LCI	Lifecycle inventory
LCOE	Levelized Cost of Energy
LESCO	Lahore Electric Supply Company
MAF	Million Acre Feet
MDB	Multilateral Development Bank
MEPCO	Multan Electric Power Company
MW	Megawatt
MWh	Megawatt-hour
NDMA	National Disaster Management Authority
NEPRA	National Electric Power Regulatory Authority
NTDC	National Transmission and Despatch Company
O&M	Operations and maintenance
OED	Operations Evaluation Department
OGRA	Oil and Gas Regulatory Authority
PAEC	Pakistan Atomic Energy Commission
PEPA	Pakistan Environment Protection Agency
PESCO	Peshawer Electric Supply Company
PMD	Pakistan Meteorological Department
PPIB	Private Power and Infrastructure Board

PV	Photovoltaic
QESCO	Quetta Electric Supply Company
RLNG	Regassified Liquid Natural Gas
SDG	Sustainability Development Goal
SSoP	Soil Survey of Pakistan
TESCO	Tribal Areas Electric Supply Company
VRE	Variable renewable energy
WAPDA	Water and Power Authority
WB	The World Bank
WSUD	Water Sensitive Urban Design
WWF	World Wildlife Fund

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1. INTRODUCTION

The true cost of hydro-power is a complex calculation that requires consideration of several factors beyond the direct cost of building and operating a hydro-power plant. Hydropower is often touted as ‘clean’ and ‘cheap’ source of renewable energy, but there’s plenty of evidence that reservoirs of large dams could release huge quantities of greenhouse gasses and their costs to the society may not be economically feasible. Dams destroy riverine ecosystems and biodiversity. They create conflicts between upper and lower riparians. Social impacts of forced resettlements and involuntary migrations both upstream and down stream of large dams are well documented. Studies also show that the dam builders systematically exaggerate their benefits and underestimate the various costs of dams - costs due to delays, debt servicing, greenhouse emissions, and the social/environmental impact of these dams.

Pakistan faces the enormous challenge of generating clean energy while dealing with climate change induced hydro-hazards. Following a global trend in the Global South, the Pakistani plans to build 10 mega-dams over the next decade. Besides producing hydropower, some dams are advertised as ‘multipurpose’ - providing water storage and flood protection too.

While there’s plenty of literature on dams and their costs in general, these do not provide an easy way for policymakers and advocacy groups to estimate the ‘true cost of hydro’, which would allow comparison with alternative options of power generation, water supply, flood control, and ecosystem management.


Photo © Abbas

Figure 1: A grave/shrine emerges as the lake levels recede in Tarbela Reservoir. Compensation for resettlement had not been the only issue facing the displaced communities.

The New York Times ran an opinion piece (NYT 2014) titled 'Large Dams Just Aren't Worth the Cost'. This piece points to external costs of dam due to currency devaluation, cost overruns leading to debt crises in developing countries and forced migrations (to some extent resettlements) making the lives worse for the local communities than prior to the dam.

"There has never been a fair playing field when dams have been compared with their alternatives … feasibility studies for new dams have regularly underestimated their costs and exaggerated their benefits," writes Patrick McCully, director of International Rivers Network (IRN), UK.

245 dams in 65 different countries, built between 1934-2007, were studied for their costs and schedule overruns. The study found average cost overruns were 96 per cent and average schedule overruns were 44 per cent (Ansar et al., 2014).

Cost overruns in the accounting books may just be one issue related to large hydel projects, but there are many unintended but unavoidable consequences of large dam with huge costs which are inevitably borne by one or more segments of society (Abbas 2018).

1.1. CONTEXT

In this study, 'true cost' of hydropower implies all the direct and indirect costs which are borne by the society and the environment during the lifecycle of a hydropower operation.

1.1.1. AIM

The aim of this study is to develop a preliminary costing methodology for making a better assessment of the true cost of large hydropower/irrigation dams, based on desk studies of the extant literature.

The methodology will particularly attend to project-proximate and system-wide costs. The former would include capital and financing costs, and social/environmental costs - displacement, livelihood disruptions, deforestation, GHG emissions, silting in the reservoir, etc. The latter would include the recurring and cumulative lifecycle costs - displacements in the downstream areas, lost ecological services, river fragmentation impacting aquatic life, degradation of wetlands and deltaic ecosystems, etc.

The methodology will be preliminary and will suggest ways for rapid as well as thorough estimation of these costs.

The goal is not to generate the definitive dollar number for any particular project, but to give probabilistic estimates based on research grounded in the extant scientific literature.

1.1.2. OBJECTIVES

The report has the following objectives:

I) Review of previous works aimed at identifying the problems caused by large dams and identifying the factors which add to the true cost of large hydropower and multipurpose dams.

II) Review of current procedures and practices prevailing in Pakistan's energy sector and the role of various organisations involved.

III) Develop a hydro-costing methodology based on extant literature for better assessment of true cost of large hydropower and multipurpose dams.

IV) Develop a methodology to compare costs of alternatives to hydropower and other functions of a multipurpose dam

1.2. HISTORICAL OVERVIEW

Many studies have attempted to fully account whether dams, in the end, bring more good or ill. With the increasing amount of data, the true costs of dams can be assessed with greater accuracy (Wong 2013).

Despite down sides of mega hydro projects being discussed in scientific community, the public perception of large hydro projects, built since the era of large dams starting 1930's, remains as that of a holy grail to solve all water and energy related issues. When Pakistan's Chief Justice of Supreme Court created a fund for dam-building in April of 2018, millions of citizens gave donations in the fund.

In 2005, when Pakistan was producing surplus power, the need for Diamer Bhasha Dam was only being promoted for food security and agriculture by the government of Pervez Musharraf. But with rampant power cuts and energy shortages hit the county in 2007, the need to meet increasing electricity demands also become an important justification for the big dams in Pakistan (International Rivers 2008).

Similarly, a concrete barrage costing $1.7 billion was built on the estuary of Nagara River. The project began as a water supply scheme for the city of Nagaragawa, but when it transpired that water was not needed, the scheme was converted to flood protection and the structures got built anyway (Pearce 2006).

> We are a Commission to heal the deep and self- inflicted wounds torn open wherever and whenever far too few determine for far too many how best to develop or use water and energy resources.
>
> (Chair, WCD 2000)

"It will supply water that nobody needs, will probably destroy salmon fishery on a beautiful river, and may even increase the risk of flooding", remarked Daniel P. Beard, former Commissioner of the US Bureau of Reclamation, about the Nagara project in Japan. Beard, speaking of his experience as the Commissioner also said that "those who promoted dam projects were not honest about costs and benefits. The truth is that dam proponents would say just anything to get a dam project approved."

The insatiable desire of construction industry to keep their businesses thriving often gets such projects through the approval processes of the host governments, in rich and poor countries alike (Pearce 2006).

1.2.1. Social and Environmental Issues in Early Times

Large dams have been opposed on social and environmental grounds since the early 1900's. Between 1908 and 1913, the US Congress debated whether to make a water resource available or preserve a wilderness when the growing city of San Francisco, California proposed building a dam in the Hetch Hetchy Valley to provide a steady freshwater supply.

The proponents of the dam held that the environment should be used in a conscientious manner to benefit society and that it provided the only source of fresh water for the city of San Francisco. Raker Bill was initiated to grant the city of San Francisco water and power rights in the Hetch Hetchy Valley (Raker 1913).

The opponents, however, believed that nature should be protected, saved from human interference, and that Hetch Hetchy valley was not the only source of water for the city. There were other viable sources of freshwater available. Led by John Muir, the opponents demanded that Congress should protect the Hetch Hetchy Valley from destruction. Muir and his allies believed that nature should be enjoyed for its beauty, and not merely used for its resources (Society for the Preservation of National Parks 1913).

The American Scenic and Historic Preservation Society (1913) argued that the government should preserve the entirety of Yosemite National Park as a natural monument for the benefit of all people. They objected to the fact that San Francisco desired to use the water for power, and that the city already controlled an abundant source of freshwater for its citizens.

More than a dozen professors from the University of Oklahoma signed a petition, which urged Congress to vote against the Raker Bill, encouraging the Congress to consider the interest of the whole country before unnecessarily invading the Valley (University of Oklahoma 1913).

Hetch Hetchy Environmental Debates witness to the birth of social and environmental activism as citizens weighed in, expressing multiple opinions about the proper use of National Park land and the relationship between local interests and national values.

In the end, however, Congress passed the bill to allow damming in the Hetch Hetchy Valley, and President Woodrow Wilson signed the bill into law on December 19, 1913. Nevertheless, the Hetch Hetchy debate raised public awareness about preservation of nature, and paved way for the creation of the National Park Service in 1916.

1.2.2. CHANGES TRIGGERED THROUGH ENVIRONMENTALISM

Although environmentalists were once viewed as ‘small but noisy opinionated elite, all too clever at mobilising the media to protect some endangered flower, fish, or dickey bird’, but this world views has changed because there are environmental groups working with rigour, scientific research, economic analyses, sociological issues, legal analyses, artistic, historical, and quasi-religious values. (Palter 1982, 1986).

Dam proponents had portrayed large dams as synonymous with modern development. This rhetoric gained strength after the completion of Hoover Dam in USA in 1930s, and the whole world went on a binge of building larger and larger dams. But by 1970s and 1980s, adverse, indirect and unintended consequences of large dams started becoming more evident. Large dams started becoming the target of public critique and opposition.

As a result, beginning in the World Bank (WB), new policies and standards started emerging to help avoid or mitigate the adverse environmental and social consequences of large dams in developing countries. Operations Evaluation Department (OED) of the WB carried out desk studies of 50 projects in which the bank was involved and found that in 26 percent of those projects, mitigation of the adverse social and environmental consequences, were neither technically feasible nor economically justified (WB 1996).

Despite the WB acknowledging in its OED review the shortcomings in social and environmental aspects of its projects, and revised its guidelines for large dam projects, the 1996 report was scrutinised and critiqued in the social and environmental circles for being biased and insufficient (Goodland 2010; McCully 1997) .

In 1998, The World Commission on Dams (WCD) was established by the WB and The International Union for Conservation of Nature (IUCN) in response to the growing opposition to large dams. The mandate of WCD was: 1) to review the development effectiveness of large dams and assess alternatives for water resources and energy development; and, 2) to develop internationally acceptable criteria, guidelines and standards for the planning, design, appraisal, construction, operation, monitoring and decommissioning of dams. The commission released its final report in 2000 (WCD 2000) after conducting in-depth case studies of 8 large dams in five continents; 17 thematic reviews on social, environmental, economic and financial issues; alternatives to dams; different planning approaches and environmental impact assessments; brief reviews of 125 large dams in 56 countries; four public hearings in different regions; and, 950 submissions by interested individuals, groups and institutions.

The WCD report is considered one of the most comprehensive and independent review of the world’s dams. Which provides ample evidence that large dams have failed to produce as much electricity, provide as much water, or control as much flood damage as their supporters originally predicted. In addition, these projects regularly suffer major cost overruns and time delays. (Imhof et al., 2002).

1.2.3. ASSESSING SOCIAL AND ENVIRONMENTAL COSTS OF LARGE HYDRO PROJECTS

The OED review (WB 1996) displayed a systematic bias in favour of large dams, using flawed methodologies and insufficient data (McCully 1997). McCully’s major observations were:

- OED did not compare actual costs and benefits for any of the 50 dams reviewed;
- Both the actual amount of power generated and the economic value of each unit of power produced was exaggerated.
- OED included in its estimates of benefits for individual dams electricity generated at other dams downstream while excluding any of the costs of these downstream plants.
- The adverse impacts of droughts on hydropower production were neglected;
- For dams with irrigation components both the areas of cropland receiving irrigation water and the yields from the irrigated areas were exaggerated.
- Impact of salinisation and water-logging upon irrigated crop yields was not assessed;

- Projected flood control, water supply and navigation benefits from dams were cited without any review of whether these benefits were realised or whether dams represented least cost methods of achieving them;
- Evaluations of the social and environmental costs of the projects were based on seriously incomplete data as were evaluations of the costs of mitigating these impacts;
- Arbitrary amount for the cost of mitigating environmental impacts were adopted without giving justification for those arbitrary numbers;
- Claims made of "major improvements" in resettlement were unsubstantiated;
- Operation and maintenance (O&M) costs were not based on actual data and no allowance was made for rising O&M costs over time due to ageing equipment and structures;
- Decommissioning dams at the end of their useful lives is not considered, rather it is assumed that dams will last indefinitely;
- OED fails to assess what the environmental impacts of alternatives to any of the specific projects reviewed might have been, nor does it review the accuracy of statements on the costs, effectiveness or impacts of alternatives in project appraisal reports;
- Demand side management and improved distribution infrastructure as a strategy of reducing growth in urban and agricultural water consumption was not considered;
- The global warming benefits of dams were exaggerated and the possible impacts on dams of climate change–induced changes in stream and sediment flow patterns were ignored;
- The claim that health problems "have in most cases been controlled at a moderate cost" was made in the absence of supporting evidence;
- The impacts of dams on natural habitats and wild fisheries were discussed without an informed understanding of the ecological impacts of dams in general or on the overall impacts of any of the specific projects;
- OED is misleadingly optimistic about the potential of reservoir fisheries to compensate for the loss of wild fisheries. OED gives no figures on predicted and actual yields from reservoir fisheries;
- Very little data on downstream impacts of dams was reviewed.
- The report reflected little understanding of the importance of the downstream impacts.

On the positive economic benefits of dams, de Faria et al., (2017) studied local socio-economic benefits of large hydropower in the context of local economies within a developing country. The report considered 56 hydropower projects in Brazil built between 1996 and 2010, and found that counties in which these projects were located had greater GDP and tax revenues during their first few years of development compared to the counties in which hydropower projects were planned but not yet built. However, those positive economic effects were short lived, mostly less than15 years. The study concluded that justifications for hydropower projects based on local long-term economic and social development should be questioned, and that more effective mechanisms for turning local short-term economic growth into long-term development are needed.

These points highlight the challenges of assessing the environmental and economic costs of large dams over their lifetimes.

1.2.4. O&M COSTS OF LARGE HYDRO PROJECTS

U.S. Government Accountability Office (GAO) was requested by the House of Representatives' Subcommittee on Water and Power to review the Bureau of Reclamation's operation and maintenance (O&M) of federal water projects. (GAO 2000). The review was build around the following questions:

- How does the Bureau define O&M activities?
- What latitude does the Bureau have in deciding which O&M costs to charge to customers?
- How does the Bureau account for O&M costs?

- How does the Bureau define overheads?
- How does the Bureau calculate the O&M costs that it charges to customers?
- What concerns have been raised by customers about excessive O&M costs and to what extent do customers have an opportunity to review cost origins and recommend reductions?
- How do the Bureau's cost recovery practices compare to those of other entities?

In order to seek answers to these questions, GAO also reviewed and analysed relevant legislation and documents, including

- Reclamation law.
- 1998 Bureau reports to Congress on O&M activities.
- 1999 Bureau cost accounting report.
- Federal guidance for determining and accounting for the full costs incurred by federal agencies in providing goods and services.
- Corps of Engineers documents pertaining to O&M activities and cost accounting,.
- State of California documents pertaining to O&M activities and cost accounting.
- Customers' bills and contracts related to the Bureau's water-related activities.

These points highlight the challenges of assessing O&M costs of large hydro projects.

1.2.5. OPTIMISM AND EXAGGERATION

Public opinion needs to be built whenever public money is to be spent on a mega project. Cost-benefit analyses are often utilised by all stakeholders to justify their preferred courses of action. However, a closer examination of these analyses reveals the significant impact that altering the underlying assumptions can have on the recommended path forward. This highlights how economic arguments can be employed to either mask or validate political decisions, emphasising the complex interplay between economic and political factors in decision-making processes (Wong 2013).

Furthermore, the issue of optimistic judgments in decision-making processes is often compounded by the presence of strategic misrepresentation by project promoters, which can be seen as a form of deception. Various studies (Flyvbjerg et al., 2002, 2005, 2009) have examined this phenomenon and have found that delusion and deception are not mutually exclusive explanations for the unfavourable outcomes commonly observed in mega projects. According to Flyvbjerg et al. (2009, p. 180), these two factors are actually complementary rather than competing explanations. However, in practical terms, it is challenging to distinguish between delusion and deception, as they often intertwine in complex ways (Ansar et al., 2014).

The challenges associated with large dams and canal-based systems are well-known, yet the proposed solutions to address these problems often involve the construction of more big dams and increased water storage capacities. Paradoxically, these solutions are politically appealing, despite their potential to exacerbate the very problems they aim to solve. The World Bank's "Pakistan Country Water Strategy" strongly advocates for the urgent construction of new storage facilities on the Indus River.

Ironically, one of the main justifications for the necessity of new large dams is the argument that existing dams like Tarbela and Mangla have lost storage capacity due to heavy sedimentation, thus requiring replacements. However, this overlooks the fact that the proposed reservoirs in the Himalayas would encounter similar sedimentation issues, as these rivers carry substantial silt loads (International Rivers 2008)

On the website of the former President, the Diamer-Bhasha Dam is promoted with the claim that the lack of large river regulation and adequate storages has already led to severe food grain shortages in Pakistan. This emotional and political narrative becomes a driving force behind the push for constructing new dams.

It is crucial to critically examine these assertions and consider alternative approaches that address the underlying challenges without exacerbating the problems.

After studying 29 large dam projects, Kirchherr et al. (2019) found significant disparity between the resettlement data obtained during the planning and design phase of a project and its actual median resettlement values, with an average underestimation of 28.3%. This discrepancy can be attributed to project proponents deliberately downplaying the figures during the initial stages of the project, likely as a strategy to minimize resistance and opposition. The issue of inaccurate resettlement figures holds particular importance for practitioners, as it can have far-reaching consequences. Decision-makers relying on underestimated data may select projects that are ultimately not economically viable, while insufficiently funded resettlement programs can result in the impoverishment of displaced communities. Therefore, it is crucial to address and rectify these resettlement inaccuracies to ensure the well-being and fairness of affected communities.

In response to criticism on underestimating costs and exaggerating the benefits of large dams, the World Bank published a document called "The World Bank's Experience with Large Dams" in 1996 (WB 1966). However, this publication was heavily biased in favour of large dams, drawing criticism for its lack of objectivity. Recognising the need for a more balanced perspective, a workshop was held in Gland in April 1997, organised by the World Bank and the International Union for Conservation of Nature (IUCN). Participants included representatives from the hydro lobby, civil society, and communities affected by dams. During the workshop, it was unanimously agreed that the Bank's submission, "The World Bank's Experience with Large Dams," was unacceptable due to its biased nature. This lead to the creation of World Commission on Dams (WCD). WCD published its report in 2000.

Instead of endorsing the report of WCD, the World Bank decided to develop its own Water Resources Sector Strategy in 2003, disregarding the findings and recommendations of the WCD. This move demonstrated a similar line of thinking to the Bank's stance in the mid-1980s regarding projects like Kedung Ombo and Narmada, where thousands of impoverished individuals had their homes flooded by reservoirs. Despite the displacement and hardships faced by these communities, the Bank justified its actions by stating that sacrifices were necessary for the greater benefit, emphasizing the provision of electricity and irrigation water to a larger number of beneficiaries and the anticipated overall gain (Goodland 2010).

Merrow et al. (1988) highlight the significant financial implications associated with the success or failure of mega projects, including large dams, as they can greatly impact the balance sheets of companies and even the balance-of-payments accounts of governments for extended periods. These warnings are substantiated by a growing body of evidence from civil society, academic research, and institutional sources, all pointing to the strikingly poor performance records of large dams in terms of their economic, social, and environmental impacts, as well as public support. Various studies, including, Scudder (2005) and the World Commission on Dams (WCD, 2000), contribute to this mounting evidence, underscoring the need for critical evaluation and reconsideration of large dam projects (Ansar et al., 2014).

Hydropower plays a significant role in the energy landscape of the Philippines, representing 18% of installed capacity; however, its capacity growth has been limited in recent years. Despite this, hydropower remains a priority in the state planning, as evidenced by the Duterte Government's (2016-2022) pursuit of foreign debt to support hydropower development, even though concerns persist regarding the financing issues associated with this energy resource. Notably, attention should be given to the dam development projects funded by China, which have garnered significant interest and implications in the country (Delina 2020).

1.3. EMERGING GLOBAL MIND

In Plato's dialogues, when King of Egypt, Thamus, was told that a new communication technology - writing - will help remember people much more than they normally can, the King had disagreed, saying that such external marks will implant forgetfulness in the souls (Gore 2013). Guterberg's invention of printing press followed in by 1450's A.D., and now the 'big data' revolution through the algorithms, internet, and artificial intelligence (AI) is taking over the globe. Each of these historical events have transformed the global mind - helping democratisation of public goods such as education, information, public safety, environmental protection and self governance etc. The emerging global mind is going to have profound impacts on the way mega projects of future will be conceived vis-a-vis their impacts on environment, indigenous lives and the society as a whole.

For several decades in recent past, when United States, for example, made up its mind, most of the world followed. But in the current information age the power to shape the future is being dispersed throughout the globe (Gore 2013).

The era of too few powerful individuals deciding for too many lesser individuals is coming to an end. Democratisation is gradually taking over in many facets of civilisation.

Consider: on this blue planet, less than 2.5% of our water is fresh, less than 33% of fresh water is fluid, less than 1.7% of fluid water runs in streams. And we have been stopping even these.

Professor Kader Asmal
Chair, WCD

1.3.1. Climate Change - A Major Consideration

Water cycles, rainfall, seasonal storm systems and climatic patterns are changing with climate change all across the globe. The hydrological statistics, on which large dams, mega diversions and large irrigation districts rely, often have little meaning anymore (Pearce 2006).

1.3.2. Controlling vs Adaptation with Nature

Established in 1902, the US Bureau of Reclamation was created to help federal efforts in the large-scale planning and construction of storage, diversion, and development of waters in arid and semiarid lands for irrigation. Between 1930 to mid 1970's, the agency went on to build more dams inside and outside of the US compared to any other organisation in the world.

Prior to 1970's, most Reclamation projects had been constructed with little or no environmental mitigation measures. But this started changing with National Environmental Policy Act of 1969 and the Endangered Species Act of 1973, which mandated increased protections for the environment. The 1976 failure of Teton Dam in Idaho led to congressional enactment of the Reclamation Safety of Dams Act of 1978, which mandated design safety and safety modifications in existing dams. The projects pursued by Reclamation from the 1970's onwards were often rejected or significantly scaled down on economic and/or environmental ground. In 1977, the Carter Administration transmitted to Congress a "Hit List" of 19 water resource construction projects to be defunded for their questionable feasibility (Stern and Normand 2020).

By 1996 Bureau of Reclamation's mission statement was revised and now it reads:

> *The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.*

The Bureau has transformed with evolving global trends and needs. "Dam removal", for example, is now considered as an 'alternative project' (Randle et al., 2021a) in the Bureau's toolkit of managing water in environmentally and economically sound manner.

The above mentioned transformation of the US Bureau of Reclamation shows how global mind has transformed from the heroics of conquering nature to maximum possible conformity with nature.

With extensive literature and studies on the impacts of large dams on communities and environment, coupled with uncertainty of benefits claimed, the decision making processes are transforming to avoid uncertain benefits for the sake of certain losses these structures would accrue (Wong 2013)

1.3.3. Indigenous Knowledge

The issues related to forced displacements and resettlement of indigenous communities are getting serious attention. There are global movements working for indigenous rights of not just land, but also water. Some Indigenous Water Protectors argue that there cannot be Land Back without Water Back. Indigenous water relationships cut across the themes of colonialism, climate change, justice, health, rights, responsibilities, and governance etc. There is growing awareness of healthy water future through indigenous knowledge and practices and culturally respectful ways of knowledge sharing (Leonard et al., 2023).

Emerging trends on environment, social and economic issues highlight the challenges we may face in a development paradigm, such as in Pakistan, which does not yet seem to be fully aligned with the evolving global mind.

1.3.4. DEMOCRATISATION OF WATER AND POWER

Just like mobile phones democratised communication and World Wide Web (internet) democratised access to information, and desktop printers democratised publications (Gore 2013), now solar energy - especially solar photo voltaic (PV) - is democratising energy (IRENA and CPI 2023).

Similarly, the world is moving away from dammed and diverted rivers to the naturally flowing rivers. Dams are being dismantled, room for the river is being recognised and even 'rights of the river' are being drafted in the international community.

The authoritative control of governments and corporations between public needs and public access is diminishing in many areas and grand ecological mechanisms of nature - such as flowing river - are being recognised for their protection and restoration.

1.3.5. ECOCIDE

The crime of 'ecocide' is generally applies to long term and or widespread damage done to the environment through wanton acts. Derived from the term genocide, lawyers from across the world are putting together a legislation for the Rome Statute to be included as crime that could be tired in International Criminal Court (ICC) alongside the crimes against humanity (Abbas 2023).

Construction of mega dams bring about widespread and longterm damages to riverine ecology and fits into the emerging definition of ecocide. The decision makers must be wary of the fact upcoming international laws may put them in hot waters if environment is recklessly ignored

> "The earth is not dying, it is being killed, and those who are killing it have names and addresses."
>
> [Utah Phillips]

2. ECONOMIES AND DISECONOMIES OF LARGE HYDRO

Large dams, especially in developing countries, are often projected as symbols of national pride and progress. These are mostly financed by multilateral development banks (MDB) and build by international consulting and engineering consortiums. These mega projects significantly impact national economies and alter regional landscapes within the river basins. This chapter discusses the extant literature covering cost, benefits, externalities, and internalities of large hydro projects along with their social and environmental aspects.

Ansar et al., (2014) analysed 245 large dams in 65 countries, built between 1934 and 2007, for which reliable costs and schedule data were available. The study finds average cost overrun by 96% and schedule overrun by 44%. The study concluded that even before accounting for negative impacts on human society and environment, the actual construction costs of large dams are too high to yield a positive return. Moreover, long time required to build a large dam (8 years or more), they remain ineffective in addressing urgent crises.

Petheram & McMahon (2019) studied 98 dams built in Australia since 1888 and found median and mean cost over runs at 49% and 120% respectively for 40 dams for which data was available. The authors found that cost overruns appear to be more for dams erected in sedimentary rock formations. Dam cost overruns have implications to predicted benefit-cost ratios. The study recommended that large dam cost and contingency estimates should be evaluated at pre-feasibility and feasibility stages by an independent organisation and persons, highly experienced in dam design, construction and costing.

The World Bank carried out their first comprehensive study on the environmental and social impacts of large dams (WB 1996). The study carried out a desk assessment of 50 Bank-financed large dams for their economic justification, and found out that 26 percent of these dams could not be justified economically and/or found infeasible for their adverse social and environmental consequences.

> Mr. Scudder, an emeritus anthropology professor at the California Institute of Technology, describes his disillusionment with dams as gradual. He was a dam proponent when he began his first research project in 1956, documenting the impact of forced resettlement on 57,000 Tonga people in the Gwembe Valley of present-day Zambia and Zimbabwe. Construction of the Kariba Dam, which relied on what was then the largest loan in the World Bank's history, required the Tonga to move from their ancestral homes along the Zambezi River to infertile land downstream. Mr. Scudder has been tracking their disintegration ever since.
>
> [NYT 2015]

Estimating the benefits of large dams require the treatment of rivers as commodities while for the assessment of environmental impacts caused by large dams the rivers have to be treated as integral systems (Luecke 1997). Only accounting for benefits of hydropower, water supply, navigation and recreation from large dams, Luecke shows that dams in American west bring economic benefits. However, without giving the financial numbers, the author points out that when rivers are seen as integrated systems, large dams cause many impacts beyond inundation. They trap sediment and nutrient, obstruct migratory aquatic species, change hydrograph and flow velocities, change the natural temperature regime of the water, induce superstaturation of outflows with gases that adversely affect native aquatic life. A combination of these effects changes river morphology and aquatic habitat downstream from a dam. Non-native species may invade and change the natural environment. Engineering tools and techniques developed in the 20th century made large dams possible. But dams alter natural flow patterns of the rivers, impacting rights and access to water, disrupting existing livelihoods, and causing environmental damages.(WCD 2000).

Palter (1988) classifies three categories of diseconomies created by large dams:

I) **System effects** like the loss of an endangered species, greenhouse gas (GHG) emissions from reservoir, etc., - an effect not generally tangible in national or local economy, but affecting human and ecological values, aesthetics, or planetary health.

II) **Off-site problems** directly caused by a project that are economically tangible in national or local terms, although often not considered in MDB project accounting before or after the fact. An example would be erosion of Indus Delta due to silt trapping in the dams upstream.

III) **Unforeseen mistakes**, such as building a dam reservoir between valley slopes prone to land-sliding or dam site selected in seismically active zone. Not accounting for risks saves direct costs of the project but the society would pay these costs in a big way in future. These effects demonstrate why it is wrong to regard environmental costs as “external”.

Decisions to build large dams are being increasingly contested with advancement in knowledge base and new technologies, and the decision-making processes are becoming more inclusive and transparent. (WCD 2000)

The impacts of large dams are discussed in view of above categories in social, environmental and economic perspectives.

2.1. PURPOSES AND FUNCTIONS

The dams were mostly built for irrigation water supply, as well as domestic, municipal and industrial water supply. But large reservoirs of water created behind large dam walls are often considered multipurpose. They store water, generate hydropower, help control floods, may facilitate navigation and create recreational environment. (WCD 2000).

The operation of reservoirs and diversions encompasses multiple functions, including hydropower generation, water supply, and flood control, with many basins utilising multiple reservoirs in a conjunctive manner to optimise overall benefits. The effectiveness of dam operation is heavily influenced by the ratio of reservoir capacity to annual flood volume, known as the impoundment/runoff index. Flood regulation necessitates the presence of empty space or a designated "flood control pool" within the reservoir's storage capacity to accommodate floodwaters (Petts and Gurnell 2022). Even in the case of small water-supply reservoirs designed to maintain high water levels throughout the year, temporary storage above the spill weir level assumes a crucial role in reducing the maximum outflow rate from the reservoir, particularly when the reservoir water area covers 2% or more of the catchment area. This significance was emphasised in a study conducted by the Institution of Civil Engineers (I.C.E., 1933).

These functions of large dams are discussed below in context of large dams built in Pakistan.

2.1.1. WATER STORAGE

As a consequence of Indus Waters Treaty, Pakistan had built two large reservoirs for storage of water, i.e., Mangla and Tarbela.

Tarbela reservoir was originally built with a live storage capacity of 9.7 MAF, but due to continued silting in the reservoir, the current usable storage capacity is 6.85 MAF. The water stored in summer months is released in winter months, primarily to supplement irrigation supplies for winter cropping, also know as *Rabi* cropping season.

Mangla reservoir was originally built with a live storage capacity of 5.88 MAF, but due to continued silting in the reservoir, the usable storage capacity was reduced to 4.59 MAF by 2004. Due to large silt load in the natural flow of the river, reduction in storage capacity due to sedimentation in the reservoir was anticipated when the dam was being planned. Consequently, the provision to raise the walls of the dam at a later stage was already kept in its design (Michel 1966). Between 2004 and 2009, the walls of the dam were raised by 30 feet, as planned, and live storage capacity was increased 2.88 MAF. The current reservoir’s live storage capacity is 7.55 MAF.

Although a proposal is under consideration to supply water from Tarbela reservoir to Islamabad and Rawalpindi, but for now, the storage in large dams is only meant for irrigation purposes.

Since reservoirs are located in the north while the irrigation system of the country extends all the way to Indus Delta, the conveyance losses of the water released from the dams are significant.

Water released for irrigation from the dam enters the river. Some of it is consumed by the environment/seepage/evaporation and only 70% of released water makes it to the irrigation canals. Conveyance efficiency of canals system from river to water courses is also 70% and that of water courses from canal to farm gate is again 70%. This implies that only 35% of water released from the dam makes it to the farm gate. Tarbela and Mangla combined, release approximately 14 MAF of water fin Rabi, but only 5MAF or so actually supplements the irrigation. The annual diversions of water for irrigation are 104 MAF (Briscoe and Qamar 2006).

It is interesting to note that Kharal and Ali (2007),, assessed the losses and gains in the Indus river system before and after the construction of the Tarbela reservoir, using historical data from 1940 to 2003, and found that post-Tarbela losses in the Indus, between Tarbela and Kotri, increased from 10.86 MAF to 18.22 MAF, a net additional loss of 7.36 MAF — which is already higher than the 6.85 MAF of water that Tarbela releases in the Rabi season. (Abbas and Hussain 2022)

2.1.2. HYDROPOWER

Hydropower in Pakistans constitutes 28% of energy mix in terms of installed capacity and 25% of mix in generation capacity (IGCEP 2022).

Though Tarbela is primarily operated for irrigation, and hydropower as 'by- product', yet, the power accounts for 60 percent of the economic benefits from the dam (ASIANICS 2000).

It is often argued by the proponents of hydropower that Pakistan has exploited only about 10% of its 'feasible' hydropower potential (Bricoe and Qamar 2006).

Currently, some under construction large hydropower projects in Pakistan include Mohmand Dam (800 MW), Diamer Basha (4500 MW), Tarbela 5th Extension (1410 MW) and Dasu (4320 MW).

2.1.3. FLOOD CONTROL

Some dams are purpose built to control floods. Their reservoirs are kept empty to absorb flood peaks and then released slowly thus breaking the flood peaks. In some multipurpose storage reservoirs, some designed freeboard is kept for absorbing flood peaks. In case of two large dams of Pakistan, i.e., Mangla and Tarbela, no freeboard to manage flood peaks was kept in the original design of the reservoirs. Any flood mitigation from these dams is only incidental (Afzal 1994).

Despite having the Pakistan's second largest dam on Jhelum River, the 1992 floods could not be prevented, causing significant loss of life and property (Abbas 2015).

2.1.4. NAVIGATION

River navigation season could be increased by releasing water from the reservoirs in low flow season. Many reservoirs are planned for supplying water for river navigation. However, in case of Indus River and its tributaries, navigation potential is not being used, therefore, none of the reservoirs build in the Indus Basin is rendering this service. It should be noted however, that according to a study published in Nature, Indus, for its navigation potential, is listed among the 34 ' Golden Inland Waterways' on the planet (Wang et al., 2020).

There are few river systems in the world as long and as reliable as the Indus. The river and its tributaries connect most major cities of Pakistan with each other and the Arabian Sea, but also Kabul in Afghanistan and the towns such as Gurdaspur and Ludhiana in India. A carefully engineered Indus Inland Waterways System, besides serving trade and commerce benefits, would also fostered regional peace. (Abbas 2016; Abbas 2019).

Despite its huge potential, inland navigation has been neglected in Pakistan due to prioritisation of other uses of the rivers. It is feasible, however, to revive river navigation after decades of neglect. Navigation in Indus is socioeconomically viable, saves transport cost, fuel consumption, road congestion and vehicle emissions. (WB 2022).

2.1.5. RECREATION

Reservoirs provide recreation and water sports opportunities to the community. However, in case of Pakistan's security paradigm, public access to large dams is restricted. However, since the reservoirs are very large, public benefits from recreation away from the dam and powerhouse structures may accrue, but this prospect is not being exploited to its potential.

2.2. SOCIAL ASPECTS

One of the major issues in large dams debates is about the social liabilities of population displacement and involuntary resettlement, both for project proximate and downstream communities - looking through the basin-wide cumulative social assessments.

China's Three Gorges Dam holds significant numerical records in terms of its social impact. It resulted in the displacement of over 1.2 million people and caused the flooding of 13 cities, along with 1350 villages. These statistics highlight the immense scale of human displacement and the extensive areas affected by the dam, underscoring the substantial social and environmental consequences associated with large dam projects (Callegari et al. 2018).

The perception of reservoirs is influenced by various emotional and economic factors, while personal variables, including gender, do not appear to have a significant impact. Key factors that shape people's opinions about reservoirs include their beliefs regarding the project's feasibility, the sense of security it provides, and the potential personal benefits derived from its construction. It is important to note that dam reservoirs not only have environmental implications but also affect the local population. Previous studies have highlighted both the social advantages and potential drawbacks of reservoir creation for the local communities. The magnitude and nature of these impacts depend on various factors such as dam size, location, and population density in the surrounding area (Piróg et al., 2019).

2.2.1. PROJECT PROXIMATE ISSUES

Large dams built for hydropower, irrigation, water storage and/or flood control have led to the involuntary displacement of millions of people over the last century (Hay et al., 2019; WCD 2000).

Randell (2022) identified major sufferings of resettled communities. Before the forced resettlement begins, people experience anxiety, stress, and depression coping with uncertainty over their impending resettlement how would they adapt to new life and livelihoods in the new location. People resettled far from their communities lose the social support of close family and friends. Farmers may get smaller or poorer quality of land or may be far from water sources, impacting their income and livelihoods. Households may receive inadequate compensation which may not be sufficient to replace their lost houses, property, and other assets. Submerged ancestral cemeteries, temples, and archaeological sites may destroy cultural heritage, especially for indigenous people who maintain strong and long-standing affiliation to their lands.

One of the most debated aspects about the social liabilities of hydropower development is the involuntary population displacement and resettlement (Cernea 1997). Cernea found that low resettlement performance is mostly due to inadequate economic analysis, externalisation of reestablishment costs to the affected population, and under-financing of the resettlement plans. Cernea reported that projects which had a budget-to-income ratio of less than 3.5 encountered problems during resettlement implementation, while fewer projects with a ratio greater than 4 had such problems. It is argued by proponents of voluntary resettlement that at a certain threshold of compensation and benefits most, if not all, people will move voluntarily, however, there are communities which cannot be persuaded because of its strong ancestral or cultural attachment to their lands (Goodland 2010). Cernea (1997) concluded that proper resettlement may involve reestablishing the income streams of re-settlers, which, in turn would require some “principal” amount to yield sufficient returns.

Impacts of resettlement within a community are not homogeneous, conventional cost–benefit analyses on which project planning and compensation calculations are based are inadequate, resettlement plans mostly lack legal frameworks or institutions in delivering good resettlement outcomes, ultimate responsibility and monitoring mechanism required to last for decades to ensure good resettlement outcomes remain fuzzy, and, no organisations or frameworks are created to ensure just benefit sharing over the lifetime of the project which may run for decades (Hay et al., 2019).

Zhao et al., (2020) studied Hongjiang and Wanmipo Hydropower Stations in China and demonstrates that on one hand, hydropower alleviating power shortages, improved grid stability, increased tax revenues, and and brought significant economic benefits, but on the other hand, the benefits accrued at the cost of the social exclusion of over 20,000 re-settlers. The resettled communities experienced distributional injustice from project benefits, injustice due to the lack of fairness, transparency, and accountability, and, procedural injustice due to the very limited participatory rights in the decision-making process before, during, and after resettlement. The communities lacked viable channels to seek redress of injustices.

Most cases of development-induced displacement have resulted in livelihood decline for the displaced population (Howe 2005; Cernea 1997). Dam-induced displacement mostly leaves affected people worse off. Displacements lead to higher risk of impoverishment, joblessness, food insecurity, landlessness, poor health, increased psychological stress and loss of community resources (Randell 2022). Forcibly displaced communities lose working production systems and income generating assets which include skilled local jobs, valuable land, and other resources (Cernea 1997). Fishers may lose easy access to the river, a critical source of their livelihood (Randell 2022). Displaced households, after being removed from their lands, homes, and communities, have to rebuild livelihoods amid new, but often poorer socio-economic circumstances (Randell 2022). A study of 44 large dams constructed from 1950s to early 2000s, displacing 1.2 million people, found that living conditions of the displaced households in 82% cases had worsened (Scudder 2005). All post hoc reviews of resettlement, including those by the World Bank, confirm that people displaced had been worse off – hence most dams increased poverty. Over 10 million people were pushed into poverty against 100 billion dollars of investment on large dams by The World Bank- something against the Banks very goal of poverty reduction (Goodland 2010). The issues of livelihood change over time are complex and linked to indigeneity, gender, benefit-sharing, homogeneity of affected communities, participatory approaches, land compensation, etc. (Hay et al., 2019).

Use of force to evacuate communities is also practiced in some parts of the world. This happens, especially, when local communities are not involved in the planning process for large reservoirs. Until 2010, The World Bank had allowed countries to employ armies to push people out of the way of a dams because it was cheaper than fair compensation. (Goodland 2010). In case of Kedung Ombo dam in Indonesia, where 5000 families were forced to move out of reservoirs way, it was argued by dam proponents that larger number of people would be benefited from irrigation than the people being displaced (Goodland 2010). Kedung Ombo dam project had not included any finance for resettlement. In 1994, Indonesia's Supreme Court found massive errors and policy violations by the dam proponents. In 1980-1982 indigenous peoples in the way of Guatemala's Chixoy dam in Guatemala were massacred when they protested. India's Narmada dam also caused unnecessary sufferings for the displaced population (Goodland 2010).

There is, however, emerging debate that mechanisms should be put in place where settlers are not just compensated for their loss of lands, water and livelihoods, but also should be able to have a better standard of living after resettlement. Additional compensation needed may not be treated as project cost or benefit sharing and such additional payments may be considered as transfer payments for mitigation measures (WB 2015)

2.2.2. LOCAL ECONOMY DURING AND AFTER CONSTRUCTION

Large hydro projects create jobs and livelihood opportunities through employment of both skilled and unskilled workforce to undertake the massive project. Most large project take five to seven years for construction and local economies benefit from cashflows and jobs thus created.

Cernea (1997) discusses the "boomtown" impacts on economy and social life of locals where a large dam project starts. The abrupt arrival of a large force of construction workers, one the one hand, may boost local businesses, but on the other, causes social and cultural problems. When the project approaches finishing point, most construction workers leave which causes another set of necessary adjustments for the local communities.

The need for study of boom towns as a consequence of large hydro projects, based on local community needs, have been identified. Feasibility studies for large dams need to explicitly anticipate the socio-economic impacts on local communities include mitigation measures (Gilmore and Duff 1976).

de Faria et al., (2017) studied the socio-economic indicators for 56 dams in Brazil, built between 1991 and 2010. In the context of a developing country the authors used econometric methods to evaluate the relationship between county-level socio-economic indicators and hydro- power development. The study found that GDP and tax revenues during first few years of dams improved. However, the positive effects were short lived (15 years or so). The study also found that other social indicators (e.g. health, income, eduction, access to piped water, etc.) did not.improve significantly. The study suggests economic and social development based on the long term hydropower projects remains questionable in Brazil.

Moreover, construction jobs come at the cost of loans taken from MDB. Interest rates on these loans for Pakistan generally vary from 12% to 15% (WAPDA 2021). In case of Dassu Hydro Power Project, for example, Government of Pakistan obtained USD 588.4 million from International Development Association (IDA) in 2014, at an interest rate of 15% with 5 years of grace period (WAPDA 2021). If due to time overrun, the project is not complete by the end of grace period and does not start producing the desired economic output (i.e., earning from power generation) the Government will be obliged to repay the loan instalments from other resources which, in turn, could burden the local economy.

2.2.3. DOWNSTREAM SOCIAL ISSUES

Kirchherr et al. (2016) carried out a systematic review of research on the social impact of dams and has noted that there is a disproportionate focus on the impacts within resettlement areas, neglecting other social groups impacted away from the project location. This has important implications for our understanding of the overall social impact of dams. By acknowledging these limitations, future research can strive for a more comprehensive and balanced assessment of the social consequences associated with dams

Historically, the downstream effects of dam construction have been largely neglected by dam planners and the authors of environmental and social assessments. This oversight can be attributed to the limited scope of these assessments, which often fail to take a basin-wide approach. However, it is crucial to acknowledge that dams and reservoirs do have significant downstream impacts, particularly in terms of irrigation benefits and flood prevention or control. These positive effects play a major role in enhancing water resource management. On the other hand, the construction of dams can have adverse socio-economic and environmental consequences, particularly affecting fishing communities. The presence of dams can disrupt riverine fisheries, hampering the reproduction and feeding patterns of certain fish species that rely on seasonal migration. Consequently, many traditional fishermen have experienced a decline or complete loss of their livelihoods due to dam construction. To address these issues effectively, it is imperative to consider the comprehensive basin-wide impacts of hydropower projects during the planning and implementation stages. This includes assessing both the positive effects, such as increased irrigation and flood control, and the negative effects outlined above. Policy responses and mitigation strategies should be developed based on these assessments, with the aim of maximising the beneficial impacts of hydropower projects while minimising or mitigating the harmful effects (Cernea 1997).

Dams have not only resulted in the displacement of millions of people but have also posed significant risks to the livelihoods of many others who depend on rivers. One example is floodplain agriculture, which has been practiced by farmers in various regions. This agricultural method relies on seasonal floods to bring water and nutrients to the soil, essential for successful crop and livestock production. However, the regulation of flood cycles due to dams can severely diminish agricultural yields, impacting farmers' income and food security. Furthermore, fishing communities are also greatly affected by dams, as they can lead to the decline of fish populations that are vital for both commercial production and local consumption. These detrimental impacts on farmers and fishing communities highlight the broader repercussions of dam construction on livelihoods and food systems (Randell 2022).

The hydroelectricity sector has had negative effects on freshwater ecosystems and the livelihoods of local fishers. Inadequate information, governance, and decision-making processes that fail to consider all stakeholders have intensified the impacts of dams. The implementation of dams in the Amazon Basin, for example, has led to reduced fishery catches, undermining the economic viability of the fisheries. Additionally, the adverse consequences of damming disproportionately affect fisherwomen. Therefore, it is crucial to provide targeted compensation and mitigation measures specifically designed to address the needs and challenges faced by female fishers if dams are constructed (Runde et al., 2020).

2.2.4. INDIGENOUS COMMUNITIES

Mega-hydropower projects have emerged as a prominent option for facilitating the transition to renewable energy. However, these projects have encountered significant opposition from indigenous communities and other marginalised groups. In response, governments and corporations have employed punitive laws, anti-terror measures, and emergency powers to justify the detention of activists, resulting in a climate of intimidation, human rights abuses, and, in extreme cases, extrajudicial killings. To understand the complex dynamics surrounding these issues, Delina (2020) employ the concept of energy scape, which encompasses not only the technological and infrastructural aspects of the energy system but also the broader social, institutional, and economic factors that shape the energy socio-technical system. By recognising the influence of intangible elements such as political ideologies, social values, demographic trends, and macroeconomic patterns, we gain a more comprehensive understanding of the multifaceted challenges and opportunities associated with mega-hydropower projects in the context of energy transitions.

The first systematic review of research on the social impact of dams has shed light on notable biases present in the literature. One major bias identified is the overemphasis on studying large dams, while other sizes and types receive less attention. Additionally, there is a disproportionate focus on the impacts within resettlement areas, neglecting other aspects of social change. These biases have important implications for our understanding of the overall social impact of dams. By acknowledging these limitations, future research can strive for a more comprehensive and balanced assessment of the social consequences associated with dams.

2.3. ENVIRONMENTAL ASPECTS

The construction of a dam brings about immediate changes to the river ecosystem upstream. The previously free-flowing river is transformed into an impoundment, altering the habitat from shallow and fast-moving lotic to deeper and slower-moving lentic conditions. These distinct environments support different species adapted to their specific characteristics, leading to a turnover in the plant, invertebrate, and vertebrate assemblages. Reservoirs further impact downstream waters by modifying the temperature regime. They absorb more heat from the sun and retain water for a longer duration compared to a natural river segment, resulting in heat storage. As a result, the temperature of downstream waters can be raised when water originating above the thermocline passes through the dam. Conversely, if water is drawn from below the thermocline, a cooling effect may occur. These deviations from the normal temperature regime can have significant consequences for aquatic life downstream. Additionally, dams without provisions for fish passage impede the migration of fish along the river. This disruption of connectivity leads to the loss of habitat availability, potentially causing the disappearance of upstream migratory fish populations and negatively impacting the overall health of the river system (Duda and Bellmore 2022).

The construction of dams, primarily using concrete as the foundational material, results in the fragmentation and channelisation of rivers, leading to the creation of unnatural systems. However, dams remain crucial for hydropower generation and flood control, with limited alternative materials available for construction. With dam removal becoming more prevalent, the growing evidence base is shedding light on the consequences. Slowed flow rates caused by dams cause sediments that would normally be carried downstream to settle within reservoirs (Elosegi and Sabater, 2013), often containing chemicals from urban runoff, excessive organic matter, and nutrients like fertilisers that contribute to reservoir eutrophication. Changes in the flow regime, in turn, impact temperature and dissolved oxygen concentrations both within the reservoir and downstream from the impoundment (Petts, 1984; Nilsson and Berggren, 2000; Elosegi and Sabater, 2013). These interconnected factors highlight the complex and diverse impacts of dams on river ecosystems and emphasise the need for further investigation within the literature review chapter of this report (Cooke et al., 2020).

Dams have emerged as a dominant force of transformation in global river systems, exerting significant alterations on their natural state. Historically, the construction of dams was primarily motivated by human necessities such as mechanical power, stable water supplies, irrigation, and flood mitigation, with limited regard for the ecological repercussions. This highlights the initial focus on fulfilling human demands without fully considering the environmental consequences associated with dam development (Duda and Bellmore 2022) .

Among the numerous hydro projects that have caused significant damage, India's Narmada dams and Indonesia's Kedung Ombo dam stand out as particularly notorious examples, with both projects originating from loans provided by the Bank in 1985. The implementation of these dams, along with similar instances, has resulted in extensive and avoidable suffering, substantial escalation of poverty levels, and severe environmental consequences. The Narmada and Kedung Ombo dam debacles serve as striking illustrations of the adverse outcomes associated with ill-planned hydro projects, highlighting the imperative need for a thorough examination of their impacts in the literature review chapter of this report (Goodland 2010).

The construction of dams has a significant impact on river systems due to the substantial obstruction of sediments and nutrients in reservoirs. This alteration enhances the biomass production capacity within the reservoir, but it also leads to a reduction in sediment and nutrient inputs to the downstream ecosystem, potentially posing an oligotrophic threat to the downstream environment. As a result, dam construction induces changes in the ecosystem health conditions of both the reservoir and the downstream areas, highlighting the ecological consequences of these blocking effects. Incorporating these findings into the literature review chapter of the report provides valuable insights into the ecological transformations caused by dam construction and their implications for reservoir and downstream ecosystems (Fang et al., 2015).

2.3.1. ECOSYSTEM SERVICES

Ecosystems provide many services to the society within their sustainable limits. But often, overexploitation and/or mismanagement/destruction of of natural ecosystems result in loss of those services. Riverine ecosystems, for example, provide fish and other foods, maintain wetlands, sequester carbon, harbour wild life, recharge aquifer, clean air, and so on.

The absence of "health" in ecosystems is often a better indicator of its true state. Signs that point to unhealthy ecosystems, include, but not limited to the loss of nutrient capital, decreased primary productivity, reduced size of dominant species, diminished species diversity, and overall system regression. Three major indicators of ecosystem health are: the activity or vigour of the ecosystem, its ability to maintain its structure and autonomy over time, and its resilience in the face of external disturbances (Fang et al., 2015).

Under natural, free-flowing conditions, river networks provide a range of valuable benefits to people through ecosystem services. These services include abundant fish populations for fisheries, the ability to practice floodplain agriculture, the presence of desirable geomorphic features in the river's form, and the cultural importance of native biodiversity in river ecosystems. However, historically, water management decisions have prioritised the development of infrastructure for services like hydropower generation and irrigation, leading to tradeoffs that diminish the benefits derived from free-flowing services. Unfortunately, the losses incurred and the costs associated with rehabilitating ecosystems in the future have not been adequately considered in decision-making processes. To achieve balanced water policy and effective watershed management, it is crucial that ecosystem service assessments take into account the benefits that exist in the absence of water infrastructure. This will provide valuable insights to inform decision makers about the true costs and benefits associated with different water management options (Auerbach et al. 2014).

In the case of hydropower systems, considering their impacts at various scales, it is necessary to assess not only the ecosystem services at the plant scale but also those that may be affected downstream in the watershed. Clearly defining the boundaries of each scale is essential. Similar scale analyses should be conducted for other types of systems to understand the delivery and location of ecosystem services (Briones-Hidrovo et al., 2020).

Ecosystem Service Assessment is conducted within an ecological economic framework, focusing on monetary valuation ($/year) of ecosystem services. The assessment process involves five key steps. Firstly, it is important to identify and select as many services, benefits, and beneficiaries as possible, following recommendations from existing literature. Secondly, the scope of ecosystem service valuation needs to be determined. Thirdly, it is crucial to identify the ecosystem type (e.g., tropical forest, meadow) and its condition (primary or secondary forest, if applicable) to ensure accurate results. It is important to note that certain services may be substituted when a hydropower dam is implemented, such as water storage and regulation. Additionally, the location of the hydropower project plays a role, as energy from water is only obtained after dam construction, particularly in flat areas or areas with negligible head. Hydropower itself should not be considered as an ecosystem service but rather as a byproduct of water (provisioning ecosystem service). Fourthly, the most suitable monetary method for valuing each service should be identified and applied, considering established methodologies in the field. Finally, a calculation is performed to obtain a net result based on the balance of ecosystem services, taking into account the interactions and trade-offs among different services (Briones-Hidrovo et al., 2020). By following these steps, an Ecosystem Service Assessment can provide valuable insights into the monetary value of ecosystem services, aiding in decision making and resource management for sustainable development.

The ecosystem services provided by rivers include the diversion of water for various purposes such as agriculture, municipal use, and industry.. They serve as transportation routes for people and goods, offer recreational opportunities, and are appreciated for their aesthetic value. River corridors also provide a source of food and fiber. Furthermore, rivers play a crucial role in providing insurance against water-related catastrophes. They help preserve native biodiversity, contribute to pollutant removal, and affect the risk of disease transmission. They absorb flood peaks and break flood velocities. These diverse ecosystem services should be considered when making decisions regarding water management and resource allocation (Auerbach et al. 2014).

Rivers encompass a broad spectrum of ecosystem services, which manifest at various scales and have far-reaching implications. At the local level, indigenous fishing communities rely on rivers for sustenance, harvesting fish and utilising water for essential purposes such as drinking and bathing. On a continental scale, governments grapple with complex river management challenges, encompassing issues such as water scarcity, storage, irrigation, pollution (both organic and inorganic), eutrophication, disease control, flood management, navigation, and sedimentation. In a global context, rivers have played a significant role in shaping the Earth's topography, as they erode rocks, transport sediments and nutrients to floodplains, river deltas, and oceans. Moreover, they serve as conduits connecting the atmosphere and the ocean through the intricate water cycle, while also serving as prominent geographic features in numerous highly populated cities around the world. These multifaceted attributes of rivers underscore their critical importance and emphasise their inclusion as a central focus within the literature review chapter of this report (Duda and Bellmore 2022).

The Water-Energy-Food nexus represents a socio-ecological system that serves as a conduit for nature's contributions to humanity. The integration of novel Nature's Contributions to People, such as flood regulation and hydroelectricity, relies on modifications to the river regime, which in turn affect the more traditional natures contributions to people supporting the livelihoods of local communities. Understanding and mitigating conflicts arising from dams necessitates the identification of trade-offs between these new and traditional contributions of nature, as well as the distributional impacts they impose. This calls for a comprehensive analysis comprising two crucial elements: (i) a community-level downscaling approach to pinpoint the communities that are most affected by gains or losses, and (ii) determining the frequency at which these gains and losses transpire. These analytical components are paramount in comprehending the intricate dynamics of the water-energy-food nexus and its associated implications, thereby contributing to the literature review chapter of this report (Food et al., 2023).

2.3.2. CARBON FOOTPRINT

Since no carbon emissions (carbon dioxide equivalent CO_2e) take place at the turbines of a hydropower dam, some authors have argued that hydropower dams possess a significant advantage in reducing CO_2e compared to alternative thermal plants. This positive attribute serves as a global benefit, as it effectively mitigates the economic costs associated with carbon damage (Awojobi and Jenkins 2015). Nevertheless, carbon footprint of a large hydropower dam comes from its construction, concrete, steel and diesel powered machines used. Further, during its operation phase, the reservoirs behind the dams emit GHGs. Finally, its decommissioning phase also has carbon footprint. Abbas and Hussain (2021) estimated that GHG emissions from under construction Diamer Bhasha dam on Indus could be as high as burning coal for equivalent energy generation.

In order to assess the sustainability of a dam throughout its life cycle, additional analyses such as carbon footprint analysis and life cycle costing are conducted. These assessments play a crucial role in identifying the key sources of GHG emissions associated with the dam and evaluating its economic performance. Carbon footprint analysis helps quantify the amount of GHG emissions produced during the construction, operation, and decommissioning phases of the dam, shedding light on its environmental impact. On the other hand, life cycle costing focuses on evaluating the economic feasibility and performance of the dam by considering the costs and benefits associated with different stages of its life cycle. Together, these assessments provide valuable insights into the environmental and economic aspects of dams, contributing to informed decision-making and the pursuit of sustainable development goals (Mostafaei et al., 2023) In most cases, however, decommissioning of dams has not been included in LCA of dams and it has been externalised to future (IHA 2020).

Hydropower, often regarded as a clean energy source, has faced increasing scrutiny due to the emission of significant amounts of methane and other greenhouse gases (GHGs) during various stages of its lifecycle. The global average carbon footprint associated with hydropower generation is approximately 173 kg of CO_2 and 2.95 kg of CH_4 emitted per megawatt-hour (MWh) of electricity produced, resulting in a combined average of 273 kg CO_2e/MWh when considering the global warming potential over a 100-year time horizon. However, the emissions among the approximately 1,500 hydropower plants analysed in this study vary significantly, underscoring the need for case-by-case evaluations. The emissions are influenced by different stages of the hydropower lifecycle. During the construction process, GHG emissions range from 0.06 to 11 g CO_2e./kWh. Transportation of materials and equipment contributes to emissions, with previous studies estimating a range of 0.06 to 5.6 g CO_2e./kWh. Operation and maintenance emissions vary widely from 0.9 to 77 g CO_2e./kWh due to variations in LCA methodologies and reservoir GHG emissions. Reservoir emissions, quantified as net reservoir emissions, depend on the baseline GHG emissions before flooding, which can be positive or negative based on prior land use. The loss of baseline GHG absorption capacity alone can contribute 7-13% to a dam's life cycle GHG emissions. These findings highlight the complexity of assessing the environmental impact of hydropower and emphasise the need for comprehensive evaluations considering the specific characteristics of each project. (Song et al., 2018; Scherer and Pfister 2016)).

The regulation of greenhouse gas emissions following the creation of reservoirs involves various factors that influence their intensity and duration. These factors include: (1) the extent of flooding that occurs during reservoir formation, (2) the age of the reservoir, with decomposition rates generally decreasing over time, (3) the quantity of plant biomass and soil carbon that is submerged due to flooding, and (4) the geographic location of the reservoir. Understanding the interplay of these factors is crucial for assessing the environmental impact of reservoirs on greenhouse gas emissions and developing effective mitigation strategies (St.Louis et al., 2000).

The expanding surface areas of reservoirs have led to the release of GHGs into the atmosphere, warranting their inclusion in global inventories of anthropogenic GHG emissions. Reservoirs, previously overlooked in terms of emissions, have been identified as significant sources of GHGs. The increase in surface areas of these reservoirs, resulting from widespread dam construction, has intensified the release of GHGs into the atmosphere. As a consequence, it has become imperative to consider reservoirs as contributors to global GHG emissions. Their inclusion in inventories of anthropogenic emissions acknowledges the substantial impact of reservoirs on the overall GHG balance and highlights the need for comprehensive assessments of their environmental implications (St.Louis et al., 2000).

The creation of reservoirs as part of large-scale hydroelectric development leads to the release of greenhouse gases, primarily methane (CH_4) and carbon dioxide (CO_2), due to the decomposition of organic matter submerged under water and the subsequent depletion of oxygen. These emissions have significant spatial implications, as they can contribute to global climate change. The release of greenhouse gases associated with reservoir creation is considered to be one of the most widespread impacts of large-scale hydroelectric development, highlighting its potential environmental consequences on a global scale (Rosenberg et al., 1997).

The carbon footprint generated by construction materials and operations in the demolition and recycling phase has been evaluated, measured in kg/m^3. The analysis reveals that the carbon footprint of concrete per cubic meter was 646 kg/m^3 during the construction phase, 170 kg/m^3 during the retrofitting stage, and 334 kg/m^3 during the destruction and recycling of the non-retrofitted dam (Mostafaei et al., 2023).

An assessment of Ghana's existing dams, namely Akosombo, Kpong, Bui, and the forthcoming Pwalugu dam, reveals that their average emissions intensities (measured in gCO_2/kWh) are comparable to those of coal-fired power stations during the first three decades of their operational lifespan. This study raises a noteworthy issue, as the combined carbon dioxide emissions resulting from the planned and identified hydro resources are anticipated to utilise 40% of Ghana's carbon budget in line with the Paris Agreement. However, it is concerning that these hydro resources will only fulfil slightly less than 1% of Ghana's future energy demand according to Paris-compliant scenarios (Kuriakose et al., 2022).

Furthermore, the degradation and loss of terrestrial ecosystems have a direct impact on the carbon cycle, particularly through the loss of carbon sequestration capacity. This loss is primarily attributed to deforestation, which is identified as the second largest contributor to climate change according to the Intergovernmental Panel on Climate Change (IPCC, 2014). The significant role of deforestation in altering the carbon cycle underscores the urgent need to address and mitigate the consequences of ecosystem loss in order to combat climate change effectively (Briones-Hidrovo et al., 2020).

The construction and operation of numerous dams have resulted in irrevocable consequences, including the loss of valuable species and ecosystems, along with the substantial emission of greenhouse gases. These adverse effects highlight the urgent need for careful consideration and evaluation of the environmental impacts associated with dam projects, in order to mitigate their long-lasting ecological and climate repercussions (Goodland 2010).

The life-cycle GHG emissions of dams in China, have the relatively low GHG emissions associated within the context of reservoir hydropower (Li et al., 2017) due to higher latitude.

2.3.3. ECOLOGICAL INTEGRITY OF RIVER SYSTEM

The extensive development of natural resources has had a profound impact on river systems globally, leading to substantial alterations. Large dams, in particular, have resulted in fragmentation of approximately 60% of major river basins. The flow regulation by dams has a significant influence on flow parameters and ecological processes, particularly those reliant on the magnitude and timing of flow extremes. The flow regulation through dams need to consider its implications on ecological integrity of the river basin (Burke et al., 2009).

The alterations to a river downstream of a dam are primarily driven by physical factors, which can indirectly impact organisms. The ecological character and integrity of a river are influenced by its natural flow regime, encompassing factors such as discharge magnitude, timing and duration of peak flows, and the rate of flow changes. Dams disrupt the natural flow regime by regulating discharge through activities like water storage, withdrawals, and turbine operations. This disruption hampers the occurrence of natural phenomena such as floods or seasonal high flows, which play vital roles in shaping the structure of gravel bars and transporting large woody debris. These processes are crucial for habitat formation and are adapted to by many organisms. The repercussions on downstream organisms can have cascading effects on freshwater food webs. Furthermore, sediment transport may be altered or halted, leading to degradation and coarsening of riverine habitats downstream. This, in turn, impacts benthic organisms and the spawning ability of fish. It is evident that dams have significant implications for the downstream ecology of rivers (Duda and Bellmore 2022). But Environmental impact assessments (EIAs), which are mandatory prior to the construction of dams, frequently fail to adequately consider the effects downstream (Runde et al., 2020).

There is substantial evidence indicating that even minor hydro-morphological impacts can have profound implications for the functioning of ecosystems. The shape and flow of channels play crucial roles in maintaining the health of rivers, and recent research demonstrates that their deterioration jeopardises the services they provide. Rivers are vital for society as they offer essential services and support a significant portion of global biodiversity, yet they face significant threats. The biodiversity and functionality of river ecosystems rely on the preservation of aquatic habitats and the maintenance of natural flow patterns. Additionally, dams have other consequences that can significantly affect ecosystem functioning, such as altering water temperature, oxygen levels, nutrient concentrations, and the movement of organisms. These impacts can have important implications for the overall health and stability of river ecosystems (Elosegi and Sabater 2013).

Upstream impacts caused by dams include the flooding of habitats and the formation of new riparian zones and deltas within reservoir lakes. Dams also have an effect on geomorphological processes, such as the cycling of sediment. Reservoirs have the ability to trap significant amounts of sediment that would have otherwise been transported downstream. Furthermore, the altered hydrology downstream of dams leads to a decline in groundwater recharge in the riparian zone, resulting in a lowered groundwater table and a reduction in the active floodplain area. (Nilsson and Berggren 2000)

Dams situated near the headwaters of a river have a substantial impact on the entire river flow. This alteration in flow patterns can bring about modifications in the riparian zone and its associated communities and may even contribute to issues like salinisation and the invasion of non-native species. (Nilsson and Berggren 2000).

Dam reservoirs have the tendency to accumulate macronutrients along the course of a river, but their impact on the fluxes and chemical composition of these nutrients varies significantly depending on the specific element. As a result, dams can bring about substantial changes in nutrient limitation patterns and overall water quality within river-floodplain systems. Furthermore, the effects extend to the receiving water bodies, encompassing lakes and coastal marine area (Cappellen and Maavara 2016).

When water is released from a reservoir, it tends to carry a significant amount of sediment and nutrients, leading to increased erosion downstream of the dam. This erosion subsequently leads to the simplification of channels and reduced geomorphological activity within the riverbed. For instance, there is a decrease in the deposition of sediment on point-bars, a reduction in river meandering, and a slower accumulation of deltas, as well as an increase in coastline erosion (Nilsson and Berggren 2000).

2.3.4. BASIN-WIDE EROSION-DEPOSITION REGIMES

The sediment mass balance from source to delta encompasses various components that contribute to sediment flux and accumulation throughout the river system. Firstly, sediment flux from the upper watershed represents the input of sediment into the system. Secondly, the net change in a reservoir along the river, reflects the sediment dynamics within this specific impoundment. Moving downstream, sedimentation occurs in the middle reach, both in the main-stem channel and floodplain channels. This sedimentation contributes to changes in the sediment balance and channel morphology. Sediment discharge is measured both in terms of suspended sediment and bed load sediment. Further downstream, sedimentation occurs in the lower reach, affecting both the main-stem channel and floodplain channels. This sedimentation process shapes the channel and floodplain characteristics. The sedimentation pattern continues in the estuary and coastal areas, where sediment deposition and redistribution occur, influencing coastal morphology. Understanding the sediment mass balance and the various stages of sedimentation from the source to the delta is crucial for comprehending the overall sediment dynamics in river systems (Warrick et al., 2015).

Petts and Gurnell (2022) compiled review of works since 1951 to 2015 which had studied channel erosion in the river beds after the construction of dams upstream. Clearwater erosion has been observed shortly after the closure of dams, initially occurring in the section immediately below the dam and then migrating downstream at remarkable rates, as exemplified by Malhotra (1951) with erosion front advancing up to 30 km per year. However, the degree of channel degradation diminishes as one moves downstream, with Wolman (1967) suggesting that the maximum degradation happens between the tailwater and a point approximately 69 channel widths downstream. Building upon this, Williams and Wolman (1984) demonstrated that in channels predominantly composed of sand beds, channel degradation can be explained through simple hyperbolic relationships. Typical manifestations of channel degradation involve narrowing, reduced width-depth ratio, decreased slope, and increased sinuosity, as evidenced by Xu (1990, 1997). Considering the importance of sediment regime in river ecosystems, it becomes crucial to address the sediment loads delivered downstream of dams, although this poses significant challenges (Wohl et al., 2015). Consequently, efforts have been made to develop sustainable sediment management systems in response to reservoir sedimentation (Coker et al., 2009; Kondolf et al., 2014a). However, it is important to note that while the primary motivation has been to mitigate reservoir sedimentation, the downstream channels have experienced substantial sediment deposition, leading to a significant reduction in bankfull cross-sectional area (Ma et al., 2012).

The issue of reservoir sedimentation poses significant challenges to the sustainable management of water resources and the long-term benefits provided by dams. The accumulation of sediment in reservoirs not only diminishes their storage capacity but also leads to costly decommissioning processes and creates intergenerational inequity. To address this problem, a new paradigm for sustainable reservoir management is necessary. Key to this approach is the implementation of monitoring systems that can accurately measure the extent and rate of sedimentation. Additionally, adopting sustainable management strategies becomes crucial, including measures such as sediment yield reduction, bypassing sediment around reservoirs, or removing sediment from reservoirs altogether. These strategies aim to mitigate the impacts of sedimentation and ensure the long-term sustainability of reservoirs for the benefit of present and future generations (Randle et al., 2021a).

When sediment enters a reservoir, it forms a delta that grows through avulsion and depositional lobe propagation. In some cases, the deposition can extend upstream beyond the reservoir limit, until a primary sediment source or a geological barrier is encountered. For example, the Mekong

River is projected to experience a cumulative sediment reduction of 51% due to the construction of 38 dams, with an estimated 96% reduction if all planned dams are built. This substantial decrease in sediment load, combined with subsidence and rising sea levels, could lead to the submergence of nearly 50% of the Mekong delta's land surface by 2100 (Petts and Gurnell 2022).

Sediment starvation caused by dams has been observed to impact the form and dynamics of channels. The effects extend to ecosystem functioning, as evidenced by research on USA Coastal Plain rivers that examined the impacts of large dams, channelisation, and levee construction. The study reported significant alterations in sediment and nutrient retention, albeit with site-specific variations influenced by factors such as river gradient and sediment size. Floodplains exhibit patchy distribution of sediment sizes, which can have significant implications for the composition and productivity of forests. Consequently, changes in floodplain inundation patterns have substantial consequences for the growth and development of riparian forests (Elosegi and Sabater 2013).

> The World Commission on Dams, in their influential report, aptly stated that the pursuit of dam-related benefits has frequently resulted in an excessive and avoidable cost. This cost manifests in adverse social and environmental consequences borne by displaced individuals, downstream communities, taxpayers, and the natural environment. The profound observation made by the Commission highlights the significant trade-offs and negative impacts associated with dam projects, underscoring the need for careful consideration of these factors in decision-making processes.
>
> [WCD 2000]

The construction of a dam on the Bouregreg River in Morocco, near the city of Rabat, has had a significant impact on the sediment dynamics in the river and its estuary. The dam has resulted in a drastic reduction in sediment loads reaching the estuary, with a notable decrease in the amount of coarse sediment, particularly sand, being transported to the sea (Aoula et al., 2021).

Globally, the transportation of sediment from continental land masses to the oceans is estimated to be around 10-20 Gt per yr. However, the construction of dams has led to a reduction in the land-ocean sediment flux, estimated to be between 2 and 5 Gt per yr. These estimates, though, contrast with much higher estimates of the total sediment sequestered behind dams, ranging from 25 to 60 Gt per yr. The scale of reservoir sediment trapping is that prior to significant human disturbance, approximately 14 to 18 Gt per yr of sediment reached the oceans. However, due to sediment trapping in reservoirs, the net effect has been a reduction in sediment loads of rivers by an estimated 1.3 Gt per yr. While there may be some variation in these estimates, the overall trend of sediment reduction caused by dam construction is consistent (Petts and Gurnell 2022).

The issue of reservoir sedimentation poses significant challenges to the sustainable management of water resources and the long-term benefits provided by dams. The accumulation of sediment in reservoirs not only diminishes their storage capacity but also leads to costly decommissioning processes and creates intergenerational inequity. To address this problem, a new paradigm for sustainable reservoir management is necessary. Key to this approach is the implementation of monitoring systems that can accurately measure the extent and rate of sedimentation. Additionally, adopting sustainable management strategies becomes crucial, including measures such as sediment yield reduction, bypassing sediment around reservoirs, or removing sediment from reservoirs altogether. These strategies aim to mitigate the impacts of sedimentation and ensure the long-term sustainability of reservoirs for the benefit of present and future generations (Sanyal et al., 2021).

Sediment trapping also has significant implications for the biogeochemistry of river systems. A large portion of key elements such as phosphorus, manganese, iron, and aluminum are associated with sediment, accounting for 90% of their river-borne flux. Additionally, 43% of the total organic carbon flux from land to oceans is in particulate form. These findings highlight the importance of considering the biogeochemical effects of sediment trapping in river ecosystems (Petts and Gurnell 2022).

2.3.5. RHYTHMS OF FLOW

The natural flow regime of a river, characterised by the varying quantity, timing, and variability of its flow, plays a crucial role in shaping and organising river ecosystems. The movement of water and sediment within the channel and floodplain influences the physical structure of the environment and defines the habitat for various species. Understanding the biodiversity, productivity, and long-term sustainability of river ecosystems requires recognising the central role played by the dynamically changing physical environment influenced by the natural flow regime. Rivers can provide a diverse range of habitat types, including ephemeral, seasonal, and persistent habitats, which support a variety of species adapted to the habitat mosaic created by hydrologic variability. However, human modifications to the flow regime disrupt this natural pattern of hydrologic variation and disturbance, leading to alterations in habitat dynamics and potentially creating unfavourable conditions for native species that may not be well-suited to the new conditions (Poff et al., 1997).

Dynesius and Nilsson (1994) estimated that water discharge of more than 75% of largest rivers in US, Canada, Europe and Russia have been strongly modified due to fragmentation because of dams and other water regulating structures and practices.

Graf (2006) emphasised that rivers characterised by high annual flow variability are particularly susceptible to significant impacts. The Platte River serves as an example, initially exhibiting a snowmelt-dominated flow regime with a distinct dry season, characterised by wide channels and a braided channel pattern. However, the construction of dams from 1885 onwards led to a reduction in annual peak flows from 400 to 90-95 m3 per second. By 1969, it was observed that channel degradation was an immediate consequence of dam construction, eventually resulting in a complete transformation of channel morphology due to river impoundment. The widths of the river branches decreased to approximately 62 m, and the channel shifted to a single-thread, sinuous, and anastomosing pattern. These alterations occurred due to reductions in mean annual and peak discharges, sediment transport, and the emergence of perennial flow. From an ecological perspective, the loss of wide, un-vegetated sand bars resulted in reduced habitat for endangered bird species. As larger flows were eliminated, vegetation colonised the abandoned parts of the old stream bed, leading to sediment trapping and aggradation, thus forming new floodplains. The old floodplain became inactive, rarely or never experiencing flooding. Consequently, human activities, such as water abstraction and dam construction, have extensively modified the natural flow regimes of rivers, jeopardising their ecological integrity (Poff et al., 1997; Nilsson et al., 2005). Dams and reservoirs, with their associated fragmentation and flow regulation, have been the primary contributors to the loss of river connectivity, affecting 59% of the world's largest river systems (Nilsson et al., 2005). In the Amazon basin alone, the presence of existing, under-construction, and proposed dams has resulted in severe losses of longitudinal connectivity for species and sediments, as well as a drastic reduction in sediment delivery to the Amazon main stem. Dams and reservoirs and their consequent fragmentation and flow regulation are the leading contributors to the lost river connectivity, particularly noticeable in planet’s largest rivers (Petts and Gurnell 2022).

In the Amazon basin alone, there are 142 existing or under construction dams, with 160 more already proposed for on the tributaries of Amazon in its headwaters. This is causing significant losses of connectivity for species and sediments, and serious reductions in sediment delivery to the Amazon’s main course (Anderson et al. 2018)

Human activities, such as the direct removal of water from rivers and groundwater bodies, and impoundment through construction of dams or weirs, have significantly modified the natural flow regimes of many rivers (Poff et al., 1997; Nilsson et al., 2005). Assuming that flow regime is of central importance in sustaining the ecological integrity of freshwater systems, the modification of the flow regime shall lead to environmental degradation (EC 2005). Natural rhythm of Indus has been disrupted by large dams, which not only case environmental problems, but also have become a source of feuds on water. Disrupted rhythm is out of sync with agronomy and and hence feuds between federating units erupt each time in early summers when dam managers want to fill their storages while the crucial summer for summer sowing are not available to the farmers (Abbas and Hussain 2021a)

2.3.6. Environmental Flows

The European Commission has provided guidance outlining the requirements for hydropower projects in compliance with EU Nature legislation, including the consideration of environmental flows. These environmental flows refer to the amount of water necessary to sustain aquatic ecosystems and ensure the provision of essential services upon which we depend (European Commission, 2015). Similarly, the International Finance Corporation (IFC) of the World Bank Group has issued its own guidance on environmental flows, aligning with their sustainability policies and standards for hydropower projects (IFC, 2018). Moreover, high-resolution holistic approaches are recommended for hydropower projects that have the potential to impact critical habitats, rare or endangered species, species assemblages, or lead to significant degradation or conversion of natural habitats. Additionally, the guidance extends to projects affecting aquatic ecosystems beyond rivers, such as estuaries or floodplains, as well as projects that hold significant social implications for communities reliant on the affected riverine ecosystem. These guidelines and considerations highlight important aspects within the realm of hydropower development and its interaction with the environment and society (EC 2015).

The recognition and importance of environmental flow releases from hydropower facilities have gained significant attention, with growing awareness and the development of guidelines. This is exemplified by the International Hydropower Association (IHA), which includes environmental flows as a key aspect within its Hydropower Sustainability Assessment Protocol. These developments highlight the increasing significance placed on understanding and managing environmental flow considerations in the context of hydropower projects (IHA 2020).

Hydropower facilities play a crucial role in electricity generation but can significantly impact the natural flow regime of rivers by returning water at different magnitudes and timings. Single-purpose facilities prioritise water release based on electricity demand rather than the water requirements of downstream ecosystems and other users. Similarly, multi-purpose dams may follow schedules influenced by flood protection, reservoir recreation, or downstream water rights, often unrelated to ecosystem or in-stream water needs. The alteration of flow regimes, which riverine ecosystems are adapted to, can cause stress on biota, disrupt geomorphic processes, and result in long-term changes to ecosystem conditions. Moreover, the temperature, dissolved oxygen, and sediment concentrations of water released from hydropower facilities can significantly deviate from natural levels, further impacting downstream ecosystems. Consequently, degraded downstream ecosystems provide fewer ecosystem services, limiting the benefits received by riverside communities and other users (Anderson et al., 2019). These findings underscore the importance of considering the ecological impacts of altered flow regimes and water quality in the literature review chapter of this report.(Ulibarri et al., 2022).

Various methodologies have been developed within the scientific field to estimate environmental flows, categorised broadly into three groups: (1) Hydrological, (2) Hydraulic-Habitat, and (3) Holistic methodologies (EC 2015).

Utilisation of biological indicators and monitoring programs, a comprehensive understanding of the long-term evolution of natural flow regimes, the proper definition and efficient implementation of ecological flows, sufficient hydrological information, robust data collection and databases, and integrated monitoring of hydrological, morphological, and biological quality elements, etc are need to be put in place for better management of environmental flows (EC 2015).

2.3.7. Water-logging and Salinity

The agricultural and irrigation sector in Pakistan is currently grappling with significant challenges, notably water-logging and soil salinity, which have adversely impacted extensive areas. However, attempts to address these issues have, in some cases, exacerbated the problems. One of the key contributing factors is the substantial diversion of river flows, resulting in a drastic reduction in water availability. As the lowest riparian state, Pakistan has borne the brunt of these adverse effects, particularly concerning agriculture and fisheries in the mangrove areas (International Rivers 2008).

2.3.8. WETLANDS

Aquatic ecosystems, encompassing various habitats such as rivers, lakes, wetlands and bogs, serve as critical biodiversity hotspots and play a pivotal role in safeguarding global biodiversity. Unfortunately, these invaluable ecosystems have suffered extensive damage due to the construction of dams worldwide. Numerous studies have investigated the impacts of dam construction on a range of organisms, including botany, plankton, benthos, microorganisms, fish, aquatic mammals, and birds. Specifically focusing on fish and aquatic mammals, the research has revealed several detrimental effects caused by dams, such as blocking migration routes, fragmenting habitats, altering water conditions from lotic to lentic in impounded areas, releasing cold hypolimnetic water from reservoirs, and modifying water flow in downstream reaches. These findings underscore the far-reaching consequences of dams on fish and aquatic mammals, shedding light on the urgent need for comprehensive measures to mitigate the adverse effects of dam construction on aquatic biodiversity (Wu et al., 2019).

2.3.9. RIVER DELTA

Geologically speaking, every eroding environment has a complementary depositional environment. The mountains in the upper Indus Basin are eroding. Indus plains are the dynamic depositional environment, while Indus Delta is the ultimate depositional environment. This erosion and deposition process is going on since the continental collision 50 million years ago (Searle 2013). In the current era, the Indus Delta has been the depositional regime of the basin, which, until the 1830s, was adding land in place of the sea. Indus is the fifth most silt carrying river in the world. Estimated between 250 and 490 million tons a year, the silt supply in the river had been so consistent over millions of years that species like blind dolphin evolved to navigate its murky waters!(Abbas 2021). However, form the natural annual flow of 220 MAF, now less than 10 MAF makes it to the seas. Silt supply to the delta has been reduced correspondingly, and the once advancing delta is now being reclaimed by the sea. Communities living in the Indus Delta are getting more vulnerable to tropical storms, sea surges and coastal flooding.

Dams have the major impacts on delta systems and the existing gaps and requirements for enhancing the resilience of social-ecological systems within deltas is required (McGowan et al., 2023).

Certain deltaic communities, such as those along the Mississippi, Rhine, Mekong, and Nile rivers, have already implemented engineering solutions to combat the significant risk of flooding. These measures include the construction of levees, dams, and land-building through diversions. However, these engineering interventions are costly and can prove inadequate when confronted with floods that surpass their design limitations. An alternative approach to mitigating coastal flooding is to adopt nature-based solutions that encourage the growth of deltas and the subsequent filling of flood-prone areas with sediment. This process mirrors the natural behaviour of deltas, where regions intersected by channels experience recurrent flooding and receive an increased sediment supply. Through this mechanism, deltas can regulate flooding to some extent by raising the land surface to match the elevation of a 100-year storm surge, provided that sediment is efficiently transported to the necessary locations within a reasonably short timeframe (Edmonds et al., 2020).

Sediment-starved deltas are taken as those deltas which are unable to accumulate enough sediment to reach the elevation necessary to withstand a 100-year storm surge event. These deltas typically encompass expansive floodplain areas exceeding 100 square kilometres, making it difficult for natural sedimentation processes to effectively raise the elevation of these flood-prone zones The survival of deltas is contingent upon an adequate supply of sediment to maintain their land mass above sea level, which is crucial for safeguarding against future storm surges. However, the presence of dams poses a significant threat to this sediment supply. Dams not only directly trap river sediments in reservoirs but also harness the power of water, resulting in reduced peak flows and impeding the ability of rivers to transport sediments. Given that low-lying deltas are susceptible to rising sea levels, it is increasingly evident that the balance between sediment supply, loss, and redistribution will play a pivotal role in determining where and how people can inhabit these regions in the coming century. (McGowan et al., 2023).

Approximately 41% of the global population exposed to tropical cyclone flooding, totalling around 31 million people, reside in delta regions. Among these individuals, 92% belong to developing or least developed economies. Additionally, a staggering 80% of these inhabitants, equivalent to 25 million people, live in sediment-starved deltas where natural flood mitigation through sediment deposition is limited (Edmonds et al., 2020). A critical challenge lies in rapidly developing modelling advancements to keep pace with the escalating rate of impoundment, as this poses an existential threat to the integrity of numerous iconic and vital river systems in South and Southeast Asia (McGowan et al., 2023).

Sediment-starved deltas pose significant challenges as they are home to approximately 25 million people who lack the natural protection against flooding provided by sediment deposition. The issue becomes more pronounced considering that many of these deltas are located at the mouths of major rivers, which are often regulated by dams causing a depletion of sediment supply.(Edmonds et al., 2020).

2.3.10. BIODIVERSITY LOSS

The construction of dams has had detrimental effects on both biological productivity and biodiversity, leading to the loss of natural resources and services provided by downstream rivers, floodplains, estuaries, and neighbouring coastal ecosystems. While the hydrological changes caused by dams, such as water quality impacts and the hindrance of species migrations, directly impact regulated rivers, it is important to recognise that the alterations in the geomorphological dynamics along the river corridors below dams and diversions are also significant drivers of these ecological impacts. These substantial geomorphic changes often result in a complete transformation of the river's geomorphic style and are frequently accompanied by shifts in the extent, stability, and species composition of riparian vegetation, which may include invasions by non-native species (Petts and Gurnell 2022)

Additionally, dams disrupt the connectivity between different stretches of a river, hindering the ability of organisms to migrate upstream or downstream in search of optimal sediment conditions, suitable water levels for spawning, and areas abundant in food resources or lower predation risk. This impact on connectivity has been highlighted in studies conducted by Poff et al. (1997). The alteration of temperatures resulting from various factors, including dam construction and flow regulation, can disrupt the emergence and growth cues for animals inhabiting downstream river reaches (Petts 1984). Dams and impoundments have become prevalent features in freshwater ecosystems, resulting in significant alterations to river habitats on a global scale. Concrete structures, extensively used in the construction of these water management systems, have been identified as a primary factor contributing to the habitat modifications observed in rivers (Van Looy et al., 2013)

The construction of dams has far-reaching effects on riverine ecosystems, impacting various aspects such as streamflow dynamics, hydraulics (depth, velocity), temperature, and the transport of nutrients and sediments. These changes have significant implications for the biodiversity and productivity of fish populations in the Mekong River basin, renowned for its abundant migratory species that undertake long-distance journeys to spawn. The Tonle Sap Lake fishery in Cambodia, which exhibits one of the highest freshwater fish catch rates per capita globally, relies on the ecological integrity of the Mekong River. However, the physical alterations caused by dam construction, combined with factors like changes in sediment and nutrient transport and overfishing pressure, have compromised fish biodiversity and production in the Mekong floodplains. The negative impacts extend even to run-of-river dams, with examples like the Pak Mun Dam in Thailand disrupting fisheries. Over time, there has been a significant decline in river connectivity, with figures dropping from 93% to 77% between 1990 and 2010 and potentially reaching as low as 10%. Moreover, diversions for off-stream power generation, exemplified by the Neelum Jhelum Hydropower Project (NJHP), can result in substantial reductions in downstream flows while augmenting flows in adjacent basins. The comprehensive understanding of these implications, as presented in the literature review chapter, is crucial for evaluating the ecological consequences of dam construction and informing sustainable management strategies in the Mekong River basin (Hecht et al., 2019).

2.4. ECONOMIC ASPECTS

Advocates of large dams anticipate numerous advantages associated with their construction. These include a significant increase in hydropower capacity, as well as a wide range of additional benefits such as the reduction of reliance on fossil fuels, flood control, irrigation, urban water supply, inland water transport, technological advancements, and job creation (Ansar et al., 2014). These perceived benefits have been highlighted by experts in the field, including the International Commission on Large Dams (ICOLD, 2010).

In line with the trend observed in developing nations, Pakistan's demand for electricity is substantial due to its status as an emerging economy. There is a positive correlation between the country's GDP and the sale of electricity, indicating that an increase in GDP leads to a higher demand for electricity. In the fiscal year 2021-22, the country experienced a 5.97% growth rate in total GDP, with growth rates of 4.4%, 7.2%, and 6.2% observed in the agriculture, industrial, and commercial/services sectors, respectively (source: Economic Survey of Pakistan). Concurrently, there was a 7.07% growth rate in electricity generation during the same period. This data further emphasises the strong association between GDP and electricity usage, as both indicators exhibited significant growth (IGCEP 2022).

2.4.1. COST-BENEFIT OVER LIFECYCLE

Supporters of hydropower often highlight its numerous advantages compared to other sources of electricity. These include its exceptional durability and reliability, making it a reliable option for long-term operation. Hydropower also boasts higher efficiencies and greater flexibility, allowing for efficient energy generation and utilisation. Additionally, the low costs associated with operation and maintenance make it an economically favourable choice. Furthermore, the reservoirs used in hydropower systems enable the storage of vast amounts of energy, ensuring a steady and reliable power supply (IHA 2019).

Apart from providing electricity, hydroelectric projects offer additional advantages that complement their power generation capabilities. These benefits include irrigation, flood control, improvement of navigation routes, freshwater supply, and the creation of employment opportunities, among others. These diverse advantages contribute to the multifaceted value and significance of hydroelectric projects (Kirchherr and Charles 2016).

A 1996 study by The World Bank (WB 1996) examined 50 large dams and concluded, that despite some issues, 74 percent of these facilities were a net gain. This study, however, received sharp critique (McCully 1997).

Awojobi and Jenkins (2015) re-examination cost related associated with a portfolio of 58 hydroelectric dams financed by the World Bank between 1976 and 2005. The study highlights the World Bank's attentiveness to environmental impacts and compensation estimation for affected communities, which often led to the inclusion of compensation payments within the reported capital costs of these projects. Consequently, the economic analysis conducted does not require further adjustments for social-environmental costs. The evaluation includes measurements of cost overruns, time overruns, and the cost of time overruns. The present value of benefits is found to be 1.8 times greater than the present value of costs for this portfolio. The study reveals that real cost overruns accounted for 27% of the ex-ante costs, while the cost of time overruns constituted 3.5%. In evaluating the risks associated with cost overruns, it is essential to consider the projected benefits of these dams. Ultimately, the ex-post real economic rate of return for the entire portfolio is estimated to exceed 17 percent.

But due to the controversial nature of large dams, not everyone agrees that large dams are as good economically as some proponents suggest. Ansar et al., (2014.) highlight the significant financial costs associated with their construction, as emphasised by the World Bank (1996) and the

World Commission on Dams (2000). Moreover, large dams have far-reaching impacts on the environment (McCully, 2001; Scudder, 2005), ecology (Nilsson et al., 2005) and society. The analysis reveals that even without considering the negative effects on human society and the environment, the actual construction costs of large dams outweigh the potential benefits, making them an inefficient solution for addressing urgent energy crises. Furthermore, the extended timeframes required for their implementation render the benefits of large dams ineffective in meeting the immediate needs of users. This temporal mismatch between when specific benefits are needed and when they become available cannot be underestimated.

Experts estimate the net present benefits-to-cost ratio of the Diamer-Basha dam to be 1.43 (WAPDA, 2011). However, even assuming the accuracy of these calculations regarding potential benefits, which is doubtful, unbiased cost forecasts indicate that the benefits-to-cost ratio would fall below one, requiring an uplift of 44-99% in constant prices. Consequently, the Diamer-Bhasha dam project in Pakistan appears to be unfeasible, without considering potential effects of inflation, interest rates, social and environmental costs, and the opportunity cost of investing such a significant capital in more prudent alternatives (Ansar et al., 2014).

de Faria et al., (2017) studied the economic impacts of 56 Brazilian hydropower plants constructed between 1991 and 2010. The analysis reveals that the counties where these hydropower plants were built experienced initial economic benefits in terms of higher GDP and tax revenues compared to a control group consisting of counties where hydropower projects were planned but not yet constructed. However, these positive effects were short-lived, lasting less than 15 years. Consequently, there is a need to question the justifications for hydropower projects based on local long-term economic and social development. The findings emphasise the necessity for more effective mechanisms to transform short-term economic growth into sustainable long-term development at the local level.

Fang et al., (2015) carried out a case study focusing on the Upper Mekong River, specifically examining the impacts of the Manwan hydropower station. The study utilises the emergy approach to assess the ecological changes caused by damming the river. The findings indicate that the dammed river ecosystem continues to provide some supporting services to human society. However, these services are not as sufficient as they were prior to the perturbation caused by the hydropower station.

A study by Flyvbjerg (2009) focuses on the disparities between ex ante estimates and actual ex post costs and benefits of large infrastructure projects. The consequences of these disparities include cost overruns, benefit shortfalls, and the systematic underestimation of risks. The limitations and concerns surrounding cost-benefit analysis for major infrastructure projects are highlighted, emphasising that such analyses cannot be fully trusted. Perverse incentives are discussed, as project promoters are incentivised to underestimate costs and overestimate benefits in the business cases presented for their projects. The subsequent sections of the literature review will explore these issues in further detail, shedding light on the challenges and implications associated with accurate cost estimation and risk assessment in large infrastructure projects.

The river scientists argue that the substantial costs associated with building such dams, along with the loss of ecosystem services and disruptions to river processes, outweigh the benefits. Moreover, they emphasise that managing the dam, reservoir, and river system in the long term presents significant challenges. Additionally, the scientists highlight that these problems are expected to worsen under future climate conditions characterised by more frequent heavy rainfall and flood events, as identified by the Intergovernmental Panel on Climate Change in their 2012 report. There are other complex trade-offs associated with large dam projects and their implications for river ecosystems (Sanyal et al., 2021).

2.4.2. COST OF FINANCING

Following numbers are taken from the Financial Report published by WAPDA (2021).

The obtained loan for the Tarbela 4th Extension Hydropower Project, amounting to USD 440 million, was secured by the Government of Pakistan (GoP) through a Subsidiary Loan Agreement dated April 12, 2012. The GoP has then transferred the loan to WAPDA Hydroelectric. The loan includes an interest rate of 8.2% (2020: 8.2%) per annum and an additional 6.8% (2020: 6.8%) per annum for "Exchange Risk Cover," charged separately on both the principal and interest amounts. Repayment of the loan will occur over a period of 25 years, including a grace period of 5 years. The repayment commenced in 2017, and the loan is set to mature in 2037.

Similarly, for the Tarbela 4th Extension project, the International Bank for Reconstruction and Development (IBRD) loan amounting to USD 400 million was obtained through a Subsidiary Loan Agreement dated April 12, 2012. The GoP has also relayed this loan to WAPDA Hydroelectric. The interest rate for this loan is 8.2% (2020: 8.2%) per annum, with an additional 6.8% (2020: 6.8%) per annum for "Exchange Risk Cover" applied separately to the principal and interest amounts. The repayment period is 19 years, including a grace period of 7 years. Repayment began in 2020, and the loan will mature in 2031.

For the Dassu Hydro Power project, the Government of Pakistan obtained a loan of USD 588.4 million from the International Development Association (IDA) through a subsidiary loan agreement dated October 13, 2014. This loan has been passed on to WAPDA Hydroelectric. The interest rate consists of 8.2% (2020: 8.2%) per annum plus 6.8% (2020: 6.8%) per annum for "Exchange Risk Cover," charged on the principal amount. As part of the project, WAPDA Hydroelectric disbursed USD 15 million to the National Transmission and Despatch Company (NTDC) for feasibility study and detailed design of transmission lines. As of the reporting date, WAPDA Hydroelectric has disbursed USD 4.484 million (2020: USD 4.045 million) to NTDC. The loan repayment duration is 25 years, including a grace period of 5 years.

Lastly, the Mohmand Dam project secured a loan of E 11 million from Agence Francalse de Developpement (AFD) through a Subsidiary Loan Agreement dated September 30, 2014. The loan was obtained by the Government of Pakistan to finance the first tranche of the project, including detailed design studies, preparatory works, and additional consultancy services needed for the Mohmand Dam Project. The GoP has transferred this loan to WAPDA Hydroelectric. The interest rate for the loan is 8.2% (2020: 8.2%) per annum, with an additional 6.8% (2020: 6.8%) per annum for "Exchange Risk Cover" charged separately on both the principal and interest amounts. The loan repayment period is 15 years, including a grace period of 5 years.

It is important to note that interest rates for these loans typically range from 12% to 15% (WAPDA 2021).

2.4.3. COST OVERRUNS

Energy mega projects inherently involve uncontrollable risks that cannot be predicted and effectively mitigated. Despite the potential financial savings resulting from economies of scale, large projects are exposed to a disproportionate level of risk. Consequently, these projects frequently experience cost overruns and delays (Callegari et al., 2018).

The accuracy of cost estimates used in the decision-making process for significant infrastructure projects is consistently and significantly misleading. This misleading nature leads to a continuous escalation of costs, resulting in billions of dollars being spent beyond initial projections. Various explanations for the underestimation of costs have been explored, including technical, economic, psychological, and political factors. However, it has been determined that underestimation cannot be attributed to mere error, but rather, it is best explained as strategic misrepresentation or intentional deception. Consequently, the cost estimates and cost-benefit analyses provided by project promoters and their analysts cannot be considered reliable or trustworthy. This raises serious concerns about the validity and accuracy of the information used to evaluate the feasibility and economic viability of infrastructure projects (Flyvbjerg et al., 2002).

Extensive evidence demonstrates a consistent bias in budgeting for large hydropower dams, as they tend to underestimate the actual costs while excluding inflation, debt servicing, and environmental and social expenses. Cost overruns not only diminish the appeal of an investment but also raise concerns about the project's economic viability. Bacon and Besant-Jones (1998, p. 317) provide a perceptive summary, highlighting that cost overruns can undermine the economic justification for the project and impact electricity pricing policies by leading to underpricing. Additionally, the financial repercussions include strain on the power utility, constraints on national financing capacity involving foreign borrowings and domestic credit (Ansar et al., 2014)

Remarkably, three-quarters of large dams experienced cost overruns when considering constant local currency values. The actual costs exceeded the estimated costs by an average of 96%, with more than double the estimates for 20% of the dams and more than triple for 10% of the dams. Furthermore, the projected benefit-to-cost ratio for these dams was typically 1.4, indicating that planners anticipated net present benefits to surpass net present costs by approximately 40%. However, there appears to be limited learning from past mistakes, suggesting that current cost forecasts for large dams are likely to be as inaccurate as those observed between 1934 and 2007 (Ansar et al., 2014).

Achieving a reduction in technical challenges arising from geological and environmental uncertainties related to dam construction necessitates a trade-off between increased initial investments to acquire more precise information and potential cost overruns encountered during the construction phase. Although eliminating the artificial bias resulting from political interests or strategic deception may not completely eliminate inaccuracies in projected dam costs, it remains an important aspect to address. Furthermore, this study offers evidence suggesting that the World Bank's efforts and extensive research on the matter have not significantly improved their ability to forecast the escalation of actual costs over time (Awojobi and Jenkins 2015).

The findings from the Brazilian context indicate that the construction costs of hydroelectric power plants exceeded the initial estimates by an average of 97.53%. The analysis suggests that the gamma distribution provides the best fit for modelling the distribution of cost overruns in these projects. In terms of delays, the construction completion time experienced an average increase of 74.28%, equivalent to a delay of approximately 3.5 years. These results highlight the significant challenges and uncertainties associated with accurately predicting and managing the costs and timelines of hydroelectric projects in Brazil (Calegari et al., 2018).

The examination of 98 dams constructed across Australia since 1888 aligns with international findings that highlight a systematic bias towards underestimating the costs of large infrastructure projects. In this Australian study, the median and mean cost overruns of 40 dams, presented as a percentage of the initial estimated costs prior to construction, are found to be 49% and 120%, respectively. The range of cost overruns varies from -48% (underrun) to 825%, illustrating the significant discrepancies between estimated and actual costs. This observation of cost overruns echoes a broader criticism of large dams and similar infrastructure projects, as evidenced by prior research (e.g., Flyvbjerg et al., 2002; Ansar et al., 2014). These findings emphasize the need for a more comprehensive and accurate evaluation of costs associated with such projects, to ensure transparency and informed decision-making (Petheram and. McMahon 2019).

Another reason for cost overrun is that the cost are underestimated to get the project approved.

Ansar et al., (2014) reviewed various works between 1974 and 2011 and concluded that the decision-making under conditions of uncertainty, two prominent explanations emerge: psychological delusion and political deception. These explanations suggest that decision-makers' forecasts and initial judgments are often affected by adverse biases. One common manifestation of this bias is observed in both experts (e.g., statisticians, engineers, economists) and laypersons, who consistently demonstrate a tendency towards excessive optimism when estimating timeframes, costs, and benefits associated with a decision. This phenomenon of optimism represents a predictable inclination towards unrealistic expectations.

2.4.4. TIME OVERRUNS

The construction of large dams has consistently experienced schedule overruns, with eight out of every 10 projects exceeding their planned timelines. On average, these dams take around 8.6 years to complete, but the actual implementation schedule exceeds the initial estimate by approximately 44%, equivalent to 2.3 years. These findings indicate that there has been no noticeable improvement in the accuracy of schedule estimates for large dams over time. The persistent challenges in meeting construction timelines highlight the complexities and uncertainties involved in such projects (Ansar et al., 2014).

2.4.5. DECOMMISSIONING

Decommissioning of dams is a costly affair. Every dam, big or small, has a useful life beyond which either it cannot perform effectively, due to silting for example, or its utility out lives. At some point in time it has to be decommissioned. In USA and EU, decommissioning and demolishing of dams is a common practice. Decommissioning is part of the lifecycle of a dam. Even some functioning dams have been decommissioned because of greater environmental, social and economic benefits.

Life Cycle Assessment (LCA) is a widely adopted and standardised methodology used to evaluate the environmental and resource-related impacts associated with a product or service throughout its entire life cycle, from raw material extraction to final disposal, commonly referred to as "cradle to grave." During the goal-and-scope phase of LCA, the system boundaries, functional unit, assessment methods, assumptions, and limitations are defined. The establishment of system boundaries is crucial for determining the extent of the analysis, including the processes included or excluded, and the assumptions made based on data availability (Briones-Hidrovo et al., 2020)

The life cycle inventory (LCI) entails collecting and analysing data on the input and output flow of materials and energy within the defined system boundaries. For energy systems, the LCI typically encompasses infrastructure construction, energy technology manufacturing (e.g., turbines, panels, boilers, civil works), and system operation. However, it is important to note that LCA has inherent limitations, and external analyses or assessments may be necessary to obtain accurate results. In the case of hydropower LCA studies, the assessment often fails to account for other sources of greenhouse gas (GHG) emissions, particularly from tropical hydropower reservoirs known for emitting biogenic carbon dioxide and methane. These gases are released not only at the reservoir but also when water passes through turbines or enters the spillway. Moreover, downstream carbon emissions from hydropower reservoirs have been identified. Therefore, it is crucial to incorporate these additional sources of GHG emissions in the LCA analysis to ensure comprehensive and accurate results (Briones-Hidrovo et al., 2020).

As part of LCA, dam decommissioning involves the removal of hydroelectric generation facilities, and in many cases, the entire dam structure. This process is pursued when a dam presents safety hazards, no longer fulfils its intended purpose, or fails to align with current social, environmental, and economic values. In such situations, removing the dam can prove more cost-effective than repairing, maintaining, or upgrading the facility to meet modern requirements. Decommissioning rates have been on the rise, particularly in Europe and North America, where the highest number of dam removals have taken place. In the United States alone, an estimated 1700 dams have been removed, while Europe has witnessed approximately 5000 to 6000 removals (Ulibarri et al., 2022)

Mostafaei et al., (2023) investigated the life cycle of a dam, from its construction to destruction, disposal, recycling and the environmental implications.

The removal of dams is a crucial approach for restoring rivers and addressing ageing infrastructure. This ongoing activity is necessary due to a significant number of ageing dams that no longer serve their original purposes, pose safety risks, or offer potential for substantial restoration efforts. The growing trend of dam removal has deepened our understanding of its impacts on rivers and their ecosystems. Rivers have shown resilience in the face of change and disturbance caused by dam removal, often exhibiting rapid improvements in water quality, hydrological flows, and the migratory patterns of aquatic species. However, certain outcomes of dam removal may unfold over longer timeframes, influenced by factors such as the life-history of key species and the implementation of complementary river restoration measures. Looking ahead, as societies grapple with evolving hydrologic and land-use drivers that affect water utilisation and conservation, dam removal will emerge as a crucial option for preserving or enhancing the values and ecosystem services provided by the world's rivers (Duda and Bellmore 2022).

Sediment accumulation in the reservoir stands as another common motive for dam removal. The build-up of sediment poses safety risks, diminishes the usable capacity of the reservoir, and can cause damage to turbines. Another prevalent reason for removal is the adverse impact of hydropower facilities on ecosystem functionality. As knowledge regarding the effects of dams on aquatic and riparian ecosystems has advanced, there has been a mounting social pressure to eliminate these structures. Dams may be taken down to restore upstream habitats for migratory fish, reinstate natural flow patterns (unobstructed by dams), and reconnect coastal sediment systems (Ulibarri et al., 2022).

2.4.6. Externalities

The World Bank Group (WBG) has been resistant to adopting guidelines proposed by reformers and the World Commission on Dams (WCD) that advocate for large dam projects to incorporate the social and environmental costs associated with their construction. Throughout the period spanning from the 1970s to the mid-1990s, the World Bank's involvement in the hydroelectric dam sector resulted in significant challenges and a concerning lack of accountability. Despite evidence of these issues, the WBG denied any wrongdoing and attempted to distance itself from the resulting turmoil. While the World Bank's mandate includes adherence to economic principles, it deviated from these principles by externalising many of the costs related to dam construction and operation to local communities and the environment. Essentially, the burden of subsidising hydro projects was shifted onto these communities and the environment. The Bank claimed to prioritise an economic least-cost analysis in selecting the most cost-effective power projects over less effective alternatives. However, by exempting or disregarding significant categories of costs, the World Bank created a difficult situation for itself. The combination of policy inadequacy and reluctance to fully internalise the social and environmental costs sparked criticism and demands for reform from various quarters (Goodland 2010).

Several key factors contribute to the adverse impacts of human activities on the environment. Firstly, the magnitude of these impacts is significant, affecting a large number of individuals in profound and immediate ways. Secondly, the absence of proper regulations and adequate legal frameworks to mitigate these adverse effects is often observed in developing countries, leading to arbitrary administrative practices during displacement processes. Lastly, biased design and planning methodologies, which prioritise one-sided economic criteria and engineering approaches that externalise social costs, persist despite evidence demonstrating their flaws. These factors collectively highlight the urgent need for comprehensive and balanced approaches to address environmental concerns and promote sustainable development (Cernea 1997).

2.5. Risks and Unforeseen

Many risk are associated with construction and O&M of large dams. If these risks are not covered, their costs are externalised to the society, environment and/or future. Proper evaluation and coverage of risks has its costs which must be catered for during the lifecycle of a large hydro project.

2.5.1. Currency Devaluation

Besides other reasons of cost overruns, currency devaluation remains a huge risk in the developing economies which are invariably dependent on foreign currency loans to undertake mega projects of large hydro power.

2.5.2. Climate Change

The planning process for hydropower projects heavily relies on historical rainfall records as a key element. However, with the impacts of climate change becoming increasingly evident, the reliability of these historical records is being undermined. The changing climate patterns and unpredictable rainfall make it challenging to accurately assess the potential water availability for hydropower generation. As a result, the feasibility and attractiveness of high-impact hydro projects are diminishing, while alternative energy sources with lower environmental impacts are gaining more appeal. It becomes increasingly difficult to justify and promote high-impact hydropower in the face of these emerging alternatives (Goodland 2010).

The examination of climate change implications on the functionality and safety of hydropower dams in the future is of utmost importance. As climate change intensifies, the occurrence of droughts poses a significant threat to the reliable generation of power and the provision of water for essential purposes such as drinking and irrigation. These prolonged periods of water scarcity can undermine the overall performance and effectiveness of dams, highlighting the need for careful consideration and planning to mitigate the potential impacts of climate change on hydropower infrastructure (Randell 2022).

Under the greenhouse gas emission scenario of 8.5, the increased frequency of higher magnitude flow events poses a significant challenge, particularly in relation to the presence of dams. This scenario suggests that the occurrence of flooding would become more recurrent with the presence of dams, ultimately resulting in elevated rates of channel degradation (Sanyal et al., 2021).

2.5.3. SOCIAL DISCORDS

Whenever a large hydro project is undertaken, it creates implications for lower riparians. Sindh-Punjab water disputes are on record since 1850s when the British Raj created their first canal colonies. Despite signing of Indus Waters Treaty of 1960, there remains a grudge between the upper and lower riparians countries at the highest level - the famous statement of recent years " blood and water cannot flow together" by no less than the prime minister of an upper riparian state is a stark reminder that mega dams do not bring peace.

And despite signing of 1991 Apportionment Accord for water distribution among the provinces of Pakistan, every year lower riparians are blame the upper riparians for not giving them their due share of water.

2.5.4. SEISMICITY

Geologically speaking, the upper Indus Basin sits in the Main Himalayan Thrust Zone. Bilham (2019) quantified along the arc of the thrust zone, along with the historical rupture zones of past earthquakes to assess the slip potential at fifteen locations. It was found that ten of these segments are sufficiently mature to cause a great earthquake of magnitude 8.0 or higher.

Such earth quakes in the Himalayas have occurred in past. Great Assam earthquake of 12 June 1897 reduced all buildings to rubble in an area the size of England and uplifted Shillong Plateau by 11 meters (Searle 2013).

An earthquake of such magnitude, the death toll could possibly exceed 100 000 due to increased populations and the vulnerability of present-day construction methods (Bilham 2019).

2.5.5. EMERGING TECHNOLOGIES

In the long term, hydro dams are expected to face challenges and potentially become obsolete due to several factors. Firstly, the increasing concerns surrounding climate change have led to a shift in focus towards renewable energy sources that have a lower carbon footprint. As the world strives to reduce greenhouse gas emissions and mitigate the effects of climate change, alternative forms of clean energy such as solar and wind power are gaining prominence. Secondly, the growing demand for irrigation to sustain agricultural activities, particularly in regions facing water scarcity, may limit the availability of water resources for hydroelectric power generation. Lastly, evolving societal priorities and environmental considerations emphasise the need for sustainable and environmentally friendly energy solutions. As a result, the role of hydro dams may diminish over time, giving way to alternative and more adaptive forms of renewable energy generation (Goodland 2010).

2.5.6. DEMOCRATISATION OF POWER

The changing landscape of the world, characterised by the rise of democracy, active civil society, and increasing transparency, has brought about a shift in priorities towards environmental and climate concerns. These changes are expected to be enduring and continue to evolve in the future. As a result, there is a growing need for more prudent standards that effectively address the challenges at hand, rather than adopting ineffective approaches. The recognition of these changing trends and the urgency of addressing environmental and climate issues highlight the importance of embracing new technologies and approaches to ensure a sustainable and resilient future (Goodland 2010).

2.5.7. EMERGING LAWS AND LEGISLATIONS

Large scale exploitation of nature by humans, inflicting widespread and longterm damages to the natural systems and the environment, cannot go on unchecked. The international law has a role to play.

Abbas (2023) summarised the evolution of international laws to protect nature.

In 1972, Swedish Prime Minister Olof Palme evoked the idea of ecocide as an international crime at the UN Conference on the Human Environment. In 1973, an Ecocide Convention was drafted, recognising 'that man has consciously and unconsciously inflicted irreparable damage to the environment in times of war and peace'.

In 2021, a panel of global experts defined ecocide as ""Ecocide" means unlawful or wanton acts committed with knowledge that there is a substantial likelihood of severe and either widespread or long-term damage to the environment being caused by those acts". This definition is prepared to include ecocide as the fifth crime in Rome Stature.

Some countries already have the laws in place to protect the environment. Giving the rights of personhood to the rivers in New Zealand and some South American countries is an example. Environmental protection laws in most countries are also getting stronger and more effective.

3. ALTERNATIVES TO LARGE HYDROPOWER AND RESERVOIR STORAGE

Fifty years ago, and earlier, hydropower was perhaps the only reliable source of renewable energy. One of the major advantages of hydropower was zero cost of fuel during the O&M phase of power generation - making it cheaper to operate. But large hydropower comes at huge external costs to the society and environment as discussed in the previous chapters. Because of very high initial costs involved, developing economies cannot undertake large hydropower power projects without.foreign currency loans taken by the governments through MDBs.

Time taken to build large hydro is also very long - usually in the range of 7 to 15 years. This makes large hydro unattractive for private investors because it keeps freezing investments over a long time without yielding returns. It is, therefore, advisable for policymakers to prioritise energy alternatives that demand lower initial investments and can be swiftly constructed (Ansar et al., 2014).

There exist several affordable, environmentally friendly alternatives to large hydropower projects. These include, especially in Pakistan's perspective, wind and solar energy sources. As solar and wind continue to advance, it has become competitive with large hydro, not only in terms of lower initial investments and shorter times for returns, but also when considering the internalisation of social and environmental costs in both cases.

Multipurpose dams, with water storage as the prime function, however,. hold greater appeal than hydropower dams when promptly benefiting the voluntarily displaced individuals. In numerous impoverished rural regions, access to water for agricultural purposes carries far more significance than electricity. Large hydro with water storage (especially for dry season irrigation), therefore, are often pressing matters with limited alternatives (Goodland 2010). However, in case of Indus River System, there exists an aquifer system which has been considered a hydrogeological miracle (Ahmad and Chaudhry 1988) - an aquifer system which can hold ten times the volume of annal surface flow (Michel 1967).

For alternatives to large storage reservoirs created by dams, alternative solutions based on the principles of integrated water resources management (IWRM) have been discussed. Integration of aquifer management, flood plains management, riverine corridors management and water conservation initiatives are discussed within the contemporary framework of IWRM.

Figure 2: A wind turbine blade being transported in Sindh, Pakistan.

3.1. ENERGY ALTERNATIVES

In order to achieve 1.5ºC Paris Agreement target, the planet needs r 61% of total electricity generation to come from renewables by 2030. the International Energy Agency (IEA) estimates that renewable energy has to increase by three folds - most of it coming from solar photovoltaic (PV) and wind (GWEC 2023).

In a recent study by Kuriakose et al. (2022) to assess the implications of large hydro dams for decarbonising energy, solar power was found more suitable pathway for achieving an energy transition that aligns with the goals outlined in the Paris Agreement. Instead of focusing on the construction of additional dams, the alternative approaches of solar power hold better potential to deliver sustainable and environmentally-friendly energy solutions.

Solar and wind have been briefly discussed in Pakistan's energy expansion plan under the category of variable renewable energy (VRE). The plan points to the need of intermittency management. VRE projects with storage support can help the grid with base load for some hours of the day, frequency control & regulation and maintaining the reactive power balance, and provide reserve power (IGCEP 2022).

An upward trajectory is evident in the electricity generation (GWh) statistics of the country from 2013-14 to 2018-19, albeit with a slight decline in 2019-20 due to reduced demand resulting from economic challenges compounded by the impact of the COVID-19 pandemic. However, since 2020-21, the trend has resumed its upward trajectory, as depicted in Chart 2-6. In parallel, the overall power demand (MW) has shown a consistent increase, indicating improved electricity supply development within the country, as illustrated by the trend in electricity peak demand in Chart 2-7. Notably, electricity consumption in Pakistan is predominantly driven by the domestic sector, followed by the industrial and agricultural sectors, as evidenced by Chart 2-9. These findings underscore the evolving dynamics of electricity generation, demand, and consumption patterns, which are crucial considerations in the context of the literature review chapter being developed for this report (IGCEP 2022).

3.1.1. SOLAR

World Bank Group has published a comprehensive report on global solar energy potential. The theoretically available PV energy potential is measured as global horizontal irradiance (GHI). 93% global population lives in countries in which range of GHI is between 3 to 5 kWh/m^2/day. Pakistan's GHI is 5.341 kWh/m^2/day. However, after considering a number of region-specific factors such as clouds, wind speed, terrain slope, terrain shading, air temperature, aerosols, etc., the practical PV output, (PVOUT), could be much less. In case of Pakistan mean PVOUT is 4.713 kWh/kWp/day as shown in Figure 3. Only 20% of the global population lives in countries with excellent conditions for PV, where the long term PVOUT average exceeds 4.5 kWh/kWp/day (ESMAP 2020). This implies that Pakistan boasts one of the best potential PV in the world.

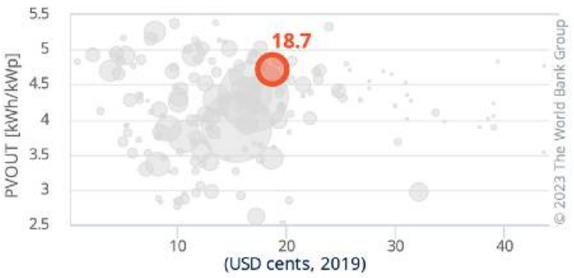


Figure 3: LCOE from Solar PV in Pakistan as esteemed for 2018 by the World Bank Group

ESMAP (2020) also estimated levelised cost of electricity (LCOE) from solar PV for each country as shown Figure __. LCOE for Pakistan is ,18.7 US cents per KWh. It is worth noting that despite having high PVOUT, LCOE for solar PV in Pakistan seems higher than many countries with much lower PVOUT. Low human development index (HDI), lack of industrialisation, etc, may contribute to a higher cost and there remains a huge potential to bring it down through indigenous production and improving HDI.

Access to solar PV is already democratising energy in domestic and agriculture sector in Pakistan as seen in Figures 4 and 5. An estimated 1568 MW of solar PV was already installed in Pakistan according to estimates made in 2018 (WB 2023).

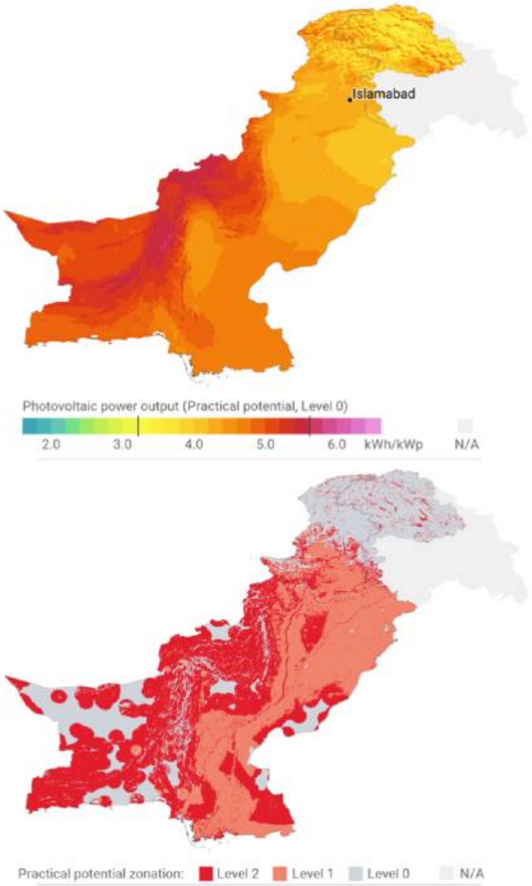
Figure 4: Rooftop solar PV in Sector E-11, Islamabad.

Figure 5: Solar power for tube wells in Rajanpur, Punjab.

'Sustainable and modern energy for all' SDG 7, to be achieved by 2030, is extremely challenging in the absence of well laid out electricity grid. Scaling up investments and policy support in the off-grid renewables sector will be crucial to closing the access deficit. Solar PV has continued to dominate the off-grid space, attracting 92% of overall global investments in off-grid technologies during 2010-2021. (IRENA and CPI 2023).

The World Bank Group describes three levels of practical potential. Level 0 disregards any limitations to the development and operation of solar power plants. At Level 1, areas due to physical/technical constraints, such as rugged terrain, presence of urbanised/industrial areas, forests, and areas that are too distant from the centres of human activity are excluded. At Level 2, other constraints are excluded such as areas unsuitable due to local regulations imposed by authorities (e.g., croplands or nature reserves). Based on these criteria, WBD has produced maps for potential development of Solar PV in Pakistan as shown in Figure 6 (WB 2023; ESMAP 2020)

Seasonality index of solar energy in a country is defined as the ratio between the highest and the lowest of monthly long-term PVOUT averages. The high-potential countries have seasonality index below 2 and their. PVOUT exceeds 3.5 kWh/kWp. In case of Pakistan, seasonality index is 1.37 and PVOUT is 4.713 kWh/kWp (WB 2023; ESMAP 2020).



The boundaries, colors, denominations and any other information shown on the maps do not imply, on the part of The World Bank, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

WORLD BANK GROUP ESMAP SOLARGIS

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Figure 6: Solar energy potential of Pakistan estimated by The World Bank Group

There are other synergies of solar PV in adaption to climate change. Roof-top systems on buildings and car parks can help prevent urban heating and large solar farms could be integrated with understorey cultivation - creating bio-crusts under the solar panels. With better research and planning, bio-crusts under the solar PV can play a vital role in dust suppression, carbon sequestration, etc., and greening of landscapes (Heredia-Velásquez et al., 2023).

3.1.2. WIND

Southern parts of in Sindh and Western parts of Baluchistan offer very good wind energy potential in Pakistan as shown in Figure 7.

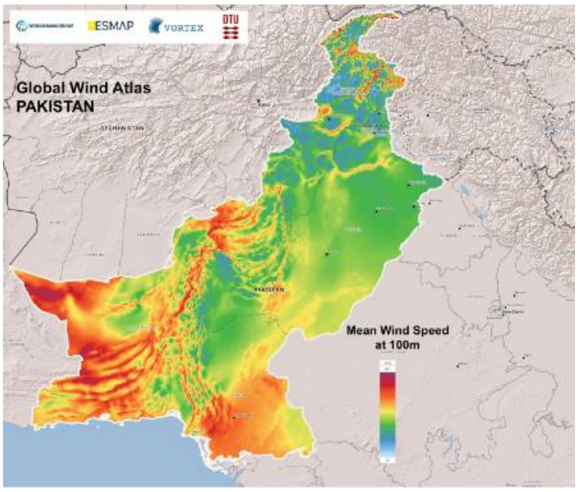


Figure. 7: Average wind speed at 100m Source: GWA 2023

According to Global Wind Report 2023 (GWEC 2023), globally, 77.6 GW of new wind power capacity was connected to power grids in 2022, bringing total installed global wind capacity to 906 GW. Global Wind Energy Council (GWEC) expects to surpass the milestone of 2 TW of installed wind power by 2030.

China achieved record additions of 68.6 GW of grid-connected onshore wind in 2020 and 16.9 GW of offshore installations in 2021. The country has moved from renewable subsidies and feed-in tariff model to 'grid parity' model, whereby electricity generated from renewables will receive the same remuneration as that from coal-fired power plants. (GWEC 2023).

Given the concentration of Industries in and around the port city of Karachi and one of the best combined solar and wind potential in southern Sindh, there is a grand opportunity to invest in combined solar and wind power projects with mini-grids and local grids to meet industrial, as well as domestic demands of densely populated metropolis of Karachi. The potential for wind energy in for 10% windiest areas of Pakistan is 606 W/m², with wind speed at 7.87 m/s at a height of 100m above ground, as shown in Figure 8 , produced by GWA (2023).

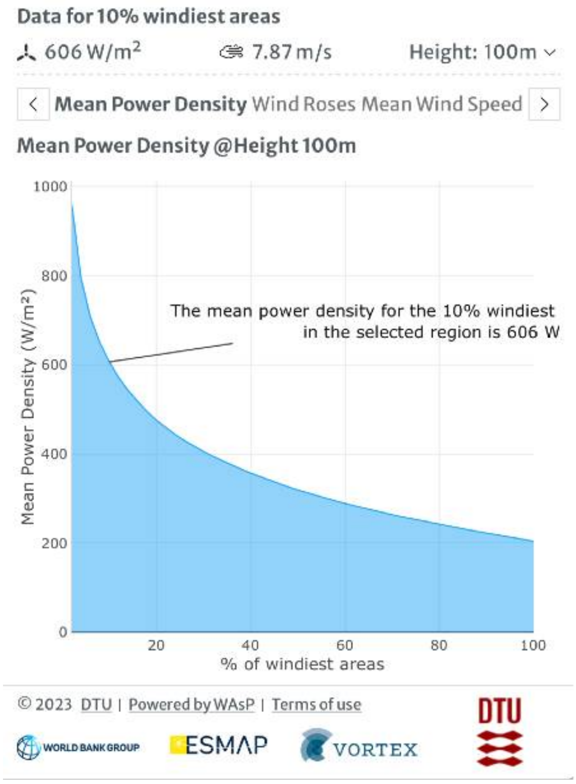


Figure 8 : Pakistan's wind energy potential

3.2. WATER MANAGEMENT ALTERNATIVES

The operation of reservoirs and diversions encompasses multiple functions, including hydropower generation, water supply, and flood control, with many basins utilising multiple reservoirs in a conjunctive manner to optimise overall benefits. The effectiveness of dam operation is heavily influenced by the ratio of reservoir capacity to annual flood volume, known as the impoundment/runoff index. Flood regulation necessitates the presence of empty space or a designated "flood control pool" within the reservoir's storage capacity to accommodate floodwaters. Even in the case of small water-supply reservoirs designed to maintain high water levels throughout the year, temporary storage above the spill weir level assumes a crucial role in reducing the maximum outflow rate from the reservoir, particularly when the reservoir water area covers 2% or more of the catchment area. (Petts and Gurnell 2022). Leaving aside the hydropower, water management functions of large dams for storage and flood control are often in conflict with each other - enhancing the capacity of one function, invariably reduces that of the other.

3.2.1. AQUIFER STORAGE

Indus aquifers are so vast that they rank among the natural wonders of the world (Ahmad and Chaudhry 1988). The formation of Indus aquifers comprises of unconsolidated alluvium deposits over the bedrock underlying the river beds and Indus plains.

Between 1928 and 1932, Dr. Bose of Irrigation Research Institute, Lahore, carried out surveys to the depth of the bedrock in Indus Plains. The survey indicated that at certain locations the bedrock more than 5000 feet deep. These unconsolidated granular formations can store large volumes of water (Ahmad and Chaudhry 1988). As shown in Figure 9, the Indus Aquifer is large, but it suffers from water quality issues. Podgiorski et al., (2018) mapped arsenic pollution of groundwater in Pakistan. Their results show that more than 90% of irrigated areas have arsenic concentration exceeding WHO standards. This is most likely due to extensive use of fertilisers, herbicides and pesticide in the agriculture sector.

Despite this pollution, the opportunity and potential of utilising aquifer storage in Indus Basin is not lost. The aquifer under the river beds and active flood plains adjacent to river channels but out side the polluted irrigated areas have the storage potential exceeding 400 MAF. This area is 21,000 square kilometres or 5.2 million acres, and is government-owned land as shown in Figure 10 (Hussain and Abbas 2019a). Storage volume in dams, compared to the volume that can be managed from the aquifer is two orders of magnitude more,. The storage system of aquifer is already juxtaposed in the landscape criss-crossing the population centres and irrigated areas which need freshwater. Managing water from these aquifers is a viable alternative option to large, expensive and time consuming storage dams in the mountains - let alone the social and environmental costs of these dams.

3.2.2. FLOOD ADAPTATION

There are three types of floods encountered in the landscape of Pakistan - riverine floods, pluvial floods and coastal floods.

Riverine floods, which are caused by the heavy downpours in the upper catchment areas of the rivers, cause the riverbanks to over flow causing flooding of flood plains and adjacent areas in the lower reaches of the rivers. In recent past, such flood were encountered in 1992 and 2010. Dams designed for flood control, to some extent, manage to break flood peaks in case of riverine floods.

Pluvial floods are caused due to direct downpours of heavy rains in plain areas, cities, agriculture areas, etc. Urban flooding of Lahore in 2018, and that of Karachi in 2020, and flooding in towns, villages and agriculture areas of Sindh and Baluchistan in 2022 was a result of pluvial flooding. Dam built in upstream reaches of the rivers cannot hold back, control or mitigate pluvial floods in the downstream areas.

Coastal floods are due to stormy conditions in the sea, such a cyclones, hitting the coastal areas. Besides heavy downpours, coastal areas also suffer from exceptionally high tides and sea surge. Such conditions were faced in 1999 in the coastal districts of Badin and Thatta. Dams built anywhere on the rivers have no influence in mitigating or managing of coastal floods.

Above in view, dams as instruments of flood control can only help in case of riverine floods when the upper catchments (upstream of dam) receive heavy downpours. However, historically, despite dams on Indus and Kabul rivers, 2010 floods could not be prevented, nor in Jhelum River in 1992 despite a large dam. WAPDA's report on 1992 floods acknowledged that large dams of Pakistan were not meant for flood control and any flood control provided by dams is 'only incidental' (Afzal 1994).

The concept of flood 'fighting' or 'controlling' is changing into 'adaptation' with the emerging global mind (Abbas 2015). Engineering approaches of controlling floods through dams, dykes and levees are based on 'likelihood values' derived from past hydrological data.

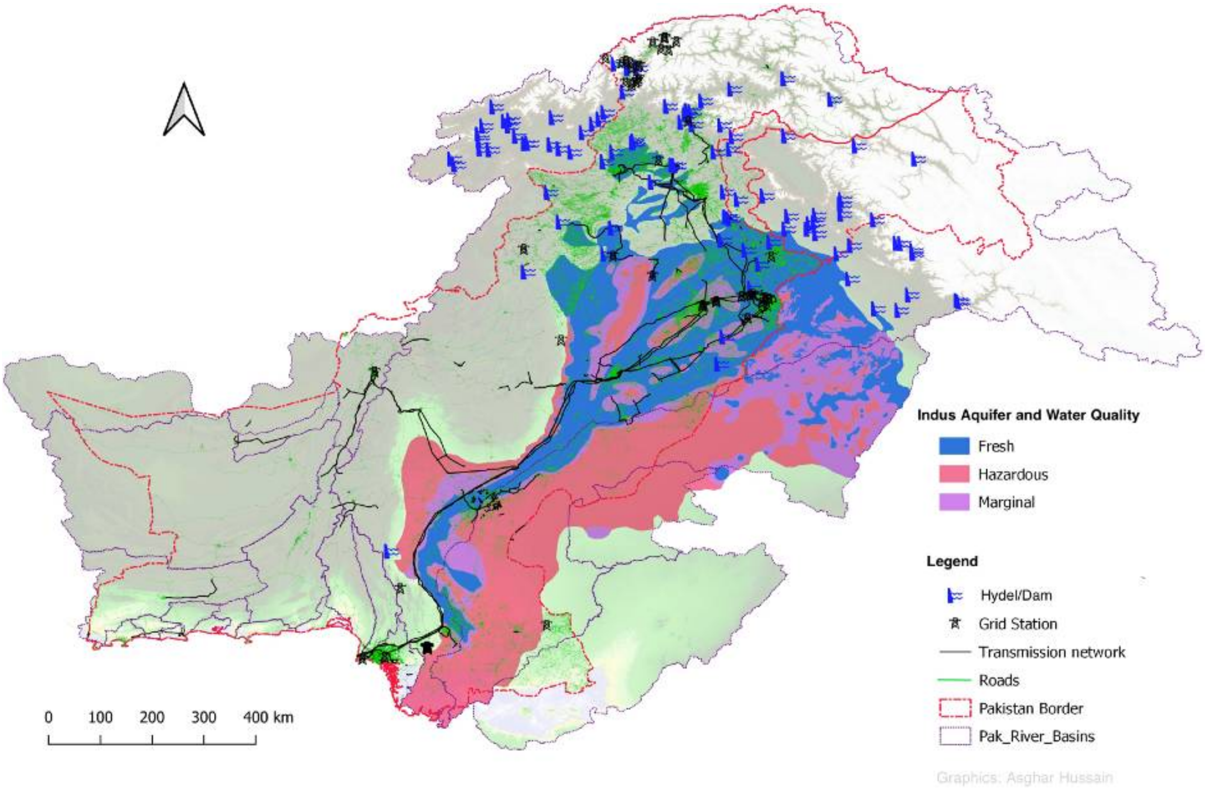


Figure 9: Indus Plains aquifer with water quality

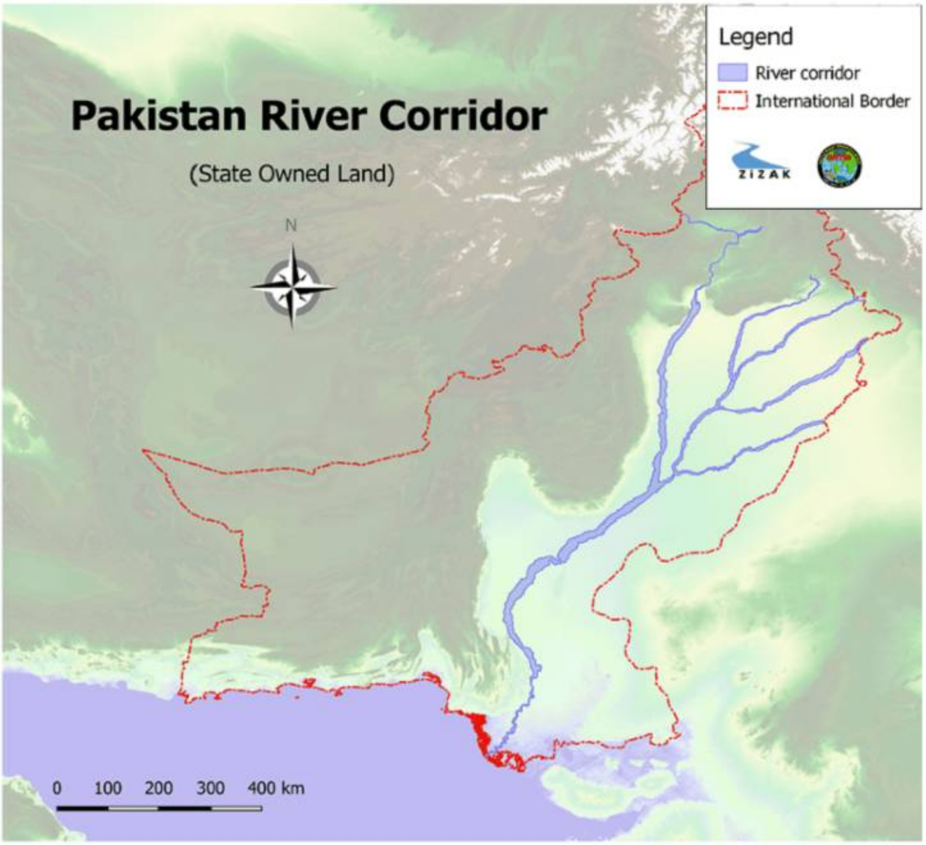


Figure 10: Indus Aquifer under the riverbeds and active flood plains (copied from Hussain & Abbas 2019)

With engineering designs in place, the likelihood values become stationary. However, the assumption - that climate events, their frequency, intensity, and the likelihood values are stationary - is no longer valid (Wenger et al., 2013).

The evolving alternates of managing and adapting to floods are being derived from nature based solutions (NBS). Dam Removal Europe (DRE), Room for the River (Climatewire 2012; Rijkswaterstaat 2023) and Rewilding Europe are some of the international initiatives underway, based on NBS, for climate compatible flood adaptation and management.

On the similar lines, managing floods, droughts and climate change through management of riverine corridors in the Indus Basin has been suggested. Restoration of wetlands, riparian vegetation along the river corridors can help absorb flood peaks and break down flood velocities. Removal of engineered levees along the rivers can create room for flood waters to spread out, and recharge aquifers along the rivers. This also helps break flood peaks. After removal of levees, the population centres being exposed to flooding can be protected by 'doughnut' levees and flood-risk management procedures and infrastructure. There is need to forgo the short-term vision of drying up wetlands and reclaiming land in the active flood plains along the rivers and putting it to "productive" use. But when these low lying areas are protected by dykes we complacently built dwellings and other infrastructure. In the long run, however, loss of these ecosystems means lost capacity of the river basin to absorb water and break flood peaks (Abbas 2015; Hussain and Abbas 2019; Hussain and Abbas 2019a).

3.2.3. DEMAND MANAGEMENT

Instead of focusing on supply management of water by investing in mega reservoirs, there also exists opportunity on investing in demand management. 95% of water used in Pakistan is taken up by the irrigation sector. However, crop per drop output of the irrigation sector of Pakistan is one of the lowest in the world (Briscoe and Qamar 2006). Water derived from inefficiency is the last remaining resource to meet demands in the overstretched river basins (Postel 1992; Postel 1999).

Fortunately, with lowest efficiency in largest water consuming sector (irrigation) comes the biggest opportunity for Pakistan to create new resources of water. Rohri Canal, emerging from Sukkar Barrage, for example, diverts between 8 to 9 MAF annually to irrigate almost 2 million acres of agriculture land in Sindh. By investing in irrigation efficiency, using current technologies of high efficiency irrigation systems, higher yields per acre are possible with only 3 MAF of water. This implies savings of between 5 to 6 MAF of water - rivalling the storage created behind a large dam. Making investment in irrigation efficiency comparable to the cost of building a large dam is more climate compatible and sustainable alternative of managing demand (Abbas 2018a).

Rohri canal is just one example. We have another 41 canal commands as opportunity - with potentially saving 50 to 70 MAF of water by investing in demand management. All compared to all the existing and conceived large dams combined in Pakistan, maximum possible storage does not exceed 40 MAF - that too not lasting more than 50 years due to silting in the reservoirs - let alone other social and environmental impacts of damming a flowing river..

4. ENERGY PRODUCTION AND DISTRIBUTION IN PAKISTAN

Pakistan's electric energy production and distribution system is centralised around a national grid. Power producers are independent but regulated/facilitated through various government agencies and procedures.

4.1. AGENCIES RELATED TO POWER SECTOR IN PAKISTAN

Major players in energy production and distribution are as follows

4.1.1. NATIONAL ELECTRIC POWER REGULATORY AUTHORITY

National Electric Power Regulatory Authority (NEPRA) accords approval/licence to Independent Power Producers (IPPs) to produce electric power. An IPP establishes its infrastructure to produce power from some source such as hydel, coal, oil, gas, wind, solar, etc. The infrastructure installed by an IPP to produce a certain amount of power is to be approved by Private Power and Infrastructure Board (PPIB).

4.1.2. PRIVATE POWER AND INFRASTRUCTURE BOARD

Created in 1994, Private Power and Infrastructure Board (PPIB) was aimed to promote private investments in power sector. In 2012 Private Power and Infrastructure Board Act 2012 (Act VI of 2012) made PPIB a statutory organisation. The Act was further amended in 2015, expanding PPIB's role to facilitate public sector power and related infrastructure for independent power producers (IPPs).

For hydropower projects, PPIB administers, on behalf of Government of Pakistan, Implantation Agreement (IA), Power Purchase Agreement (PPA) and Water Use License (WUL) with the hydropower producers.

4.1.3. NATIONAL TRANSMISSION AND DESPATCH COMPANY

National Transmission and Despatch Company (NTDC) incorporated as a Public Limited Company. NTDC was created after unbundling of WAPDA in 1998. It is owned by Government of Pakistan. NEPRA granted Transmission License to NTDC in December 2002 to engage in the exclusive transmission business for a term of thirty (30) years

The prime function of NTDC is to link power generation units with load centres spread all over the country, through the national transmission grid network.NTDC takes power from the hydroelectric, thermal and other IPPs and delivers it to the Power Distribution Companies (DISCOs) through primary transmission network of extra high voltage (EHV).

4.1.4. CENTRAL POWER PURCHASE AGENCY

Central Power Purchasing Agency (CPPA-G) is a Company incorporated under the Companies Ordinance, 1984 and wholly owned by the Government of Pakistan (the "GOP"). Since June 2015, CPPA-G has assumed the business of National Transmission and Dispatch Company (the "NTDC") pertaining to the market operations and presently functioning as the Market Operator in accordance with Rule-5 of the NEPRA Market Operator (Registration, Standards and Procedure) Rules, 2015 (the "Market Rules").

Core functions of CPPA-G include, but not limited to, power procurement on behalf of DISCOs, finance, strategy and market development, legal and corporate affairs, and market development.

4.1.5. Independent Power Producers

Independent Power Producers (IPPs) invest in and operate infrastructure to generate electric power and sell the government. IPPs are both public and private entities.

To being a project, an IPP is assessed by PPIB and generation licence is given by NEPRA.

As per CPPA list, there are are 90 IPPs currently operating in Pakistan:

S/no	IPP
1	ACT Wind (Pvt) Limited
2	AJ Power (Private) Ltd.
3	Almoiz Industries Limited
4	Altern Energy Ltd.
5	Appolo Solar Development Pakistan Limited
6	Artistic Energy (Pvt.) Limited
7	Atlas Power Limited
8	Attock Gen Limited
9	Azad Jammu & Kashmir Power Development Organzation
10	Best Green Energy Pakistan Limited
11	Central Power Generation Company Limited-(Genco-2)
12	Chanar Energy Limited
13	China Power Hub Generation company (Pvt.) Ltd
14	Chiniot Power Limited
15	Crest Energy Pakistan Limited
16	Davis Energen (Pvt) Limited
17	Engro Powergen Qadirpur Limited
18	Engro Powergen Thar (Pvt) Limited
19	F.D QESCO (Collector of Customs Quetta)
20	Fatima Energy Limited
21	Fauji Kabirwala Power Company Ltd.
22	FFC Energy Limited
23	Foundation Power Company Daharki Ltd.
24	Foundation Wind Energy-I Limited
25	Foundation Wind Energy-II (Pvt.) Limited
26	Gul Ahmed Wind Power Ltd
27	Gulf Powergen (Pvt) Ltd
28	Habibullah Coastal Power Co. (Pvt.) Ltd.
29	Halmore Power Generation Company Limited
30	Hamza Sugar Mills Limited
31	Harapa Solar (Pvt) Limited
32	Hawa Energy (Private) Limited
33	Huaneng Shandong Ruyi Energy (Pvt) Ltd
34	Hydrochina Dawood Power (Private) Limited
35	Jamshoro Power Company Limited-(Genco-1)
36	Japan Power Generation Ltd.
37	JDW Sugar Mills Ltd.
38	Jhimpir Power (Private) Limited
39	Karachi Nucelar Power Plants
40	Kohinoor Energy Ltd.
41	Kot Addu Power Company Ltd.
42	Lakhra Power Generation Company Limited-(Genco-4)
43	Lalpir Power (Private) Limited
44	Laraib Energy Limited
45	Liberty Power Tech Limited
46	Master Wind Energy Limited
47	Metro Power Company Ltd
48	Mira Power Limited
49	Narowal Energy Limited
50	National Power Parks Management Company Private Limited
51	Neelum Jhelum Hydropower Company (Pvt.) Ltd.
52	Nishat Chunian Power Limited

S/no	IPP
53	Nishat Power Limited
54	Northern Power Generation Company Limited-(Genco-3)
55	Orient Power Company (Private) Limited
56	PAEC Chashma Nuclear Power Plant.
57	Pak Gen Power Limited
58	Pakhtunkhwa Energy Development Organization (Malakand-III)
59	Pakhtunkhwa Energy Development Organzation (PEDO)
60	Pakistan State Oil
61	Port Qasim Electric Power Company (Pvt.) Limited
62	Quaid E Azam Solar Power Pvt Ltd
63	Quaid-e-Azam Thermal Power (Pvt) Limited
64	Reshma Power Generation (Pvt) Ltd
65	Rousch Pak Power Ltd.
66	RYK Mills Limited
67	Saba Power Company (Pvt.) Ltd.
68	Sachal Energy Development (Private) Limited
69	Saif Power Limited
70	Sapphire Electric Company Limited
71	Sapphire Wind Power Company Limited
72	Sarhad Hydel Developement Organization
73	Southern Electric Power Co Ltd.
74	Star Hydro Power Limited
75	Tavanir Iran
76	Tenaga Generasi Limited
77	Thal Industries Corporation Ltd
78	The Hub Power Company Limited
79	Three Gorges First Wind Farm Pakistan (Private) Limited
80	Three Gorges Second Wind Farm Pakistan Limited
81	Three Gorges Third Wind Farm Pakistan (Private) Limited
82	TNB Liberty Power Ltd.
83	Tricon Boston Consulting Corporation (Private) Limited
84	Uch Power Ltd.
85	Uch-II Power (Pvt.) Limited
86	UEP Wind Power (Pvt)Ltd
87	WAPDA Hydel
88	Yunus Energy Limited
89	Zephyr Power (Pvt.) Limited
90	Zorlu Enerji Pakistan Limited

4.1.6. DISTRIBUTION COMPANIES

Distribution companies (DISCOs) take power from the central grid and supply it to the end user. Each DISCO has its own domain and together they cover the entire country as shown in Figure 11. These also serve and collect power bills from the consumers along with taxes/subsidies imposed on power sector by the Government.

DISCOs
Faisalabad Electric Supply Company (FESCO)
Gujranwala Electric Power Company (GEPCO)
Hazara Electric Supply Company (HAZECO)
Hyderabad Electric Supply Company (HESCO)
Islamabad Electric Supply Company (IESCO)
Karachi Electric Supply Company (KESC) (Now privately owned as K-Electric)
Lahore Electric Supply Company (LESCO)
Multan Electric Power Company (MEPCO)
Peshawar Electric Power Company (PESCO)
Quetta Electric Supply Company (QESCO)
Sukkur Electric Power Company (SEPCO)
Tribal Electric Supply Company (TESCO)

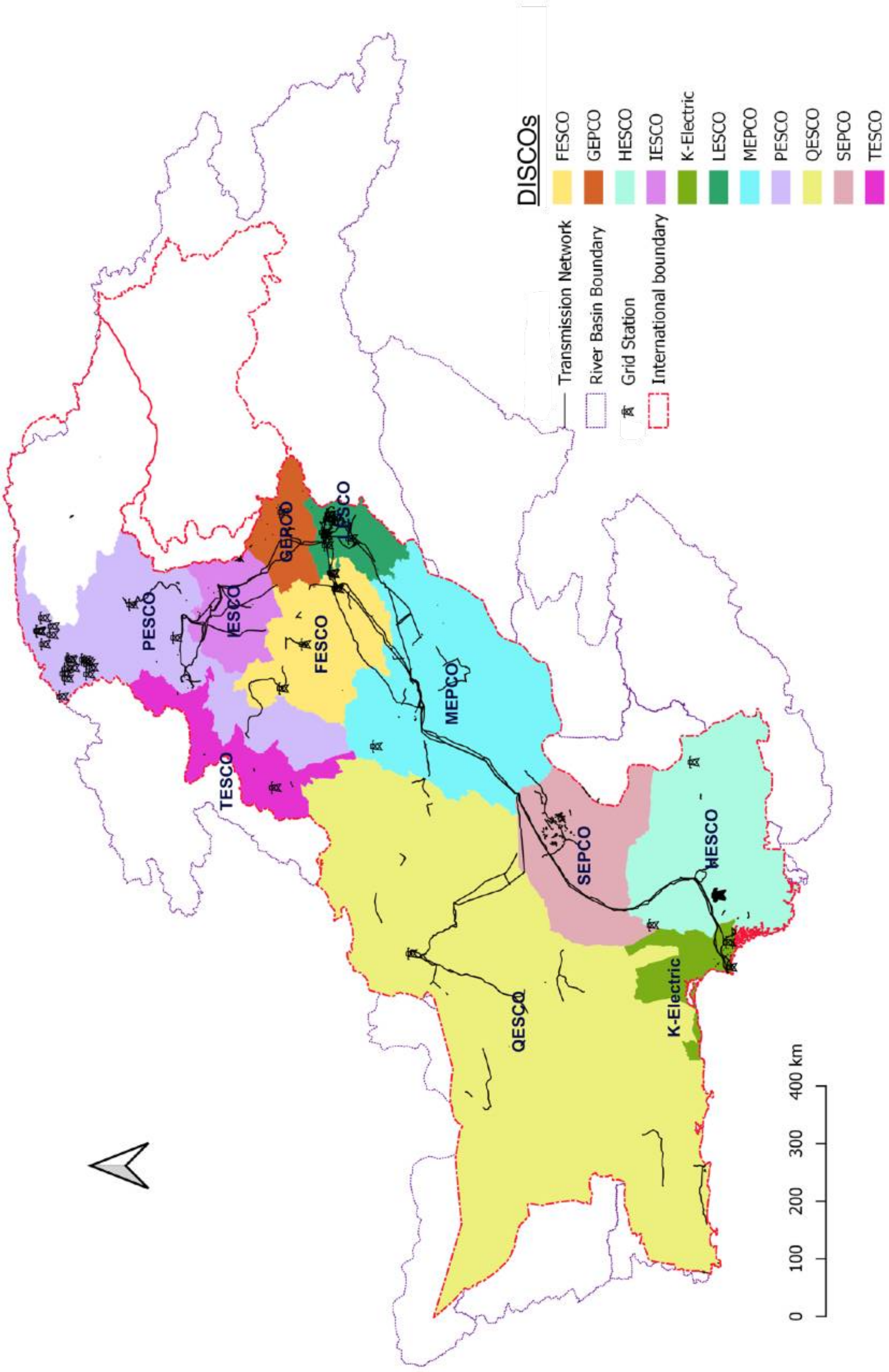


Figure 11: Areas and jurisdiction of various DISCOs in Pakistan

4.2. ENERGY MANAGEMENT

DISCOs estimate power demand and convey it to CPPA. CPPA purchases the power from IPPs to meet the demand. IPPs supply the power to NTDC, which monitors how much power has entered the grid and then supplies power to DISCOs. This has been explained in Figure 13.

4.2.1. PRODUCTION, TRANSMISSION AND DISTRIBUTION

NTDC transmits power to DISCOs through extra high voltage (EHV) lines. NTDC also monitors the power received by DISCOs after any losses in EVH transmission. DISCOs supply power to the endusers - domestic, industrial, municipal and agriculture etc. There are losses between energy received by DISCOs and supplied to consumers. DISCOs bill their consumers to pay for the energy used. The tariff includes system/transmission and administrative losses. From every generation to enduser consumption, the entire system is supposed to run from the tariff collected from the consumers. The tariffs, therefore, as finally set by NEPRA after taking input from IPPs, DISCOs, government's taxes/subsidies.

4.2.2. ESTIMATION OF TARIFF

IPPs use a host of fuels for generation of energy, including renewables - solar, wind and hydro. PPIB assesses and validates an IPP and NEPRA issues the licence, authorising an IPP to generate power. CPPA purchases all the power form IPPs on behalf of the Government. The power from IPPs is received in National Grid which is administered and monitored by NTDC.

Tariff depends on the type of fuel used by an IPP, and is different for different mode of production. Other factors determining the tariff may include government subsidies, local factors catered by DISCOs, transmission losses, etc.

In the Indicative Generation Capacity Expansion Planning (IGCEP), the consideration of seasonality in the output of hydroelectric projects is achieved by utilising average seasonal values of monthly energy and capacity provided by the project executing agencies. This approach enables the incorporation of the varying energy and capacity levels throughout different seasons, allowing for a more comprehensive assessment of the hydroelectric project's performance over time (IGCEP 2022).

Figure 14 explains how data from meteorology, environment and social sector impacts a particular fuel used for energy generation. The figure also shows the organisations which may be involved in collecting and managing these data parameters. Data from social sector, for example, is used by DISCOs to determine energy demand. Similarly, a number of data parameters are connected to energy production from hydro power. These data parameters will be used in determining the cost of hydro power production and determination of tariff.

It is worth noting that current format of assessing hydropower tariff is only based on:

- Costs of civil and mechanical works to build the project
- Cost of financing
- Resettlement costs

The tariff calculations do not take into consideration lifetime costs of the facility from inception to decommissioning. It also excludes environmental and social externalities.

4.3. WATER MANAGEMENT

There are more than 50 agencies, provincial and federal, looking after water management in Pakistan. However, we shall only discuss water management in the context of large dams. Indus River System Authority (IRSA), WAPDA and provincial irrigation departments deal with the water withheld in large dams.

Ministry of Water Resources (MoWR) takes advice from International agencies like International Commission of Irrigation and Drainage (ICID), International Commission on Large Dams (ICOLD), and national agencies like Pakistan National Committee on Irrigation and Drainage (PANCID).

National organisations like Indus River System Authority (IRSA), Water and Power Development Authority (WAPDA), Federal Flood Commission (FFC) and Pakistan Commissioner for Indus Waters (PCIW) work under MoWR. These organisations are responsible for various projects being been panned, and being implemented.

Project Monitoring and Implementation Unit (PMIU) also works under the ministry and looks after the projects.

Water Sector Capacity Building and Advisory Services Project (WCAP) also works under the MoWR

The schematic given in Figure 12 shows the general organogram for MoWR

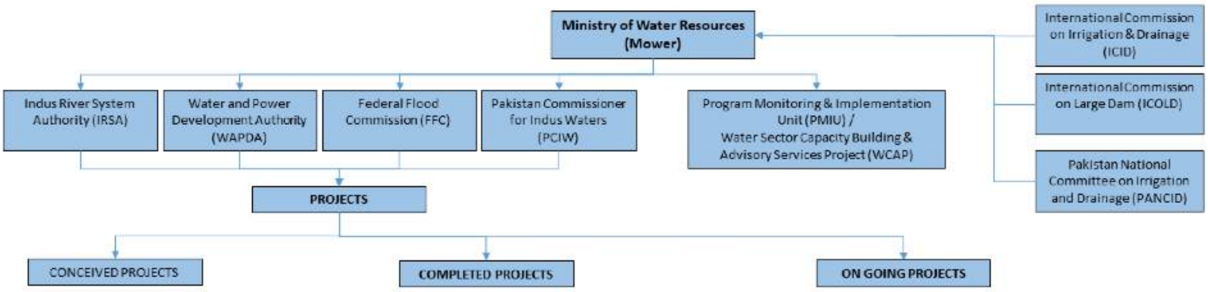


Figure. 12: Functioning of MoWR

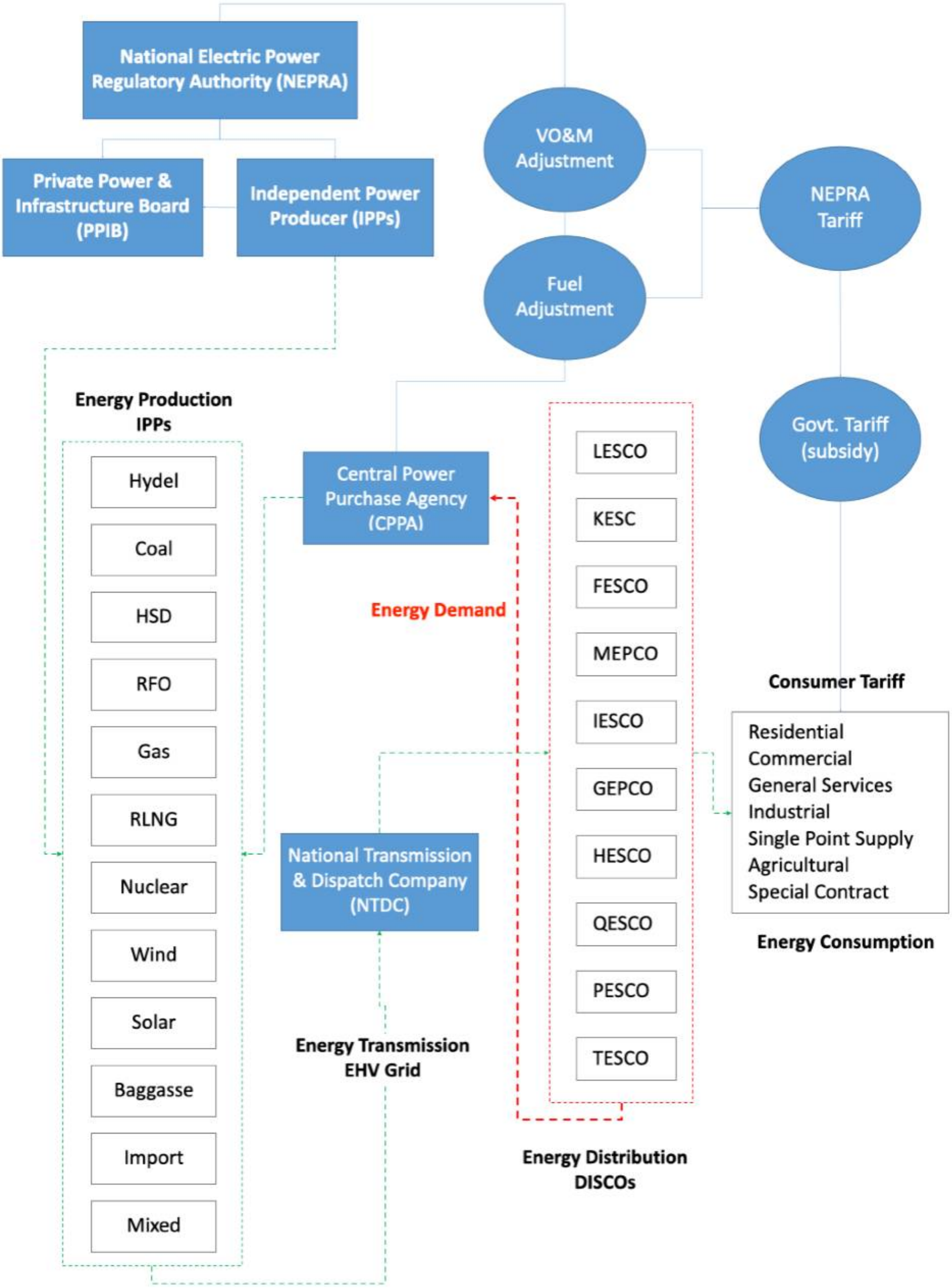


Figure 13: IPPs produce power, NTDC transmits power to DISCOS, consumers receive power from DISCOS

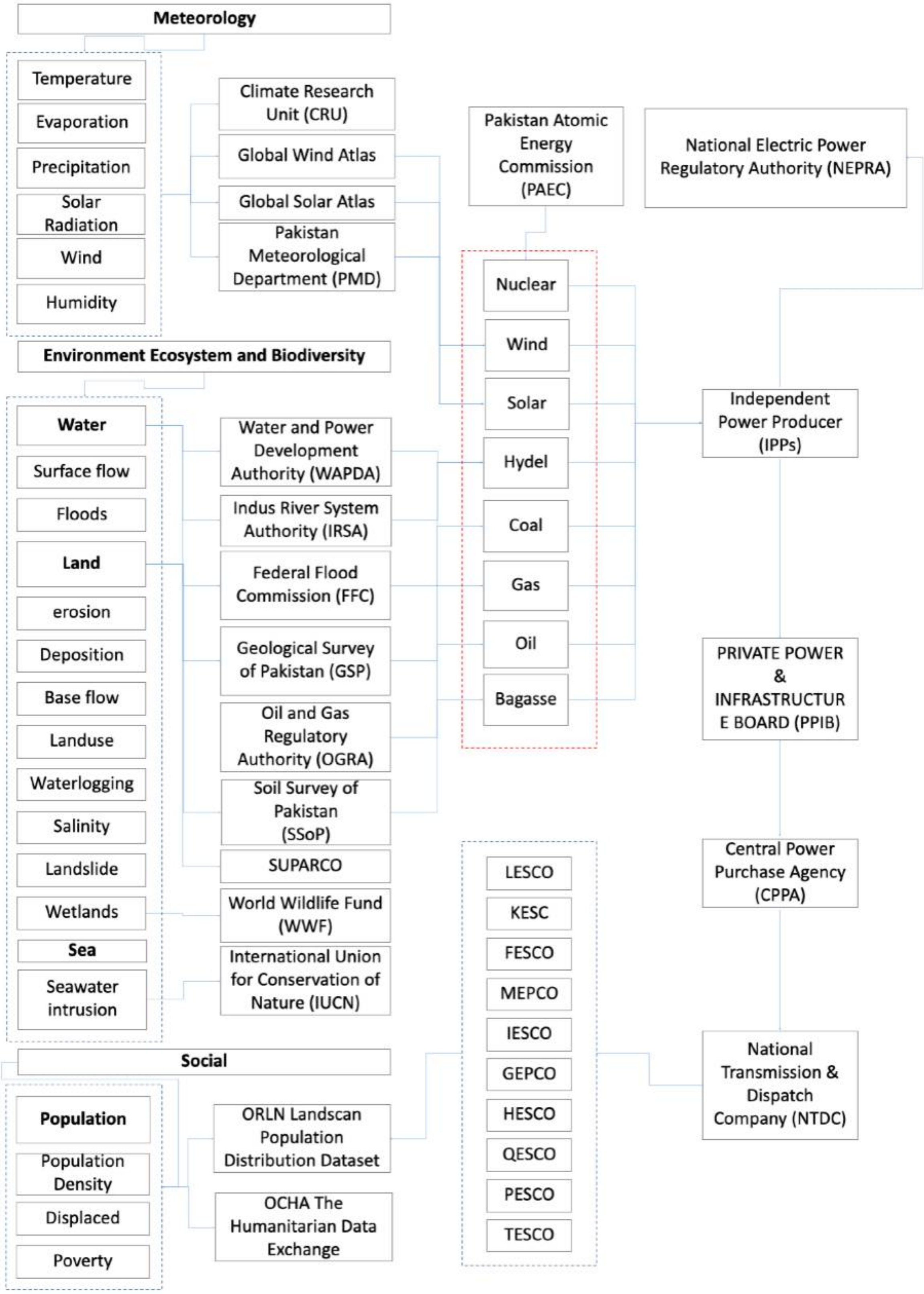


Figure 14: Data parameters, data sources, energy production and stakeholder organisations

5. HYDRO-COSTING FOR LARGE DAMS

The Integrated Generation Capacity Expansion Plan (IGCEP) holds a significant position in the advancement of the power system, as it serves as a framework for expanding the generation capacity in a cost-effective manner to meet the growing demand. While the plan takes a long-term perspective, it primarily serves as an indicative guide, offering insights to potential investors and market participants regarding the future demand-supply dynamics and the anticipated generation mix. By providing this foresight, the IGCEP aids in decision-making and facilitates strategic planning for the stakeholders involved in the power sector (IGCEP 2022). According to IGCEP last report, hydropower plays a significant role in Pakistan's energy landscape, accounting for approximately 28% of the country's installed capacity and 25% of its generation capacity. This highlights the substantial contribution of hydropower to Pakistan's overall energy mix, emphasising its importance as a renewable and sustainable source of electricity generation in the country.

Hydropower stands as the foremost contributor to renewable energy on a global scale, playing a pivotal role in the pursuit of sustainable power sources. To achieve the ambitious target of net-zero emissions, the International Energy Agency advocates for a 3% annual growth in hydropower generation until 2030. This recommendation highlights the importance of hydropower in realising a carbon-neutral future. Furthermore, the construction of new hydropower dams remains unabated, with approximately 3,700 dams currently in the planning or construction stages. This accelerated pace underscores the continued emphasis on harnessing the benefits of hydropower for energy production and advancing socio-economic development (Randell 2022).

> Science without policy is still science, but policy without science is a gamble
>
> [David Grey]

Hydropower, as a renewable and environmentally friendly energy source, offers substantial advantages for economic progress and the shift towards cleaner energy. Nevertheless, the construction and operation of hydropower facilities are accompanied by significant social and environmental consequences. These impacts encompass the transformation of aquatic and riparian ecosystems, displacement of communities, deforestation, loss of biodiversity, disruption of river-dependent livelihoods, and modification of coastal sediment dynamics. It is crucial to recognise and address these multifaceted challenges to ensure the sustainable and responsible development of hydropower, balancing its benefits with the need to protect vulnerable ecosystems and local communities (Ulibarri et al., 2022).

However, the impacts of dams, reservoirs, and diversions on fluvial processes, their effects on the natural flow patterns and sediment transport within the downstream river are significant as discussed in Chapter 1. These alterations in flow and sediment loads have significant implications for the morphology of the river channel, leading to profound ecological consequences for physical habitats and the connectivity between the channel and floodplain (Petts and Gurnell 2022). Sustainability of there river basins cannot be ignored..

In order to provide a comprehensive economic analysis for project appraisal, several aspects need to be considered (WB 2015). Firstly, the early involvement of the project economist is crucial, as they can conduct a reality check on the cost and benefit data available and assess the likelihood of the project meeting the required hurdle rate. Additionally, it is important to address any data gaps that require immediate clarification. The rationale for the proposed investment project should include a presentation of the energy sector background, considering factors such as "least cost" planning, both in terms of financial costs to utilities and the broader concept of societal costs. The impact of the project on local (e.g., river fragmentation) and global (e.g., greenhouse gas emissions) externalities should be evaluated, taking into account carbon reduction targets and policy reviews related to transparency, equity, sustainability, and efficiency. Methodology-wise, data requirements and sources, approaches for setting counterfactuals, and the consideration of internalities and externalities should be clearly defined. Cost estimation should be transparent, encompassing factors like consumptive water use, sediment management, labor costs in large hydro projects, and pricing.

5.1. EXTANT LITERATURE ON HYDRO COSTING

The hydro costing analysis should go beyond traditional cost-benefit analysis (CBA) to consider uncertainties related to climate change, emerging technologies, future energy demands, and falling energy prices. Dealing with uncertainties can be approached through robust decision-making, real options analysis, and probabilistic scenario approaches. Data availability for counterfactuals, especially for generation rehabilitation projects, may pose challenges, requiring careful consideration of conditions degradation and sediment management. Alternative site-specific energy systems should be compared to site-specific hydro, and both internal and external factors should be accounted for in the economic analysis.

The World Commission on Dams (WCD) report did not advocate for the complete cessation of large dam construction. Instead, it put forward a proposition that large dams should be built according to a framework of internationally agreed-upon norms that align with global and international laws, as well as principles related to human rights, environmental protection, and the rights of indigenous peoples. The crux of the WCD report emphasised that the financing of high-impact dams should occur only after the quality of dam design has been significantly improved to meet the standards set by best practices in the field (Goodland 2010).

Social impacts of large hydro projects are the first to show up in public with the resettlement issues. In the process of conducting Social Impact Assessment (SIA), several key steps are involved. Firstly, it is crucial to identify the individuals and communities who are both interested in and affected by the proposed project or intervention, thereby identifying the stakeholders. Secondly, facilitating the active participation of these stakeholders in the decision-making process is essential to ensure their voices and concerns are taken into account. Thirdly, collecting baseline data and conducting social profiling helps establish a comprehensive understanding of the current social context. Subsequently, identifying and describing the specific activities that are likely to result in social impacts is a crucial step known as scoping. Once the potential impacts are identified, the next step is to predict these impacts and consider how stakeholders may respond to them. In order to provide a comprehensive analysis, it is important to identify and assess various intervention alternatives, including the option of not intervening at all. Recommendations for mitigation or compensation measures can then be formulated based on the findings. Finally, the development of monitoring and management programs ensures the ongoing assessment and effective management of the social impacts throughout the project's lifecycle (Tilt et al., 2009).

The World Commission on Dams, in their influential report, aptly stated that the pursuit of dam-related benefits has frequently resulted in an excessive and avoidable cost. This cost manifests in adverse social and environmental consequences borne by displaced individuals, downstream communities, taxpayers, and the natural environment. The profound observation made by the Commission highlights the significant trade-offs and negative impacts associated with dam projects, underscoring the need for careful consideration of these factors in decision-making processes (WCD 2000)

The adoption of the safe-minimum-standard approach worldwide emphasises the importance of meeting all minimum safety standards before approving hydroelectric projects. This includes minimising impacts on people, biodiversity habitats, agricultural land, greenhouse gas emissions, waterborne diseases, and downstream riverbank communities. It emphasises that no single aspect, such as low impact on biodiversity, should outweigh the potential flooding of human settlements. Four main categories of no-go areas for hydroelectric dams are identified: areas with high human population densities, lands belonging to indigenous peoples, habitats with rich biodiversity, and areas of significant cultural heritage (woodland 2010).

The rights-and-risks approach promoted by the WCD (2000) encourages negotiated agreements with communities affected by dam projects, providing them with legal enforceability. Rectifying previous damage is crucial, as exemption from cleanup responsibilities can lead to lower standards and inadequate accountability. Violence should be unequivocally abandoned as a tool for economic development, with market economics embracing the principles of willing seller-willing buyer and full-cost pricing. Environmental and social impact assessments are essential and increasingly cost-effective tools, although they require safeguards to prevent abuse. The WCD suggests practical rules-of-thumb for evaluating hydropower projects based on factors such as the ratio of affected individuals to generated megawatts and the ratio of land area preempted to megawatts generated. Mandatory greenhouse gas assessments should be conducted for all dam proposals, and carbon-sequestration offsets, such as forests, should be integrated into projects emitting greenhouse gases. As the climate changes, the risks associated with dam-induced restricted low flows and downstream flooding must be given greater consideration. Biodiversity conservation is paramount, and compensatory offsets should be financed and maintained indefinitely to mitigate any adverse impacts caused by dams on biodiversity.

In the field of assessing the environmental and ecological impacts of dams and related projects, several methodologies are utilised. These include life cycle assessment (LCA) and environmental impact assessment (EIA), which provide comprehensive evaluations of the life cycle and environmental consequences of such projects. Carbon footprint and carbon budget analyses are employed to quantify the carbon emissions associated with the dam, while methane emissions assessment focuses specifically on methane release. Carbon emissions are assessed to understand the overall carbon impact. Ecological-economic assessment examines the interplay between ecological and economic factors, while ecological losses and ecological compensation address the ecological impact and potential mitigation measures. River ecosystem analysis focuses on evaluating the impact of dams on river ecosystems. Ecological economics explores the economic aspects of ecological systems. Trade-off analysis examines the balance between competing factors. Ecological benefit-loss evaluation assesses the net gain or loss of ecological benefits. Energy analysis is used to evaluate the energy and resource flows within the system. These various methodologies contribute to a comprehensive understanding of the environmental, economic, and ecological aspects related to dam projects (Briones-Hidrovo et al., 2020).

In order to comprehensively assess the impacts of existing and planned hydrological alterations, there is a pressing need for a deeper understanding of their effects. This understanding is crucial not only for evaluating the consequences of already constructed projects but also for predicting the outcomes of future endeavours. Additionally, this knowledge serves as a prerequisite for implementing ecological restoration initiatives, which are gaining increasing prominence. However, thus far, no water-regulation project has been accompanied by a thorough description of the effects on riparian processes prior to construction. The development of such projects has historically lacked a proper understanding or acknowledgment of the ecological implications for riparian zones (Naiman et al., 1993).

Proper inclusion of all stakeholders is essential to ensure a comprehensive assessment of impacts associated with dam projects. These stakeholders encompass a diverse range of individuals and groups, including relocated communities, residents both upstream and downstream, those affected by associated infrastructure like roads and transmission lines, as well as conservation organisations concerned about environmental consequences. By involving all affected parties from the outset, there is a higher likelihood of garnering local support, minimising negative impacts, and initiating discussions on mitigation and compensation measures. It is important to allow all stakeholders to contribute to the selection of variables considered in the Social Impact Assessment (SIA). Moreover, a range of alternative locations and designs for dam projects should be thoroughly evaluated separately, offering decision-makers a spectrum of options that are technically and financially viable while minimising social and environmental repercussions. Mitigation or compensation measures should be incorporated into the selected alternative, with clear identification of the responsible agency or organisation. Monitoring of impacts throughout the dam's life cycle, spanning planning, construction, operation, and decommissioning, is crucial to compare projected impacts with actual outcomes. Recognising the interdependence of science and policy is vital within the public decision-making process, including the Strategic Environmental Assessment framework. Scientific understanding of environmental interactions, uncertainties, and significance of impacts is necessary, while policy supports funding for scientific studies and enforcement of Environmental Impact Assessment (EIA) recommendations during long-term monitoring and permitting processes before, during, and after dam construction (Tilt et al., 2009; Tullos 2009).

Incorporating new knowledge on the ecological effects of hydrological alterations into the policymaking process can be challenging, as there are often influential economic and political interests that support river regulation and downplay the ecological impacts of dams. This bias towards minimising ecological effects is reflected in the limited financial support allocated to the post-audit stages of hydroelectric projects compared to the planning and construction phases. This imbalance underscores the difficulty of integrating scientific findings into the decision-making process (Rosenberg et al.,1997).

As discussed in Chapter 1, large dams built for hydropower and storage have a number of unintended impacts on society, economy and environment. When costing for large hydro projects, many of these costs are externalised and not accounted for in hydro costing. However, over the full lifecycle, from inception to decommissioning, the external costs could be significant in order to assess the net benefits of a large hydro undertaking to the national economy.

It must be noted that externalities do not apply only to hydropower projects. If any alternatives are proposed to hydropower, the alternatives too have externalities of their own. For a fair and objective comparison of various alternatives, transparency and consistency in cost estimates is the key.

Ansar et al. (2014) suggest four policy positions to mitigate risks. These are:

Policy proposition 1 emphasises the preference for energy alternatives that do not rely heavily on site-specific characteristics, such as unfavourable geology. This policy acknowledges that energy solutions with fewer site constraints are more desirable in terms of feasibility and implementation.

Policy proposition 2 highlights the importance of energy alternatives that minimise reliance on imports and align liabilities with future revenue in terms of currency. This policy recognises the value of reducing dependence on external sources and mitigating currency risks associated with energy investments.

Policy proposition 3 suggests that reducing implementation schedules to shorter timeframes can mitigate the risks of inflation and uncertainties. Energy alternatives that can be built sooner, with lower schedule overruns and modular designs, are considered more favourable under this policy.

Policy proposition 4 underscores the preference for energy alternatives that do not constitute a significant proportion of a country or company's balance sheet. Policymakers, particularly in economically developing countries, are advised to avoid highly leveraged investments denominated in multiple currencies.

These policy propositions question the effectiveness of relying on large hydropower dams as the dominant solution to global energy challenges. They propose exploring smaller, more numerous interventions that offer better risk management and potentially higher net present value, despite potentially higher unit production costs.

Considering the failure risks associated with cost and schedule overruns, it is evident that projects with poor performance in these areas also tend to have unfavourable environmental and social track records. Geological risks, although anticipatable to some extent, are challenging to hedge against completely due to the substantial costs and the possibility of encountering unforeseen conditions. Currency exposure and the high propensity for unanticipated inflation pose additional challenges for large dams, making them financially vulnerable and potentially leading to adverse outcomes for companies and countries lacking the capacity to absorb such risks. The argument is made that economies of scale associated with large-scale projects may not justify the increased exposure to risk and potential financial impairment.

IHA (2020) has developed a Sustainability Assessment Protocol for large hydro projects. The principles that underpin the protocol emphasise the concept of sustainable development, which involves meeting present needs while safeguarding the ability of future generations to meet their own needs. Sustainable development encompasses various aspects such as poverty reduction, human rights respect, the transformation of unsustainable production and consumption patterns, long-term economic viability, protection and management of natural resources, and responsible environmental stewardship. Achieving sustainable development requires a careful consideration of the interplay between economic, social, and environmental values, taking into account synergies and trade-offs. This balance should be pursued in a transparent and accountable manner, leveraging expanding knowledge, diverse perspectives, and innovative approaches. The core principles of social responsibility, transparency, and accountability are integral to the sustainability framework. Furthermore, hydropower, when developed and managed sustainably, has the potential to generate national, regional, and local benefits, making it a valuable contributor to achieving sustainable development objectives within communities.

5.2. LIFECYCLE COSTS OF LARGE HYDRO

Following essential cost components have been identified from extant literature which directly or indirectly effect the cost of a large hydro project incurred to the society and the environment.

5.2.1. DIRECT COSTS

Direct Costs of erecting the infrastructure would including operations and maintenance would include:

- Feasibility
- Design
- Land acquisition
- Relocation
- Construction
- Financing
- O&M

The above mentioned costs are catered for in the estimation of tariff by PPIB.

However, there are other unavoidable direct costs relating to infrastructure and operations which have not been reflected in the estimation of hydro tariff. These may include are:

Security - because of global and local geopolitics Pakistan has to cater for her internal security. All existing large hydropower projects are considered national assets and are guarded by heavily manned and equipped for security outfits. This cost is not reflected in the O&M but borne by the tax payers nevertheless.

Major upgrades - from raising of walls of Mangla Dam to inclusion of new power tunnels in Tarbela, there are upgrades planned in large hydro project to be implemented at a later stage. These upgrades need to be included in the lifecycle cost of the project - especially when these are preplanned

Major repairs - the larger a facility the larger are the risks of expensive major repairs during its lifecycle. Collapse of tailrace tunnel at NJHP is an example. This risk may be covered through, for example, through an insurance instrument, which could have a recurring cost over and above the regular O&M expenses.

Decommissioning - every large hydro facility has a useful life and needs to be decommissioned at the end. Decommissioning should not be simply externalised to the next generation. But decommissioning of a dam is expensive, especially when it requires restoration of rivers as part of decommissioning. Decommissioning plans have to be part of the project design and operations over its lifecycle. It is discussed in Section 2.4.5.

5.2.2. SOCIAL COSTS

Project Proximate Issues - these issues relate with displacements, cultures, heritage and human relations in the vicinity of large dams as discussed in Section 2.2.1

Local Economy - it covers both boom and bust of local jobs during and after the construction, as well as loss of existing livelihoods during and after the project as discussed Section 2.2.2

Downstream Social Issues - deal with communities impacted by upstream damming, fragmentation of river, loss of wetlands, changed silt erosion of river delta, loss of livelihoods and consequent displacements due to land degradation and and erosion of river delta as discussed in Section 2.2.3.

Indigenous Communities - the issues of indigenous communities include, but not limited to lack of their participation in decision making for the mega projects impacting them and often complete disregards of local knowledge and practices as discussed in Section 2.2.4.

5.2.3. ENVIRONMENTAL COSTS

Ecosystem Services - Ecosystem services at work , for example, sequester carbon, clean air, filter water, support biodiversity, provide wild fisheries, maintain forests, supply water to wetlands, supply water and silt to river delta, and flush salts out of the landscape and into the sea as discussed in Section 2.3.1. Impact of dam on any ecosystem service has to be assessed and its monetary value to be evaluated against the cost of hydropower.

Carbon Footprint - there are many ways of establishing carbon foot print of large dams, from construction to operations to decommissioning. Details are discussed in Section 2.3.2

Ecological Integrity - flowing rivers a continuous and contagious ecological systems from source to delta. Any big or small barrier across a flowing river creates fragmentation in flow and impacts ecological integrity as discussed in Section 2.3.3.

Erosion-Deposition - Erosion and deposition are complementary morphological process of every river system. Dams not only trap suspended load of the river and cause siltation in the reservoirs but also deprive depositional environments such as river delta from the crucial supply of silt needed to prevent or balance-out sea water intrusion in river delta. Section 2.3.4 discusses this issue in more detail.

Rhythms of Flow - Dams disrupt the natural pattern of flows in the rivers, usually decreasing average high season flows and increase average low season flows. They tend to even-out the variability. However, many socio-ecological functions over millennia have evolved with the natural rhythms and seasonal variability of the flowing rivers. The related issues are discussed in Section 2.3.5.

Environmental Flows - a certain quantity of water is essential to maintain salt balance, silt transport and ecosystem health of a river system. Section 2.3.6 deals with environmental flows required in a rivers system.

Water-logging and Salinity - too many diversions from the river into the drier areas have caused both water logging and salinity in our landscape. Flowing rivers provide the vital service of flushing out salts from the landscape. Dams and diversions prevent waters from reaching the sea and consequently water and salts left in access of natural capacity of the landscape cause. Managing water-logging and salinity has costed the us projects worth billions of dollars in the past and such costs should be attributed to large hydro projects. Section 2.3.7 deals with these issues.

Wetlands - Indus River System is composed of wetlands all along the rivers in its flood plains. Many RAMSAR sites exists in the Indus Basin. Impact of dams on Wetlands. Wetland are discussed I Section 2.3.8.

River Delta - Erosion of Indus Delta due to many projects upstream is a very serious socio-economic and environmental issue as discussed in Section 2.3.9.

Flow Regulation Impact - the issues related to flow regulations for the sake of power generation, irrigation or flood control are discussed in Section 2.3.10.

Biodiversity Loss - Biodiversity loss and its impacts are discussed in Section 2.3.11.

5.2.4. COST OF RISKS

Cost of risk mitigation through social, structural and financial instruments needs to be added to the total cost of a large hydropower project. Ignoring these risk mitigation costs implies externalising risks into future.

Currency Devaluation - is a common occurrence in developing economies. It can have significant impacts on foreign currency loans and repayment plans. The related issues are discussed in Section 2.51.

Climate Change - can create problems of both floods exceed gin the capacity of structures and prolonged droughts. This can have serous implication both during construction and O&M costs of large dams as discussed in Section 2.5.2.

Social Discords - are common between upper and lower riparian communities and may cost a jurisdiction for maintaining peace and harmony with its various communities. The issues are discussed in Section 2.5.3.

Seismicity - is a high risk in Upper Basin Basin as discussed in Section 2.5.4.

Emerging Technologies - large hydro projects are old technologies, developed and perfected in the previous century. Many new technologies are have rendered old technologies redundant. The risk of losing the return on investments in hydro due to new emerging energy technologies is discussed in Section 2.5.5.

Democratisation of Power - Power markets, coupled with emerging technologies, could move towards laissez-faire economic models and render current centrally controlled models redundant. These risks are discussed in Section 2.5.6.

Emerging Legislations/Laws - Stricter environmental laws/regulations and emerging international legislations like ecocide pose risk to huge investments in dams which may cause either longterm or/and widespread environmental harms as discussed in Section 2.5.7.

Cost overruns - is almost an inevitable risk for dam builders and it is discussed in Section 2.4.3

Time overruns - is also an inevitable risk for large dams and is discussed in.Section 2.4.4.

5.2.5. TARIFF ESTIMATION

Power tariff for a generation plant is estimated based on type of fuel used, type of technology to burn the fuel, total capacity of the plant, capital cost , transmission/distribution costs incurred etc. IPPS, CPPA, NEPRA, DISCOs and etc are the agencies involved in estimation of tariff which is charged from the endusers of power.

Generation - Cost of generation is estimated by IPPs and approved by NEPRA

Procurement of power from IPPs is carried out by CPPA as procurement contracts

Transmission - NTDC estimates transmission costs taking into account the system losses

Subsidies/taxes/fuel cost adjustment etc are approved by NEPRA

Consumer/Enduser Costs are finalised after adding the operations and other expanses by DISCOs.

5.3. DUE DILIGENCE MATRIX

As discussed in the previous section, there are a host of factors which require evaluation in order to establish the lifecycle cost of a large hydro project.

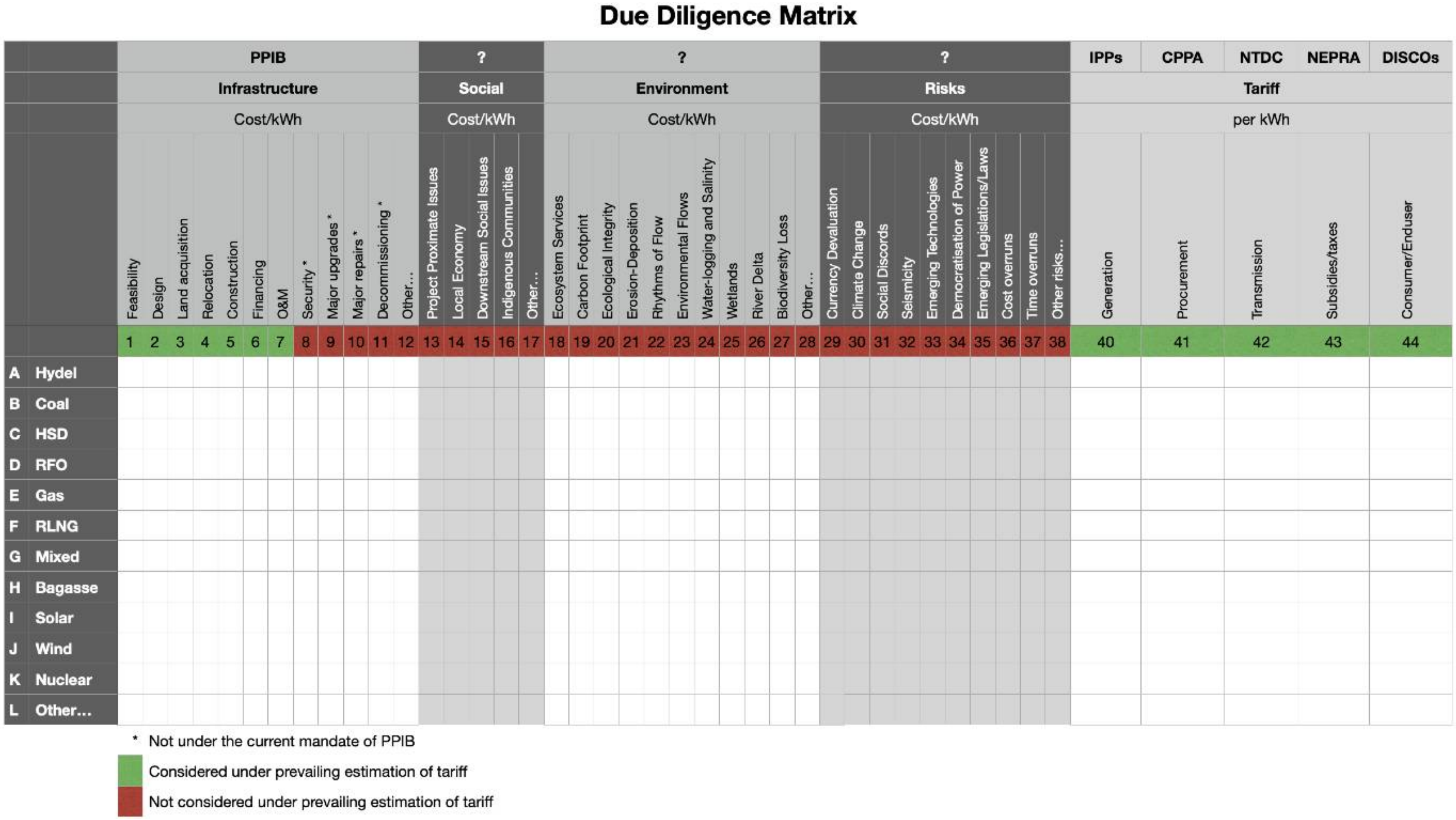
To determine the net economic return on the investment made in a large hydro project over its lifecycle, all direct and indirect costs need to be put together in a way that is tangible, transparent and readily understandable.

A matrix for due diligence of true cost of hydro power (or any other power project) is presented in Figure 15. The matrix has been termed as Due Diligence Matrix or DDM.

DDM provides columns for all conceivable direct and indirect costs that a power project may incur. In Section 5.2, the conceivable costs of a large hydro project are discussed. These are under the categories of direct costs, social costs, environmental costs, and cost of risks involved. After taking into account all these costs over the lifetime of the project, columns are provided for the estimation of tariff.

DDM also provides space for any other energy project to be analysed in a similar manner. This provides a transparent means of comparing all types of energy projects wit each other.

Rows of DDM, numbered alphabetically, relate to types of energy project. Columns of DDM, numbered numerically, relate to heads of costs incurred estimated for each kWh energy produced by the project. Each cell in the matrix can have an alpha-numeric identity for reference. For example cell A3 represents land acquisition costs for Hydro. It can be readily compared with cell J3 which represents the same cost for Wind.



Due Diligence Matrix

		PPIB												?					?											?										IPPs	CPPA	NTDC	NEPRA	DISCOs
		Infrastructure												Social					Environment											Risks										Tariff				
		Cost/kWh												Cost/kWh					Cost/kWh											Cost/kWh										per kWh				
		Feasibility	Design	Land acquisition	Relocation	Construction	Financing	O&M	Security *	Major upgrades *	Major repairs *	Decommissioning *	Other…	Project Proximate Issues	Local Economy	Downstream Social Issues	Indigenous Communities	Other…	Ecosystem Services	Carbon Footprint	Ecological Integrity	Erosion-Deposition	Rhythms of Flow	Environmental Flows	Water-logging and Salinity	Wetlands	River Delta	Biodiversity Loss	Other…	Currency Devaluation	Climate Change	Social Discords	Seismicity	Emerging Technologies	Democratisation of Power	Emerging Legislations/Laws	Cost overruns	Time overruns	Other risks…	Generation	Procurement	Transmission	Subsidies/taxes	Consumer/Enduser
		🟩 1	🟩 2	🟩 3	🟩 4	🟩 5	🟩 6	🟩 7	🟥 8	🟥 9	🟥 10	🟥 11	🟥 12	🟥 13	🟥 14	🟥 15	🟥 16	🟥 17	🟥 18	🟥 19	🟥 20	🟥 21	🟥 22	🟥 23	🟥 24	🟥 25	🟥 26	🟥 27	🟥 28	🟥 29	🟥 30	🟥 31	🟥 32	🟥 33	🟥 34	🟥 35	🟥 36	🟥 37	🟥 38	🟩 40	🟩 41	🟩 42	🟩 43	🟩 44
A	Hydel																																											
B	Coal																																											
C	HSD																																											
D	RFO																																											
E	Gas																																											
F	RLNG																																											
G	Mixed																																											
H	Bagasse																																											
I	Solar																																											
J	Wind																																											
K	Nuclear																																											
L	Other…																																											

* Not under the current mandate of PPIB

🟩 Considered under prevailing estimation of tariff

🟥 Not considered under prevailing estimation of tariff

Figure 15: Due Diligence Matrix for comparison of costs for energy production from different resources

DDM already highlights the parameters which add to the cost of hydropower but not included in the current procedures of estimating hydro tariff.

For example, a hydropower project would disrupt the rhythms of natural flow. The economic impacts of this disturbance would be evaluated for cell A22. Using spatial indexing and other methods in the extant literature, value for A22 would be evaluated and plugged in the DDM While comparing, for example, solar power as an alternative, the corresponding cell for solar is I22. Since solar does not impact flows, value in I22 would be null.

5.4. SPATIAL INDEXING

The aim of spatial indexing is to generate numbers that feed into the DDM. Each cell in the DDM represents a cost estimate.

Each cost estimate needs data, assumptions, parameters and boundary conditions etc, along with a methodology for evaluation.

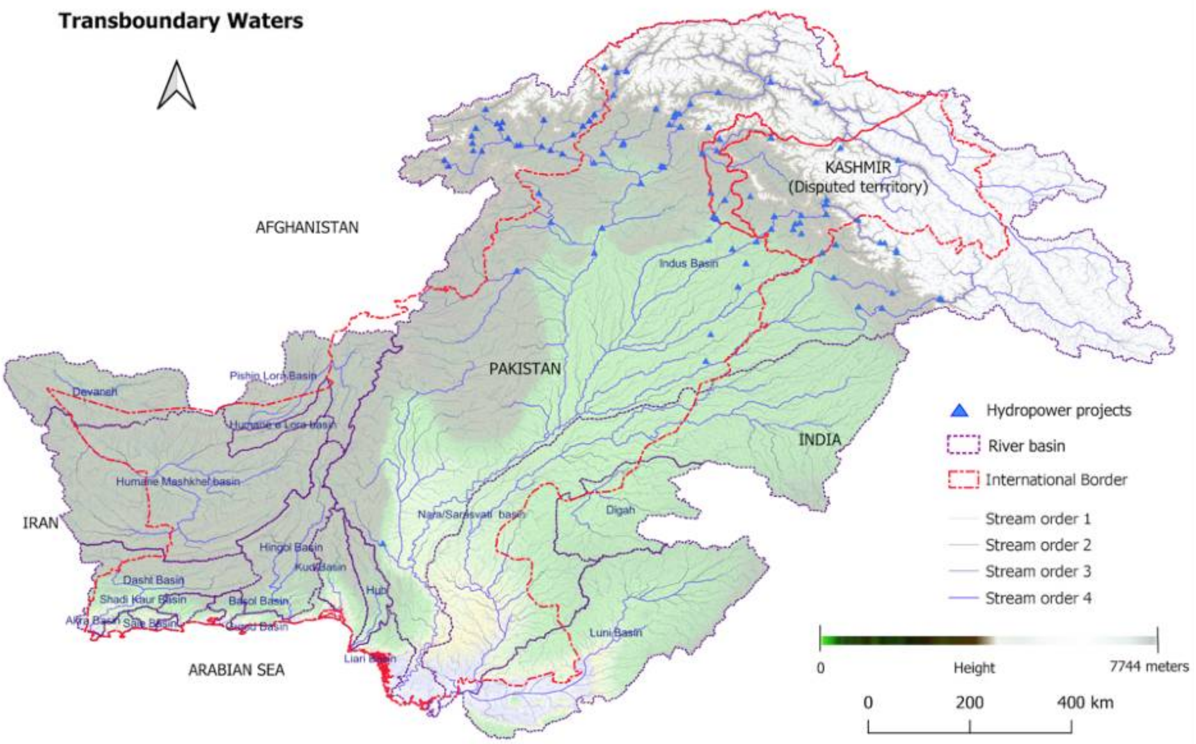
Spatial indexing is a methodology to evaluate costs for various cells in DDM, especially those cells where spatial information is involved in the analysis. An illustrative overview of spatial indexing is given in Figure 17.

The illustration shows hypothetical and simplified concept of, for example, calculation of energy demand. This will entail using GIS layers from rural, urban and industrial land-use, and adding spatial distribution of population density on land-use layers. Data for energy usage in rural, urban and industrial sector can be spatially represented as the data product. Further inputs from other resources can be taken to evaluate the cost of energy from a particular type of energy generation. For estimating external cost related to energy generation, social and environmental parameters can be obtained from GIS data layers and analysed.

Another benefit of using spacial indexing is that it highlights the spacial extents of the parameters impacting a particular cost.

The map in Figure 16 shows the location of all hydropower projects in Indus Basin along with the drainage and river network of the entire basin. One can see how the impact of all the dams in the basin converges downstream in the-Indus Delta - which otherwise lies almost a 1000 km away from the dams.

Figure 16: GIS representation of Dams and drainage network of River Basins of Pakistan



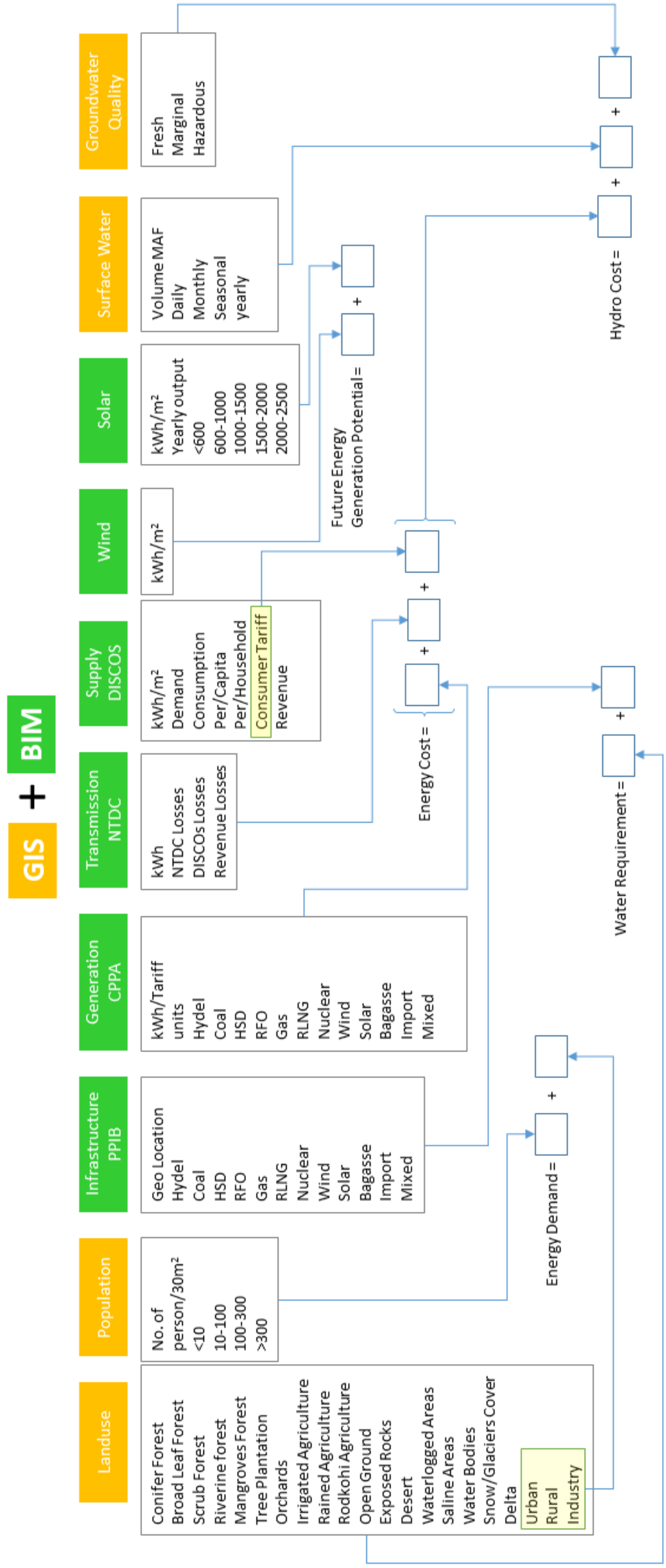


Figure 17: BIM-GIS Spatial indexing illustration for costing of hydropower

5.5. POPULATING DUE DILIGENCE MATRIX

Each cell of the DDM is a number which can be estimated through various means. However, as can be seen from the list of factors influencing the cost of a large hydro, it is difficult to evaluate exact cost of some of the listed factors.

The estimation of values for some factors will require bespoke methods for specific projects, while some could be estimated in more generalised manner. Moreover, some listed factors may not be relevant to a particular project.

The final values estimated for most of the factors in a case-study cannot be presented as exact dollar values. Rather the number may specify a range of possible values along with the more likely values.

The values will depend on data, boundary conditions, conceptual models, assumptions and ground based verifications, etc.

5.6. CONCLUSION

The final results of true cost of hydropower and its alternatives will be presented in a comparative way. The values presented in DDM will be indicative of true cost, but not exact. The main aim is to draw comparison with the alternatives which can help decision makers in setting investment priorities for the energy section.

This methodology and any costing exercise for a specific hydro project will help improve Indicative Capacity Generation Expansion Plan (IGCEP) for the subsequent years.

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