THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON HYDROPOWER

IEA Hydropower

VALUING HYDROPOWER SERVICES

The Economic Value of Energy and Water Management Services provided by Hydropower Projects with Storage

IEA Hydro Technical Report

Summary Report

October 2017

FINLAND JAPAN NORWAY BRAZIL USA EU CHINA AUSTRALIA

OVERVIEW OF THE IEA TECHNOLGY COLLABORATION PROGRAMME ON HYDROPOWER

The IEA Technology Collaboration Programme on Hydropower (IEA Hydro) is a working group of International Energy Agency member countries and others that have a common interest in advancing hydropower worldwide. Member governments either participate themselves, or designate an organization in their country to represent them on the Executive Committee (ExCo) and the working groups (Annexes), through which IEA Hydro's work is carried out. Some activities are collaborative ventures between the IA and other hydropower organizations.

Vision

Through the facilitation of worldwide recognition of hydropower as a well-established and socially desirable energy technology, advance the development of new hydropower and the modernization of existing hydropower

Mission

To encourage through awareness, knowledge, and support the sustainable use of water resources for the development and management of hydropower.

To accomplish its Mission, the Executive Committee has identified the following programme-based strategy to:

- Apply an interdisciplinary approach to the research needed to encourage the public acceptance of hydropower as a feasible, socially desirable form of renewable energy.
- Increase the current wealth of knowledge on a wide array of issues currently associated with hydropower.
- Explore areas of common interest among international organizations in the continued use of hydropower as a socially desirable energy resource.
- Bring a balanced view of hydropower as an environmentally desirable energy technology to the worldwide debate.
- Encourage technology development.

IEA Hydro is keen to promote its work programmes and to encourage increasing involvement of non-participating countries. All OECD and non-OECD countries are eligible to join. Information about membership and research activities can be found on the IEA Hydro website www.ieahydro.org.

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ACKNOWLEDGEMENTS

This Annex started in 2011, with a kick-off meeting followed by a number of Workshops and meetings. Sessions were also arranged at three annual HYDRO Conferences.

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EXECUTIVE SUMMARY

The IEA Hydro's recent work on Valuing Hydropower Services (Annex IX) included a multi-country review that investigated the many factors contributing to the full value of hydropower and its associated services. It is apparent that in many jurisdictions, the multiple value chains are not always appropriately recognised. As power systems transition and hydropower adjusts to new operating conditions, utilizing new or existing technologies, IEA Hydro members believe it essential that policy, regulatory and financial instruments evolve to appropriately recognise the important contributions that hydropower provides. Understanding these roles was an objective of the recently published Summary Report, which covered:

- Services provided to energy security, water security and sustainable development;
- Basic methodological concepts to assess the value of services;
- Suitable economic assessment approaches to quantify the value of services
- Preliminary valuations of key energy and water management services
- Initial assessment of the appropriate valuation methods for each service
- Basic methodologies to estimate fair allocation of costs between various stakeholders

The report, with appendices, identified methodologies useful in assessing the various value streams, broadly differentiated between hydropower production and water management and their related services. Means exist to reasonably estimate the value of water services, however, understanding the full value of hydropower energy services is more challenging. An increased level of detail is required and a handbook on international best practices was planned, as the basis for analysing the full value of hydropower. Undertaking such an analysis would help ensure appropriate levels of investment and reinvestment in critical hydropower infrastructure, which in turn would support the orderly and profitable transformation of electricity markets.

Energy Services

The role of hydropower in centralised grids is recognized as the most flexible low emissions source of electricity. However, power, energy, storage, and flexibility services are often classified and compensated in different ways in their respective markets. This report highlights the methods applied to value energy services, which can vary significantly between regions, based upon the context in which they are being assessed. For instance, methodologies applied may differ due to: the type of service being assessed; characteristics of the electricity market in which the service is assessed; the perspective and objective of the stakeholder conducting the analysis; the tools used to value the service; and the time-frame in which the analysis is being conducted. This report reviews the most frequently utilised approaches to value energy services, including: market-based valuation; avoided cost valuation; cost-based valuation; and qualitative valuation analysis.

Globally, many aspects of power system transformation are underway, including the rapidly increasing levels and sources of Variable Renewable Energy (VRE). Previously, balancing the lower levels of VRE penetration was achieved mainly through conventional sources of hydropower storage and thermal generation. With most countries having levels of VRE penetration below 30%, this is generally manageable. However, levels in excess of 30% introduce constraints to the system that can be hard to manage. The future prognosis is that energy storage will take on an increasingly important role, driving development of hydropower storage reservoirs and pumped storage schemes. Future generation investment must evolve in an orderly manner addressing the 'Energy Trilemma' of Supply Security, Affordability and Environmental Sustainability.

Water Services

It can be considered that all hydropower developments are multipurpose and that in addition to power production, consideration has to be given to water management services within the context of the water/energy nexus. Rivers and reservoirs are fundamental to sustaining life and economies. The breadth of services range from sustaining healthy ecosystems to providing water supply and irrigation diversions to enhance agriculture. In some regions, flood mitigation and drought management predominate, while in others, recreation and navigation are important. In each case, appropriate valuation of the water management services is crucial to decision making around overall development and management. Valuing a diverse range of water services is typically more difficult than valuing energy services. As such, this report considers a variety of methodologies that can be employed to determine the costs and benefits associated with various water services. For instance, the value of flood control benefits is derived from the avoided costs of flood damage, less the costs of providing storage space, whilst the value of recreational use can be based on survey results assessing a consumers' willingness-to-pay to engage in a given recreational activity on the reservoir. Services considered cover:

- Water Quantity Management
- Water Quality Management
- Regional Development
- Human Development
- Environmental Goals

Future Activities

Flexible Energy and Balancing Services

IEA Hydro recognizes the crucial role that hydropower provides for balancing power systems, as VRE penetration expands rapidly, and as an alternative to flexible operation of gas and coal fired thermal plants. This dynamic should present as a significant and profitable opportunity for producers of hydropower services. Therefore, the Annex will continue into a second phase of collaboration to address the future role(s) of hydropower as a critical dispatchable renewable energy source. These will include:

- technical issues for hydro balancing and providing flexibility services
- market and commercial aspects
    - costs (capital and operating) associated with the provision of storage and energy services,
    - value to the electricity network in providing these services.

This next phase will highlight the important role for hydropower in new and transitioning power systems globally. Results from R&D projects in member countries will provide input to a Roadmap, having the objective of appropriately valuing (and incentivising) hydropower balancing services. Important aspects include:

- clearly identifying the role of hydropower and the energy services provided in various future scenarios,
- addressing issues, alternatives and options for flexibility and balancing
- estimating costs and benefits for the power system

The Roadmap would conclude with the future profitable roles that hydropower can provide in providing storage and other services (such as balancing VREs) and what is required to enable this outcome. This has to be achieved within the overall market goals of providing safe and reliable energy and meeting environmental and social objectives at minimum cost of service.

Water Management Services and Climate Change

Climate change is a crucial factor in the consideration of water management services with impacts already being observed and documented through flood and drought events. Countries with large hydropower storage can help balance water flow and reduce impacts from such events. Phase II will consider designs and operational changes that mitigate these impacts. Also covered will be enhanced options for flexible operation where flood routing is strongly linked to reservoir capacity and pumped hydro schemes. The impacts of climate change on other water management services, such as irrigation, potable water supply, navigation and transportation, recreation and tourism are also issues that will be included in Phase II.

1. BACKGROUND AND ANNEX DESCRIPTION

1.1 Introduction

All hydropower projects which have any form of reservoir (even diurnal storage) are multipurpose and the services analysed in this Summary Report are potentially applicable to all projects. Historically, the broad range of energy and non-energy services provided by hydropower plants have not been explicitly valued, being part of a utility's mission. In many countries, large multipurpose hydropower projects were originally developed by national governments through state-owned corporations or authorities. More recent liberalization and privatization of the electricity sector has seen market mechanisms, regulatory frameworks and business models which do not take into account the diverse nature of services that can be provided beyond electricity generation. Energy and water systems are interdependent. However, the provision of multiple services may engender trade-offs between energy production and water management objectives as hydropower facilities respond to time-varying demands and market valuation of services.

The large capacity range of hydropower, together with its ability to quickly respond to operation changes and its capability to regulate the available water quantity in a river basin through reservoirs, enables hydropower to deliver a broad range of energy and non-energy services.

The final report of the World Commission on Dams (WCD, 2000) concludes that "… *a simple accounting for the direct benefits provided by large dams – the provision of irrigation water, electricity, municipal and industrial water supply, and flood control – often fails to capture the full set of social benefits associated with these services. It also misses a set of benefits and indirect economic (or multiplier) benefits of dams*

Furthermore, experts from international financing institutions acknowledge the challenge to integrate economic viability into financial viability considerations. Some projects which should have been built from an economic point of view have not been built because the broader societal benefits could not be factored into the criteria used to determine the financial viability. On the other hand, sometimes projects have been designed to satisfy primarily financial viability criteria, while not developing their full potential from an economic perspective[1].

In 2013, the IEA Technology Collaboration Programme on Hydropower (IEA Hydro) initiated an Annex to address this subject. As a first step in the documentation and dissemination of the outcomes of this Annex, this Summary Report has been prepared

1.2 Objectives and Scope of Annex

The objectives of the Annex are to:

Identify the energy and water management services created by hydropower developments and their spatial and temporal distribution, as applicable

[1] Typically, economic analysis of projects only goes as far as is necessary to demonstrate economic value. Once sufficient value has been demonstrated to exceed the necessary hurdle rate then there is no further effort to value the more difficult services which are simply described qualitatively and then often ignored. So a project may be described as having a 14% economic rate of return plus a range of unquantified benefits (or costs).

Enhance the understanding of the economic values and costs related to the provision of energy and water management services as well as of other socio-economic contributions by multipurpose hydropower projects.

Suggest appropriate methodologies to estimate the value of these services and generate policy recommendations for optimum development

To achieve these objectives, the Annex was sub-divided between two major tasks:

- Task 1: Energy Management Services
  - Energy Management (Grid or Energy) Services
- Task 2: Water Management Services and Other Socio-Economic Contributions
  - Water Management Services (water quality, water supply and flood/drought protection)
  - Transport and Navigation
  - Agriculture and Irrigation
  - Recreation and Tourism
  - Aquaculture
  - Socio-Economic Contributions

Specific activities of the Annex included:

1. Identify the services that hydropower can provide to energy security, water security and sustainable development, and their spatial and temporal distribution;
2. Estimate the economic value and costs of integrating variable renewable resources, such as wind energy and solar energy that is both large scale and subject to rapid fluctuations in supply;
3. Identify market and economic values for the provisions of energy services;
4. Estimate the economic value of services provided in the fields of water management and other socio-economic contributions through hydropower project development and operations;
5. Document appropriate economic assessment methods to quantify the value of these services;
6. Document the existing cost allocation modalities between multiple services of major hydropower projects and the different stakeholder in the project planning phase vs. plant operation phase
7. Identifying possible trade-offs in balancing various and sometimes conflicting needs for energy and water management services
8. Indicate how regulatory frameworks, market mechanisms and business models can sustain or hamper the optimal deployment or development of multipurpose hydropower services.

Literature reviews were initiated to collect region-specific case-studies, with the outcomes to be presented in a synthesis report. Dissemination will be through the IEA Hydro website and other communication tools at specific occasions and to target audiences.

The scope focuses on economic impact analysis in a macroeconomic assessment perspective with a particular focus on services which can be expressed in monetary values. Its valuation efforts will be based on observed behaviour and on marked based approaches to quantify the value of using water resources for man-made energy, water, development and ecosystem services "….w*hereas Cost-Benefit Analysis (CBA) is concerned exclusively with comparisons of benefits and costs to society created by a dam, economic impact analysis examines the distribution of the full range of economic impacts and outcomes that may occur as the result of a project, policy or other intervention."* (WCD, 2000)

The purpose of the Annex was to contribute factual information for use in:

- Project planning and financing
- Licencing/relicensing
- Pricing of water management services
- Pricing of network regulation services
- Successful business models
- Benefit sharing
- Policy-making and implementation of regulatory framework in the areas of:
    - Water (e.g. implementation of EU Water Framework Directive)
    - Energy (e.g. value of services for energy security)
    - Climate change (e.g. value of CC mitigation & adaptation measures)
    - Development (e.g. regional indirect + multiplier effects)

This was to be achieved through the development of:

- Case studies from different river basins across the world with assessment methods validated by internationally recognised economists
- A methodological handbook providing advice through:
    - economic assessment methods for use in determining the value of specific energy & water management services
    - templates covering the types of information to collect for case studies
    - a synthesis report summarizing outcomes discerned through analysis of case studies that address the five specific objectives of the study

1.3 Scope of Summary Report

As a first step in the documentation and dissemination of the outcomes of this Annex, a Summary Report has been prepared, with a scope covering the following key topics.

- ➢ Services that hydropower can provide to energy security, water security and sustainable development;
- ➢ Basic methodological concepts that can be used to assess the value of these services;
- ➢ Economic assessment approaches which are considered suitable to quantify the value of these services
- ➢ Preliminary valuations of key energy and water management services (illustrative examples by country/region as the values are very location-specific)
- ➢ Initial assessment of the appropriate valuation methods for each service

- Basic methodologies to estimate fair allocation of the costs of providing multiple services between the various stakeholders

These topics will be supported by existing case studies from different river basins and following review of this report, the next steps for the completion of this Annex will be determined and scoped.

1.4 Definition of Hydropower Services

1.4.1 Multipurpose Hydropower Projects

Hydropower Projects with Storage (Multipurpose Services) (MPHPP) are defined by the International Commission on Large Dams (ICOLD), Committee on Multipurpose Dams, as:

"Hydropower projects which are designed and/or operated to serve beyond electricity generation one or more other purposes".

However, all hydropower projects which have any form of reservoir (even diurnal storage) are multipurpose and the services analysed in this Summary Report are potentially applicable to all projects. Since each hydropower project is tailored to specific needs, there is a broad array of possible purposes which can be fulfilled. For this study the purposes have been classified as energy services provided to the power system, and water management services related to regional and human development.

1.4.2 Energy Management Services

Energy management services (some of which are referred to as ancillary grid services) are needed for proper operation of the power system. They are needed to maintain the balance between electricity supply and demand, maintain power system stability, and enable electrical energy to be delivered safely, reliably and economically from generators to consumers. In addition to these primary functions, grid services also provide various other contributions that make the operation of the power system more efficient and make electricity more affordable for consumers. In principle, grid services and contributions provided by hydropower and PSH plants can be grouped into several categories:

- Bulk power services
    - Energy generation
    - Energy/price arbitrage
    - Generating capacity
- Ancillary and reliability services
    - System inertia
    - Frequency regulation and control (primary, secondary, tertiary)
    - Contingency reserves (spinning, non-spinning, replacement/supplemental)
    - Energy imbalance, ramping, and load following
    - Voltage support
    - Black start service
- Transmission services
    - Transmission congestion relief
    - Transmission investment deferral

- System-wide effects (portfolio effects)
    - Better integration of variable renewables (e.g., wind and solar)
    - Reduced cycling and ramping of thermal units
    - Reduced overall system operating costs
    - Increased energy security

This is not an exhaustive list but it captures the bulk of the services and contributions typically provided by hydropower and PSH plants to the power system. Note that the names and terminology used to describe certain grid services may vary in different countries and regions of the world. For this reason, a Glossary of Terms is provided in this Summary Report to help with better understanding of various grid services, their purpose and provisions.

In the United States, a subset of grid services has been defined by the Federal Energy Regulatory Commission (FERC) as ancillary services (FERC 2016). In its landmark Order No. 888 (1996), FERC defines the following grid services as ancillary services:

- Scheduling, System Control and Dispatch
- Reactive Supply and Voltage Control from Generation Sources
- Regulation and Frequency Response
- Energy Imbalance
- Operating Reserve – Spinning Reserve
- Operating Reserve – Supplemental Reserve

1.4.3 Water Management Services and Other Socio-Economic Contributions

Water management services can be defined as covering the functions of integrated water management, regional development and human development as well as global and local environmental services. While most services are related to the direct use of the water resource from the reservoir, it should be noted that the regulating effect of the water retaining structures on the reservoir will affect the river far downstream, and in some cases to where it reaches the sea or another lake or reservoir. Thus, water management services should include all zones that could be affected by the reservoir impoundment and its operations

- Water Quantity Management
    - Flood control
    - Drought control
    - Ground water stabilisation
    - Water supply (increased water availability for other uses)
- Water Quality Management
    - Oxygenation
    - Temperature management
    - Cleansing of water (trash removal)
    - Sediment Management
    - Habitat Management (via flow management)
    - Barrier to saline water intrusion
- Regional Development
    - Navigation (transport)
    - Irrigation (agriculture)
    - Recreation and tourism

  - Aquaculture (fisheries and food)
  - Drinking water supply management
  - Industrial water supply management (e.g. cooling water)
  - Improved Infrastructure (roads, buildings, ramps, etc.)
  - Access roads and improved economic opportunities
  - Energy intensive industries

- Human Development
  - Health services
  - Education
  - Sanitation
  - Domestic power
  - Community services
  - Housing
  - Livelihoods
  - Nutrition and food supply
  - Professional competence development
  - New economic activities
  - Landscape enhancement through impounding reservoirs

- Environmental Goals
  - Reduction of GHG emissions
  - Reduction of atmospheric emissions
  - Creation of wetlands
  - Micro-climate around reservoirs
  - Ecosystem conservation
  - Carbon storage in reservoir sedimentation

2. BASIC METHODOLOGICAL CONCEPTS

Ideally, multipurpose projects should be financed based on positive net economic benefits or value covering all energy and water management services. Using this approach, even with imprecise estimates, provides the basis for project planning

2.1 Introduction to Methodological Concepts

Section 2 presents the basis of this study's methodological approach as well as fundamental economic concepts. This includes services having no market price, but evaluated by other means

2.2 Economic Analysis Versus Financial Analysis

In general, past investment decisions for hydropower projects have been taken based on financial analysis, but not all of these decisions were able to take a broader welfare perspective in the form of a sound economic analysis. The World Commission on Dams (WCD, 2001) revealed in general a lack of adequate understanding when it comes to potential macroeconomic effects.

Financial and economic analyses have similar features. Both estimate the net-benefits of a project investment based on the difference between the with-project and the without-project situations. The basic difference between them is that the financial analysis compares benefits and costs to the enterprise in terms of expenditures and revenues associated with a project, while the economic analysis compares the benefits and costs to the whole economy.

Economic analysis is concerned with the true value a project holds for the society as a whole. It subsumes all members of society, and measures the project's positive and negative impacts. In addition, economic analysis would also cover costs and benefits of goods and services that are not sold in the market and therefore have no market price.

There are two more significant differences between financial and economic analysis. While financial analysis uses market prices to check the balance of investment and the sustainability of a project, economic analysis uses economic prices that are converted from the market price by excluding tax, profit, subsidy, etc. to measure the legitimacy of using national resources to certain projects. Financial and economic analyses also differ in their treatment of external effects (benefits and costs), such as favourable effects on health. Economic analysis attempts to value such externalities in order to reflect the true cost and value to the society. The inclusion of externalities raises difficult questions of their identification and measurement in terms of money.

It should also be noted that opportunity cost is the fundamental building block of modern economic analysis. The true economic cost of one unit of a particular product reflects the cost of opportunities foregone by devoting resources to its production. This cost measures the economic value of outputs, products and services that would have been possible to produce elsewhere with the resources used to produce the last unit of the product (IPCC, 2001).

2.3 Regional and Macroeconomic Analysis

A large dam project can create a broad range of economic impacts. Regional and macroeconomic impacts refer to the effects of a project which are resulting from the interlinkage among various markets and economic sectors. (WCD, 2000 and Aylward, 2001). The introduction of a dam into an economy leads to a change in the supply of energy and water services. Table 2.1 below examines some regional and macroeconomic impacts

Category of Economic Impact	**Typical Groups Considered**	**Key Questions Addressed**
Changes in Economic Growth and Productivity	- Industry sectors - Consumers - Labour - Government agencies	• Do MPHPP inputs and/or outputs create shifts in productivity in various sectors? • Does the MPHPP create changes in aggregate output at the regional or national level relative to the baseline? • If so, by how much do economic growth and productivity change? • Within the most affected sectors, what are shifts in production factors?
Price Impact	- Consumers - Producers - Upstream and Downstream industries	• Which markets for goods or services are affected? • What is the magnitude of price changes in this sector? • How do these impacts make specific groups of consumers and/or producers better (or worse) off? • How are markets for substitutes and complements affected?
Production and Employment Impacts	- Industry and employment sectors - Labour - Government agencies	• Which industry sectors experience improved outlook for business? • Which sectors experience decline? • What are the implications of production changes for labour markets and wages? • What groups of labour will be affected the most? (e.g. seasonal workers)

Changes in Government Revenues and Expenditures	- Government Agencies - Taxpayers - Creditors - other sectors dependent on government	• Is the MPHPP financed with public funds? • If so, how significant a component of overall government borrowing does it represent? • How will the project's impacts on economic growth affect tax revenues and groups dependent on revenues (e.g. subsidised agriculture, public education)
International Trade and Competitiveness Impacts and Regional Balance	- Labour - Exporting Industries - Consumers - Creditors - Government Agencies - International Development Agencies	• How do other impacts affect exchange rates (demand for currency), export demand, trade balances? • What groups are most reliant on the export sector? • How does the project alter the strategic balance between regions?

Table 2.1. Examples of Regional and Macroeconomic Impacts (Source: Aylward, 2001. P.96)

2.4 Environmental Goods and Services

Environmental goods and services can be considered as products or activities that measure, prevent, limit, minimize or correct environmental damage to water, air and soil, as well as manage issues related to waste, noise and ecosystems. Basically, the purpose of environmental goods and services is to prevent, reduce and eliminate pollution and any other form of environmental degradation and to conserve and maintain the stock of natural resources, hence safeguarding against depletion.

Environmental goods and services can be classified under three headings; pollution management, cleaner technologies and products and resource management, where the latter is broad and includes sustainable agriculture, forestry and fisheries.

Environmental goods are typically non-market goods which provide social and environmental benefits, both in the present and for future generations if not negatively affected. Goods can be used for preserving the environment, such as solar panels, wind turbines etc. Environmental goods can include: clean air, clean water, green transport infrastructure (footpaths, cycle ways, greenways, etc.), public and urban parks etc.

Environmental services can be classified into physical structure services, scientific services, information services and social/cultural services and refer to the qualitative functions of the natural assets of land, water and air (including related ecosystem) and their biota. There are three basic types of environmental services:

- Disposal services which reflect the functions of the natural environment as an absorptive sink for residuals,
- Productive services which reflect the economic functions of providing natural resource inputs and space for production and consumption, and
- Consumer or consumption services which provide for physiological as well as recreational and related needs of human beings.

2.5 Ecosystem Services, Water Services and Hydropower

The relationship between ecosystem services and water management services provided by multipurpose hydropower projects is complex. Ecosystem services have been defined as benefits which humans derive from ecosystems (TEEB, 2008).

The complexity is enhanced as in some cases it has been found that if a watershed has been modified by hydropower, it does not necessarily imply a depletion of natural goods previously found. Throughout history, freshwater ecosystems have been changed to meet specific water, energy or development objectives and many highly managed ecosystems provide important ecosystem services, thus restoration to reference conditions may mean the loss of these services (UK NEA, 2011). Furthermore, it is seldom recognised that reservoirs can provide tools to actively manage water resources and fish resources. Without reservoirs there are fewer means of providing positive active water management interventions (flood control, fish support flows, water quality, sediment management etc.)

In general, it has been found that a water body regulated by hydropower provides water management services which might have been provided by ecosystems before the regulation, but which still are provided after human intervention. There are also examples of ecosystem services that have been lost, as multi-purpose hydropower schemes can result in both gains and losses. A study has investigated the conceptual foundation that links economics and ecology, and highlights the relationship between biodiversity and ecosystem services (TEEB, 2010). Examples include water and air quality regulation, nutrient cycling and decomposition, plant pollination and flood control, all of which are dependent on biodiversity. They are predominantly public goods with limited or no markets and do not command any price in the conventional economic system, so their loss is often not detected and continues unaddressed and unabated. This in turn not only impacts human well-being, but also seriously undermines the sustainability of the economic system.

Water management services from hydropower schemes are valued using ‘use values’ which result from direct human use (consumptive or non-consumptive) or are derived from the regulation services provided by species and ecosystems, as described in Section 3.

2.6 Availability and Withdrawal

Water resources from rivers and reservoirs are considered as a fundamental component of the water-energy nexus, with water scarcity, variability, and uncertainty becoming more prominent in many regions of the world. Hydropower with reservoirs may actually contribute to increase water availability and as such can be part of the solution to the water scarcity challenge. While hydropower is sometimes viewed as a major consumer of water, it is generally accepted that this use is non-consumptive. The water withdrawn from the reservoir or forebay and diverted through the intakes for hydropower generation is ultimately discharged into the downstream reaches of the river (US DoE, 2014). While this non-consumptive use may possibly result in changes to the flow regime of the river, hydropower production has minimal effect on the net discharge volume over time.

There may be evaporative losses from reservoirs, however this is part of a natural cycle and most reservoirs are formed in areas of existing bodies of water.

- Estimation of evaporation losses should be based on net change.

- Many reservoirs were originally developed to provide multiple services, or were upgraded during their operation to add services. Any net changes to evaporation should be attributed to each of the services that benefit from the reservoir formation
- Storage of water provides many benefits, including the improved availability of water for the various services at their time of need. This needs to be balanced by any changes in evaporation
- Reservoirs are operated to balance the requirements of the various water users, wherever possible. For many reservoirs, water levels are drawn down during the warmer, dryer months, when peak evaporation can occur.

Overall, the impacts of hydropower generation can be hard to quantify both in terms of evaporative consumptive losses and altered quality of water, since the formation of a reservoir can result in flows that are much colder than the original flowing streams.

Multi-purpose hydropower developments tend to be unique in terms of their physical features and it is difficult to take a common approach to the estimation of water consumption and withdrawal.

2.7 Direct, Indirect and Induced Impacts

Multi-purpose hydropower projects (MPHPP) can convey a number of direct, indirect and induced impacts. A large dam project can create a broad range of economic impacts, including the creation of new jobs for both the construction and operations phase. Direct impacts from development of a MPHPP include both inter-industry linkage from the production of goods and services and consumption induced impacts on the regional/national economy. However, the magnitude of indirect impacts of a MPHPP on the regional output and its added value will depend on the intensity of linkages among various sectors of the economy. Direct impacts include financial transactions, such as payments of wages and taxes, whereas indirect impacts include jobs created by suppliers of goods and services. Induced effects result from increased levels of income arising from the direct and indirect impacts. Table 2.2 examines some potential impacts of MPHPP under different conditions.

Activity	Potential Impact
For all MPHPP projects	
• Production of renewable electricity • Capacity to provide balancing services to stabilise the electricity supply-transmission-demand system (energy or grid services) • Enhanced options for surface water management (water quality) • Groundwater level stabilisation	• Modification of ecosystems • Change in the river's hydrological regime • Interruption of river continuity (barrier for fish migration, sediment transport and navigation); • Physical modification of river bed and shoreline
For site-specific issues, dependant on reservoir size	

• More diversified recreation and tourism activities
• Enhanced options for water quantity management (flood protection / drought prevention)
• Increased economic activity around a project promoted by the project
  o Improved access brought about by infrastructure development such as roads and bridges
• Increased availability of freshwater facilitating water uses
  o irrigation/agriculture
	• Inundation of land
	• Land use change
	• Resettlement

○ water supply (municipal/industrial) ○ transport by ship	

Table 2.2: Some Direct, Indirect and Induced Impacts of MPHPP

2.8 Non-market Valuation of Project Costs and Benefits

There are a number of primary and secondary costs and benefits which cannot be valued directly by market mechanisms. For example, the market cannot adequately price environmental assets such as river water, biodiversity, wetlands etc., as these are shared and others enjoy their benefits and share the costs. The basic market mechanism of balancing demand and supply fails to determine the true economic value of many such environmental assets. This is compounded as many individuals and institutions are not familiar with many of the services and functions that ecosystem and biodiversity provide.

There is also the situation where several goods and services may be produced at the same time, for example when a hydropower plant is built, the reservoir can also make water available for other purposes. This dependency can reduce transaction costs, with the value that goods and services, produced at the same time, an economic issue. Traditional economics assume that one good is produced at a time, but when several goods are produced simultaneously, transaction costs are reduced.

There is therefore a strong need to consider other means to assess the true value of unpriced environmental resources in order to handle trade-offs between conservation and development. Policymakers need to be aware of the value of natural resources, and the non-market valuation of environmental costs and benefits can support decision-makers in how best to manage natural resources. There are now a number of methods to estimate the value of environmental assets, some of the most recognized methods are presented in the following section. However, it has to be kept in mind that valuing environmental assets is an approximate approach and judgement will be needed.

2.9 Multiplier Effects

New supply and demand into a local or regional economy is likely to create a multiplier effect. An injection of extra economic activity will lead to more consumption, which creates more income and the multiplier effect refers to the increase in economic activity arising from new injections of consumption and spending.

The size of the multiplier effect on the non-tradable sector of the economy (i.e. construction) is project specific and depends on the types of jobs created, the availability and capability of local labour supply and the supporting infrastructure. The construction industry is considered to generally have a strong effect on economies and create a positive multiplier effect. However, the magnitude will be affected by local regional and political factors such as the unemployment levels, the level of government intervention in the economy and the labour market.

Multiplier effects will include all aspects of economic impact, thus using a multiplier to assess the economic benefit is difficult if combined with other assessment methods due to the danger of double counting. Further information can be found on multiplier effects and indirect economic impacts of dams in World Bank publications (Bhatia, 2008)

3 ECONOMIC ASSESSMENT METHODS

Section 2 presented the basic methodological approach as well as fundamental economic concepts related to hydropower energy and water management services. This section presents economic assessment methods which are considered suitable to quantify the value of these services. It should be noted that Section 3 is based on the World Commission on Dams (WCD) Thematic Review on Financial, Economic and Distributional Analysis (Aylward, 2001).

3.1 Introduction to Valuation Methods

The WCD Thematic Review of Economic and Financial Issues presented in its good practice tool chest, an overview of existing economic assessment methods for market and non-market valuation. Table 3.1 indicates methods that are generally considered to be suitable to value the different multi-purpose hydropower services (MPHPS).

For the purpose of this Summary Report, direct and indirect valuation approaches based on *Observed Behaviour* will be covered in the review of economic assessment methods as well as direct approaches of *Hypothetical Behaviour.* These include "Market Prices (direct observed)", "Revealed Preference (indirect observed)", Stated Preference (direct hypothetical) and Choice Modelling (indirect hypothetical) approaches.

	Observed behaviour	**Hypothetical Behaviour**
DIRECT	**Market Prices (Direct observed)**	Stated Preference (Direct Hypothetical)
	Competitive market prices, Shadow-pricing	Contingent Valuation (dichotomous choice, willingness-to-pay, bidding games)
INDIRECT	**Revealed Preferences (Indirect Observed)**	Choice Modelling (Indirect Hypothetical)
	Productivity Methods	Contingent referendum
	Avoided costs, preventive expenditures	Contingent ranking
	Travel Cost	Contingent behaviour
	Hedonic Pricing	Contingent rating
	Substitute Goods	Pairwise comparisons

Table 3.1: Valuation Methods (Source: Aylward, 2001. P.45)

3.2 Market Prices (direct observed)

The market price method estimates the economic value of products or services that are bought and sold in commercial markets. The market price method can be used to value changes in either the quantity or quality of a good or service. It uses standard economic techniques for measuring the economic benefits from marketed goods, based on the quantity people purchase at different prices, and the quantity supplied at different prices.

3.2.1 Price based valuation methods

The market price method uses prevailing prices for goods and services traded in markets. It measures the economic benefits based on the quantity people purchase at different prices, and the quantity supplied at different prices. The advantages of the market price method include that the valuation outcome is based on actual, not hypothetical, choices and does not require the analyst to make assumptions about people's behaviour.

3.2.2 Production based valuation methods

Production based valuation methods estimate the economic value of environmental resources or amenities that affect the cost of producing a marketed good or service. They can also assess the change in market value of marked traded products and services. Productivity methods are quantifying the output change. They essential look to value changes in output using market prices if these are available, or using unit values for the output derived from other methods.

The production function approach determines the value of environmental or natural resource inputs which are inputs into production processes. For example, a reduction of water quality may affect fish populations and reduce the income from fisheries. Similarly, poorer water quality may increase treatment costs for drinking water. Another valuation method used in this approach is the modelling of supply and demand curves, before and after an intervention/project, which allow to estimate changes in consumer and producer surplus and arrive at the benefits or costs of the impact. Supply and demand modelling is a rather straight forward assessment of quantities and unit prices to establish the net benefit.

3.2.3 Cost based valuation methods

Cost based valuation methods comprise several types of cost appraisal methods such as:

- Avoided costs
- Alternative costs
- Mitigation costs and
- Opportunity costs

Avoided cost methodology (also known as avertive expenditure, defensive expenditure or preventive expenditures) is typically used to value non-market environmental goods or services that enter into household activities or apply to commercial production and municipal services. It is often used to value the benefits of pollution control or to estimate the avoided pollution costs.

Examples of avoided costs include:

- Avoided emissions
- Sediment management in the catchment (dredging upstream can avoid costly infrastructure modifications further downstream).
- Defensive expenditure, such as the reduction in expenditures on water treatment due to improvement of water quality
- Preventive expenditure such as investment in flood control infrastructure or measures avoids or reduces major flood damage

The change must be from a pattern of expenditures aimed at avoiding welfare reducing effects of poor levels of environmental quality or service provision. In other words, the environmental damage must already be the status quo and defensive behaviour must be observed

Alternative cost methodology (also referred to as replacement cost approach) considers what expenditure would be necessary were a (new) degradation of environmental function to occur. The fundamental premise of this cost based valuation method is that the potential user should not pay more for the good, service or resource than it would cost to build an equivalent good/service or to replace it. It is also used as an accounting procedure to estimate monetary compensation that provides the same level of benefits to investigate whether it is worth it.

Examples of alternative costs include the ecological service of flood control provided by wetlands and cost estimation of man-made alternatives.

Mitigation or restoration costs are the actual and imputed expenditures for activities aiming at the restoration of depleted or degraded natural systems, partly or completely counteracting (accumulated) environmental impacts of economic activities.

Example of mitigation or restoration costs include revegetation, restoration of seagrass or wetlands

Opportunity cost method is used to assess potential returns not earned on an investment because the capital was invested elsewhere. It appraises the loss of potential gain from other alternatives when one alternative is chosen. The notion of opportunity cost plays a crucial part in attempts to ensure that scarce resources are used efficiently or to appraise the value of future potential investment opportunities which might be lost by a given choice.

Examples of opportunity costs include valuing the possible loss of potential flexible power production through reservoir level restrictions

The above descriptions of cost based valuation methods cover the broader social economic approach which may be more appropriate for multi-purpose valuation of water and energy services. In comparison, descriptions of economic assessment methods from a more business-focused perspective are summarized below.

The fundamental premise of the cost based valuation method, also referred to as asset based business valuation method, is that the potential user should not pay more for the good or service than it would cost to build an equivalent or replace a business. This can be referred to as replacement cost. Methods to estimate this replacement cost include:

- Asset accumulation method
- Excess earnings method

The asset accumulation method is a framework for tabulating the market values of business assets and liabilities, with the difference being the business value.

Important off-balance sheet assets include the internally developed intellectual property, and valuable business agreements. On the other side, the method accounts for contingent liabilities such as costs associated with regulatory compliance. The capitalized excess earnings method includes the value of business goodwill.

3.3 Revealed Preference (indirect observed)

The revealed preference approach is a method of analysing choices made by individuals, mostly used for comparing the influence of policies on consumer behaviour. These models assume that the preferences of consumers can be revealed by their purchasing habits. In general, economists believe what people do, rather than what they say they will do and that economic activity is the best indicator of what people actually want. Furthermore, by analysing individual behaviour in substitute and/or complementary markets, economists can infer values for the non-market resource or impact of concern

3.3.1 Hedonic Pricing method (property cost)

The basic premise of the hedonic pricing method is that the price of a marketed good is related to its characteristics, or the services it provides. Therefore, the value of the individual characteristics of goods can be determined by considering how the price that people are willing to pay changes when the characteristics change.

The hedonic pricing method is used to estimate economic values for ecosystem or environmental services that directly affect market prices. It is most commonly applied to variations in housing prices that reflect the value of local environmental attributes. This includes the economic benefits or costs associated with:

- environmental quality, including air pollution, water pollution, or noise
- environmental amenities, such as aesthetic views or proximity to recreational sites

3.3.2 Travel cost method

The travel cost method is used to estimate the economic use values primarily associated with visiting ecosystem areas or recreation sites. This method covers variations in economic benefits or costs due to:

- changes in access costs for a recreational site
- elimination of an existing or addition of a new recreational site
- changes in environmental quality at a recreational site or ecosystem areas

The basic premise of the travel cost method is that the time and travel cost expenses that people incur to visit a site represent the value, which can be estimated based on the number of trips made using the different travel costs.

3.4 Stated Preference (direct hypothetical)

Stated preference methods refer to a family of hypothetical techniques that involve the creation of contingent or hypothetical markets. They are often regrouped together under the heading of contingent valuation methods (CVM). Stated preference approaches attempt to measure willingness-to-pay values directly. Unlike revealed preference approaches, which rely on markets to infer values for environmental and social factors, stated preference methods develop values by conducting surveys to directly elicit information about respondents' preferences for non-market factors. They require purpose designed surveys for the collection of data.

3.4.1 Contingent valuation / willingness to pay

Contingent valuation (CV) is the most frequently employed stated preference technique. It is based on the premise of asking people to indicate their willingness to pay for a goods or service, contingent on a specific hypothetical scenario and description of the goods or services as well as based on the creation of a hypothetical payment vehicle. It makes the assumption that people would follow through with their commitment which is a recognised weakness in the method. Although CV can be used to value many different types of non-market factors (and CV remains the only established method for assessing intrinsic values) the reliability and validity of CV has been the subject of much controversy.

In the dichotomous choice methodology, respondents are presented with a proposed price and are asked to accept or reject it. This is generally agreed as the preferred method of eliciting responses to willingness-to-pay questions.

An example is to ask tourists how their behaviour with regard to site visits would change, with a rise in entrance fees.

3.4.2 Choice modelling / conjoint analysis

Contingent choice modelling/conjoint analysis is similar to the contingent valuation in that it is based on asking people to state their willingness to pay, founded on a specific hypothetical scenario and description of various goods and services, but with a variety of choices. Making choices between alternatives, rather than assigning value, is the main feature of this method. Formats for choice analysis include discrete choice, ranking and rating.

3.5 Estimation of Value Transfer (indirect hypothetical)

The process is used to estimate economic values for ecosystem services by transferring the value from existing studies in another location and to use a comparative weighting technique. Benefit transfer can be used when it is too expensive and/or there is too little time available to conduct an original valuation study.

Estimation of transfer valuation methods do not require primary data gathering (e.g., surveys) or other primary economic research. Rather, they involve the application of unit value estimates, functions, data and models from existing studies to estimate benefits associated with the resource or impact under consideration. It involves three basic steps:

- Identifying and characterising the resource or service to be valued.
- Reviewing existing valuation literature to identify potentially applicable studies.
- Conducting the transfer valuation and calculating economic benefits (or losses).

In general, value transfer estimates will be more meaningful and defensible if the study has the following characteristics:

- Reliance on high-quality studies based on adequate data, sound economic methods, and correct empirical techniques.
- Consistency between the resource to be valued and the resource in existing studies.
- Consistency in the characteristics of the affected population (e.g. age, income, education level, proximity to the site, etc.).
- Accurate estimate of the size of the population holding values for the project resource or impact.

4. VALUATION OF ENERGY MANAGEMENT SERVICES

4.1 Introduction

Energy Management Services are needed to support power system operation and generation, transmission, and distribution of electricity from generating units to consumers. They typically include services related to power generation, grid stabilization and grid integration of variable sources of renewable generation. Since variable electricity generating sources cannot provide the full range of electric power system energy services, hydropower is often seen as the large scale technology option of choice to supply these services in a cost-efficient way.

Studies are reputedly taking place in various jurisdictions covering various aspects of Energy Management Services (also referred to herein as energy services), including:

- Research aimed at improved the understanding of how hydropower energy services are produced and contribute to power system stability, reliability, and flexibility, including specifics such as:
    - regulation of increasingly dynamic power systems,
    - rapid up-ramping and down-ramping of conventional generating capacity to accommodate increasing availability and imperfect forecasts of variable renewable generation,
    - voltage and frequency control assistance available from hydropower assets
    - storage of must-run generation, including that from wind, solar, and run-of-river hydropower assets.
    - the influences of hydropower asset design and hydrology on the capability of assets to produce energy services
    - facilitating optimal operation of thermal power plants by:
        - allowing them to run constantly at their most efficient level (DB notes "But then hydro generation not running efficiently"
        - ensuring that enough cooling water is available in the river
        - dispersing and reducing the water temperature of a river when it gushes through the turbines or over the spillways
    - improvement of existing generation dispatch and power flow modelling methodologies to resolve the time-varying availability and value of hydropower services
    - operation and maintenance costs, including additional wear and tear, associated with increased cycling of hydropower assets and increased fluctuations of load on hydropower facilities[2]
    - environmental impacts particularly associated with the provision of energy management services
- Economic and policy aspects of hydropower asset conception, design, and operation to provide energy services:
    - energy services market designs and their role in encouraging or discouraging the provision of hydropower services

[2] There would likely be a trade-off between increased hydropower O&M costs due to flexible operation and a decrease in the O&M costs of thermal plants. The net result might be positive or negative. If the same entity owns a portfolio of thermal and hydro plants in the same system, hydro can help reduce the overall O&M costs in the system and that avoided cost can be counted as a portfolio benefit of hydro. For an entity that only owns hydro, the benefit will be an externality unless the market compensates for it.

- business models for investment in and design of hydropower assets providing energy services
- balancing sometimes conflicting needs for energy and water services
- decreased hydropower energy production and water use-efficiency for providing energy services in response to short-term market fluctuations
- analysis of market rules and government policies that influence market participation and coordination of variable renewable generation and hydropower services
- expectations and (un)certainty of hydropower services revenue streams, including those from pumped-storage hydropower assets
- public and private investments and operational frameworks to encourage hydropower to provide services that integrate increasing generation from variable renewables sources
- allocation of costs associated with the provision of hydropower services

4.2 Task Objectives

In the current efforts to achieve greater economic independence from fuel price variations and to mitigate climate change through the increased deployment of renewable energy sources, the issue of energy security is high on political agendas. As the penetration of variable non-firm renewable generation in electric power systems continues to rise, there is a growing need to integrate and back-up these new sources with firm and flexible renewable energy sources, such as hydropower. At the same time, there is also a need to improve the understanding of what kind of energy management services different types of hydropower plants are able to provide and at what costs. Hydropower is generally considered to be a flexible electricity generating source, though frequent changes in operation will entail increased wear and tear on electrical and mechanical equipment. Since energy security can easily be compromised by a lack of appropriate market mechanisms, business models or regulatory frameworks are needed to ensure that the required energy management services are available when required. This task will investigate how the provision of energy services is valued and rewarded in different regions.

The objectives of Task 1 of the original Annex were to:

Identify the energy services created by hydropower developments

Develop an understanding of key issues associated with the expedited large-scale provision of hydropower energy management services, especially those that facilitate integration of variable renewable resources, such as wind energy and solar energy

Enhance the understanding of the economic values and costs related to the provision of energy services provided by hydropower projects.

Region-specific perspectives that may be leveraged within the task were to include:

- Hydropower energy management services from Norwegian hydropower assets to support continental European variable renewables integration utilizing existing and new transmission assets
- Japanese pumped-storage hydropower development and operation

- Optimizing the operation of relatively scarce hydropower storage to enable integration of massive developing run-of-river capacity in Brazil
- The role and value of hydropower and pumped storage power plants in integrating wind and solar generation into traditional and restructured electricity markets in the United States.
- The role of hydro energy management services in the Australian National Electricity Market

4.3 Review of Published Literature

1. Argonne National Laboratory's project on "Valuation of PSH Power Services in the United States" (ANL, 2014)

The main purpose of the study was to develop detailed simulation models of advanced pumped storage technologies in order to analyse their technical capabilities to provide various grid services and to assess the value of these services under different market structures and for different levels of renewable generation resources (wind and solar) integrated within the power system. This included providing information on the full range of benefits and value of PSH plants.

In addition, one goal of the study was to improve the modelling representation of advanced PSH plants in production cost and electricity market simulation models. While most production cost models can accurately simulate PSH technologies when using an hourly simulation time step, there is a need to improve the modelling representations of PSH plants and properly capture their flexible operating characteristics in high-resolution simulations.

Another goal of the study was to perform production cost and revenue simulations and assess the role and value of various services and contributions that PSH technologies provide to the power system. The analysis focused on several geographical areas and was carried out for different levels of renewable energy generation in the power system. The analysis examined the benefits and value of PSH plants in both regulated and competitive electricity market environments.

Models were used to perform production cost and revenue simulations for the Base and High Wind renewable energy scenarios with and without PSH plants in the system. Both cost-based and market-based approaches were used in the analysis, with the study indicating the economic value of PSH in the following areas:

- Production Cost Savings
- Energy Arbitrage
- Operating Reserves
- Integration of Variable Energy Resources
- Reduced Cycling of Thermal Generating Units
- Reduced Thermal Start-up Costs
- Reduced Thermal Generator Ramping
- PSH Impacts on Power System Emissions
- PSH Impacts on Transmission Congestion

A paper summarizing the results of the study are shown in Appendix A.1. The full report is referenced.

2. CEATI's project on *"Quantifying the Non-Energy Benefits of Hydropower* (CEATI 2010)

Hydropower project owners and operators have historically competed with moderately priced carbon-based energy from oil, coal, and gas. At the same time, they have suffered increasing energy and non-energy trade-offs, with little recognition for their economic values or impacts.

In addition to their power dispatch characteristics, greater demands are placed on the use of hydropower resources, such as providing tangible social and environmental benefits. Hydro power is usually the power system operator's first choice for dispatching resources to serve reserve power needs, or providing an increasing demand for load-following capability where variable supply renewable resources are involved. The impact to hydro power from these "reserve" and "environmental" benefits comes both in the form of lost opportunity costs and in generally higher power costs.

The CEATI project notes the role of hydro projects value to net social welfare and equity is an important objective achievable through the explicit monetization of project benefits and associated values.

3. CEDREN's project on "HydroBalance" which addresses some key challenges for the development of large scale energy balancing and storage from Norwegian hydro (2013 to 2017)

Norwegian hydro power reservoirs offer the possibility for balancing the growing intermittent power production in European countries which are in the process of increasing the share of renewable energy in their electricity generation. European countries are adding more energy production from wind and solar power to the electricity market and the variable, fluctuating nature of these energy sources creates an increased need to balance consumption and generation. Hydroelectric power generation systems can store energy in reservoirs and offer flexible operation, but it is also possible to store energy for later electricity generation by pumping water from a lower reservoir to a higher one. Norwegian hydroelectric reservoirs have considerable storage capacity of 84 TWh, which represent 50 percent of the whole European hydro storage capacity. The HydroBalance project (Harby, 2017) investigated the potential use of the Norwegian hydropower system for providing flexible generation and energy storage in the European power market. The project covers:

- Identifying potential future uses of hydropower flexibility and storage through 2050
- Assessing the need for flexibility and storage provided by Norwegian hydropower
- Investigating how balancing as a service provided by hydropower may enter the markets, and assess economic opportunities.
- Examining environmental impacts of new operational regimes in reservoirs, and how to mitigate these.
- Analysing challenges in terms of regulatory framework, policy, public acceptance and economic conditions.
- Summarising the results throughout the project in a roadmap for large-scale energy balancing and storage from Norwegian hydropower.

A summary of this project is contained in Appendix A.3.

4.4 Valuation Approaches for Energy Services

The provision of energy services has a significant economic value as it enables stable and reliable operation of the power system and increases the flexibility of the electrical system to accommodate the changes in load and variable generation. Certain key energy services are considered critical to maintaining the operations and stability of the grid and are designated by the National Electric Reliability Corporation (NERC) as essential reliability services (US DOE, 2016)

In addition to energy generation, which can be easily monetized, there are also several grid services for which market-based procurement mechanisms are typically established in restructured electricity markets and which can be used to estimate the value of those grid services. For instance, most restructured electricity markets have established competitive markets for the procurement of regulation service, and spinning and non-spinning reserves. On the other hand, typically there are no established market mechanisms for many other energy management services and it is not easy to monetize them or estimate their value. In addition, the fact that decisions are widely based on financial considerations, rather than comprehensive economic assessments, adds to the challenge.

Hydropower operations typically provide multiple services at the same time and it's difficult to place a specific value on certain services and contributions (i.e., inertial response, voltage support, transmission deferral, and energy security). For these services, the normal approach is to value them in qualitative terms (Koritarov, 2014).

Different organizations in different jurisdictions take varying approaches to the valuation of energy services. The valuation approach may also be different based on the type of grid service under consideration, the type of electricity market environment (regulated or restructured electricity market), the perspective of the stakeholder performing the analysis (e.g., utility, independent power producer, regulator, etc.), the tools used for the valuation analysis, the time frame (short-term or long-term horizon), and other factors. Some of the most frequently applied valuation approaches include:

1. **Market-based valuation approach**. When there is an established market for certain service, typically a market-based analysis is performed to estimate the value of that service.

2. **Avoided cost valuation approach**: In cases when there is no market for that service available, the valuation is typically performed utilizing the avoided cost approach. The avoided cost approach compares the results of two cases, one with the specific grid service available (reference case) and the other in which that service is not available or is partially available. The difference in costs between these two cases (with and without certain grid service) may serve as a proxy monetary value of that particular service. If this monetary value is divided by the difference in grid service provisions assumed in the two cases, a monetary value per unit of service can be obtained.

3. **Cost-based valuation approach**. This approach attempts to account for actual costs of providing certain grid service. Typically, there are two sub-approaches: (1) calculating the actual costs of providing a grid service by certain technology or technologies, and (2) calculating the costs of grid service if provided by an alternate technology (or technologies). The first sub-approach may frequently underestimate the economic value of certain grid services, especially if they are presently provided at low cost (e.g., by

hydropower). The latter sub-approach is similar to the avoided cost approach, with the key difference being whether it is assumed that there may be a shortage of the grid service under consideration or the service will be fully provided by alternative sources or technologies.

4. **Qualitative valuation analysis**. As noted above, for certain grid services for which it is hard to quantify their monetary impacts it may be very difficult to apply the cost-based or avoided cost approach. In those cases, the value of those services is typically provided in qualitative terms. This may also be the method used where the economic value is already proven by valuation of other parts of the project; then rather than spend time and effort carrying out difficult and time consuming analysis of additional value services these are listed qualitatively as "other benefits"

The valuation approaches also differ with regard to time frame for the analysis. If the valuation focuses on the short-term, typically the analysis deals with the system operation and utilizes production cost models to simulate system operation and estimate its reliability and cost parameters. If a long-term valuation of a grid service is desired, then it is typically performed as an integrated resource planning (IRP) analysis to examine the evolution of the power system in the long-term and how the evolving plant mix may affect the provision and value of that grid service over time. The IRP analysis includes both a production cost model and a capacity expansion model. The purpose of the capacity expansion model is to look into both supply and demand options and try to determine the least-cost development of the power system over time. The role of the production cost model is to perform detailed simulations of system operation and calculate operating costs and reliability parameters.

The results of both short-term and long-term simulations can be used as inputs for various economic and financial analyses. This is often performed if the valuation analysis is used to determine whether potential investments into providing certain grid services will be financially viable. For example, the valuation of grid services is needed to determine the financial viability of an investment into a technology that can provide those grid services. The costs and revenues for providing those grid services can be used to perform the cost-benefit analysis, calculate expected cash flow over time, and calculate various financial parameters and ratios (internal rate of return, payback period, etc.).

Different stakeholders may also perform financial but usually not economic valuation analysis with different objectives. Whereas a traditional utility may perform a valuation analysis of grid services using a cost-based approach, an independent power producer may apply a market-based approach to determine potential revenue streams that can be achieved for certain grid services in a particular electricity market. On the other hand, electricity market operators may be interested in the valuation analysis to determine if present market rules provide fair compensation for provisions of grid services and whether they need to be adjusted or modified. In addition, electricity regulators may be interested to determine whether there is a need to provide certain incentives to developers of certain technologies that may improve the provisions of certain grid services that are currently underserved. For example, government regulators may decide to provide production tax credit (PTC) or investment tax credit (ITC) to developers of flexible generating technologies that are capable of providing more grid services. This can fill that gap between the economic and the financial valuations

4.4.1 Valuation of Bulk Power Services

Bulk power service provided by hydropower and PSH plants include energy generation, energy/price arbitrage, and generating capacity. It is important to emphasize the interrelationship between the different services listed, in that hydropower energy generation provides inertia and also potentially provides voltage support, capacity and frequency regulation

Energy Generation

The valuation of energy generation is a relatively straightforward process as it is based on electricity prices and can be easily monetized in both traditionally regulated and restructured electricity market environments. Depending on the nature of the market, both spot market pool prices and contract prices would need to be included to determine the value of energy generated. However, this is based on energy generation in a full supply market. If energy is replacing alternative fuels or lack of supply then alternatives are needed. It is noted that in general, this focusses on developed markets and needs adaptation to a developing country scenario

Energy/Price Arbitrage

The value of energy/price arbitrage can be determined from the differences in results of two cases, one with and the other without energy/price arbitrage, using the avoided cost approach.

Generating Capacity

The value of generating capacity provided by hydropower and PSH plants is more difficult to determine and it may require the use of different approaches, depending on the market environment and the time horizon for the analysis. In traditionally regulated environments, the value of generating capacity is typically determined in the long-term, as hydropower capacity replaces the need for investments into other generating capacity. An IRP analysis is performed to determine what other generating capacity would be necessary to build to replace the missing hydropower capacity and provide the same reliability of system operation in the long term. The differences in the investment and operating costs between these two cases would provide the value of hydropower or PSH capacity under consideration.

In restructured electricity markets, the valuation approach is different as there may be multiple generation companies competing in the market. In this case, the value of generating capacity is tied to how much revenue the capacity owner may earn in the market. Certain electricity markets are energy-only markets (e.g., California ISO, ERCOT in Texas, etc.) and the investments into generating capacity are expected to be fully recovered through sales of electricity generated by that capacity including for example through the sale of capacity ‘cap’ contracts that reflect the value of capacity in the market.

On the other hand, certain electricity markets in the USA such as PJM and MISO have capacity markets in a form of capacity auctions, which provide capacity payments for the new generating capacity. Capacity markets have also been introduced in some countries in the EU, (France and the UK). The time horizon for capacity auctions is rather short (rolling 3-year periods) and the objective is to procure enough generating capacity to ensure reliable system operation with adequate reserve margins. Similar to the IRP analysis, the capacity auctions allow for both supply and demand options (e.g., demand response) to bid into the capacity market. The resulting auction prices represent the capacity payments, which can be used as a proxy for the value of generating capacity in restructured electricity markets. However, in practice the capacity payments are typically rather low as the auction prices tend to be dominated by low-cost capacity options (e.g., gas turbines or demand response). Also, the relatively short-term horizon for capacity auctions (up to 3 years) does not take into account the optimal plant mix that may be needed by the power system in the long term.

4.4.2 Valuation of Ancillary and Reliability Services

Ancillary and reliability services include system inertia, frequency regulation, contingency reserves, ramping and load following, voltage support, and black start capability. However, it should be noted that the following subsections are primarily relevant to developed markets and need adaptation to developing country scenarios

System Inertia

System inertia is provided by the rotational mass of generators that are in operation and synchronized to the grid. The inertial response of rotating machines has a stabilizing effect on the grid, especially in case of outages of generating units or sudden changes in demand. System inertia tends to oppose the change in frequency caused by these events. With a larger penetration of variable renewables and other technologies that do not provide adequate amounts of system inertia, it has been noticed that power systems become increasingly unstable in the case of outage events and large frequency deviations. While power systems in the past had plenty of system inertia, as most of electricity was generated by rotating machines, at present many power systems with large penetration of variable renewable have decreasing amounts of system inertia and there is a need to procure additional inertial response service. FERC in the United States and AEMC in Australia are presently exploring the needs for system inertia and investigating the potential establishment of market mechanisms for procurement of inertial response service. The research studies so far have mostly dealt with quantifying the needs for system inertia and not much work has been done on the valuation of inertial response.

Frequency Regulation

Frequency regulation or frequency control is a service that keeps system frequency within a narrow range around nominal frequency (e.g., 50 Hz in Europe and Australia, 60 Hz in the United States). Frequency regulation typically includes both the governor response (frequency response of turbine governors) and the Automatic Generation Control (AGC). It is provided by generating units that are online and have frequency responsive governors, and by demand resources that can rapidly respond to AGC signals and provide regulation up or down to maintain system frequency within a specified range. The valuation of frequency regulation is rather straightforward as most restructured electricity markets have a competitive market for regulation reserve which is procured through a bidding process. Some markets, such as California ISO, have separate markets for regulation up and regulation down reserves. In traditionally regulated utilities, the cost of providing regulation reserve is part of the overall electricity generation cost and its value is determined using cost-based approach.

Contingency Reserves

Contingency reserves (spinning, non-spinning, and supplemental/replacement reserves) are primarily deployed in case of an unexpected outage of generating capacity (contingency) in order to balance system generation and demand and return system frequency to its nominal value. Spinning and non-spinning reserves are typically deployed within 10 minutes following an outage event, while supplemental or replacement reserve is typically deployed within 30-60 minutes. The primary purpose of supplemental reserve is to replace the deployed spinning reserve, so that it can be available and ready for another outage. Since contingency reserves also help restore system frequency, they are considered a part of the frequency control. Most restructured electricity markets have established market mechanisms for procuring contingency reserves. The market prices for spinning, non-spinning and supplemental reserves, typically determined through a competitive bidding process, may serve as a proxy for the value of these services in electricity markets. In regulated vertically integrated utilities, the value of these services can be determined using the cost-based and avoided-cost approaches. Depending on the plant mix, the cost-based approach may underestimate the value of these services, especially if they are presently provided by low cost units like hydropower and PSH plants. The avoided-cost approach provides a more realistic valuation of these services.

Energy Imbalance, Ramping and Load Following

Energy imbalance service supplies any hourly mismatch between the energy supply and the load being served in the control area (FERC Order No. 888). Therefore, energy imbalance accounts for the difference between the scheduled and actual energy generation, power exchanges, variable generation, and system load. Ramping and load following refer to the increase or decrease in the power output of generating units in order to follow the changes in electricity demand from hour to hour and to counter the intra-hourly variability of variable generation (wind and solar). Load following resources must have the ramping capability to pick up the hourly load ramps between scheduling steps as well as to maintain the system frequency by compensating the intra-hourly variability of variable renewables (flexible ramping reserves). Load following may be provided by units operating under AGC or through manual control.

Low capacity factor and variable generation resources, such as wind power, require load following capability that hydropower can provide. However, this can reduce the resources that existing hydro power provides for contingency reserves. In addition, the demand for load following capability, or reserve peaking capacity, also increases where residential demand becomes a large share of system loads.

Most restructured electricity markets have established market mechanisms for procuring load following service. With the increasing penetration of variable renewables, some markets, such as California ISO, need more flexibility and ramping capabilities and are introducing new market mechanisms (e.g., Energy Imbalance Market) for procuring flexible ramping services. In vertically integrated utilities, both load following and flexible ramping can be valued using the avoided cost approach.

Voltage Support

Voltage support service utilizes reactive power control mechanisms to keep transmission bus voltages at nominal level. As reactive power does not travel well over long distances, voltage support is by nature a local service. As they are essential for the stable operation of the power system, voltage support and reactive power control have been studied extensively. In contrast to the technical nature of this service, which is well known and its operation is a routine process in all power systems, the cost impacts of voltage support are more challenging to determine. One way to assess its value is to use the cost-based approach, where the cost of an alternate technology that can provide voltage support (e.g., capacitor banks) is used as proxy for the value of voltage support provided by hydropower or PSH units. Valuation approaches for voltage control also include assessing the power loss by reactive power supply from hydropower generators and the operating cost increase to keep the desired voltage level.

Black Start Service

Black start service or system restart allows parts of the power system to be re-energised by black start equipped generation capacity following a system-wide blackout. Unlike other generators, black start equipped generators can be started up without requiring a supply of energy from the transmission network.

Valuation approaches for black start services are typically cost-based and include assessing the maintenance and operating costs for keeping the station power supply during power interruption. In restructured electricity markets, in contrast to other grid services that are often procured through competitive market mechanisms, black start service is typically procured through a contract between the plant owner and market operator. Again, similar to the valuation of black start service in traditionally regulated utilities, the contract normally assumes a cost-based valuation of the black start service.

4.4.3 Transmission Services

These services include transmission congestion relief and deferral of investments into new transmission capacity.

Transmission Congestion Relief

Transmission congestion occurs when there is not enough transmission capacity available to transfer power from areas with excess generation or to areas that have insufficient power supply. The congestion typically occurs in areas that have weak transmission connections with other areas of the power system. These areas may have either high internal loads and not enough generation (load pockets) or too much generation and not enough load (generation pockets)[3]. Transmission congestion causes the differences in locational marginal pricing (LMP) in different areas of the power system. Areas with too much supply experience very low LMPs of electricity, sometimes even negative LMP values. On the other hand, areas with shortage of electricity supply experience very high LMPs. It would be worth mentioning that LMP/nodal pricing is not universally applied, and in particular, not in Europe, which leads to significant “re-dispatching” costs in countries such as Germany. Unless LMP were to be introduced, other valuation measures would be needed, e.g. based on the re-dispatching revenues.

While the long-term solution for transmission congestion can be achieved by constructing additional transmission capacity, or new generating units in load pockets, or developing energy storage and demand response resources, the transmission congestion relief typically refers to temporary actions that can be performed in the short term, utilizing the existing resources. This temporary congestion relief can be achieved by re-dispatching some of generation resources, curtailing excess renewable generation, deploying demand response resources, utilizing energy storage, or other actions. Flexible hydropower, and especially PSH plants, can provide significant amount of transmission congestion relief by reducing the need for re-dispatch of generation sources, reducing curtailment of variable renewables, and by reducing the need for demand response actions.

[3] An example for a generation pocket was the Texas panhandle, which around 2010 had a lot of wind generation but not much load in the area. Often, the excess wind generation had to be curtailed because it could not be transferred to load centres elsewhere in the state due to weak transmission connections. These issues have been mitigated since by the construction of additional transmission lines.

The value of transmission congestion relief in the short-term can be determined by analysing the differences in LMPs and the differences in curtailed energy generation and system load. This is a short-term analysis, so transmission relief actions are limited to generation and demand sources that are already existing and operating in the system, not the ones that could be constructed or developed in the future.

Transmission Deferral

Transmission deferral refers to postponing the investments into new transmission capacity by performing certain actions that can reduce or defer the need for the construction of new transmission capacity. This is similar to transmission congestion relief, except that transmission deferral primarily deals with longer timeframes. Therefore, in addition to actions that can bring temporary congestion relief, transmission deferral also considers actions that can reduce or postpone the need for the construction of new transmission capacity for several years or more. Those long-term actions may include the construction of new generating capacity in load pockets, adding energy storage to the system, developing demand response programs, and others.

PSH plants can provide an effective transmission deferral solution for both generation and load pockets. By constructing PSH plants in those areas so that they can either store excess generation or create system load when needed, the need for new transmission capacity may be reduced or completely eliminated.

Similar to the valuation of transmission congestion relief in the short term, the value of transmission deferral in the long-term can be determined by analysing the differences in LMPs and the differences in curtailed energy generation and system load. Since this analysis deals with the long-term timeframe, the actions can include the construction of new generating capacity, energy storage, and demand resources. The capital investment and operating costs of these new resources should also be accounted for in the analysis.

4.4.4 System-Wide Effects

System-wide or portfolio effects of hydropower and PSH operation include better integration of variable energy resources, reduced cycling and ramping of thermal generating units, reduced overall system operating costs, increased energy security, and others.

Integration of Variable Renewables

Flexible hydropower and PSH plants can provide support for grid integration of variable renewables by counterbalancing their variability and storing their excess generation, thus reducing their curtailments. The value of hydropower and PSH technologies for the integration of variable renewables can be determined using the avoided cost approach, by running two cases, with and without hydropower and PSH capacity in the system. The differences in the level of variable renewables that can be accommodated in the system, in their total electricity generation and in reductions of curtailments provide an indication of the value of hydropower and PSH plants in integrating variable energy resources into the grid.

Reduced Cycling and Ramping of Thermal Generating Units

The flexibility that hydropower and PSH plants provide to the system also contributes to reduced cycling and ramping of thermal generating units. The fast ramping of hydropower and PSH capacity and load-levelling operation of PSH plants create a flatter net load profile to be served by thermal generating units. This allows thermal generating units to operate in a steadier, more efficient mode, with less ramping up and down and fewer starts and stops.

Again, the value of hydropower and PSH units for reduced cycling and ramping of thermal generating units can be estimated using he avoided cost approach by running two cases, with and without hydropower and PSH plants in the system. The differences between the two cases in the ramping “mileage” of thermal generating units, and the number of their starts and stops, can provide an estimate of the value of hydropower in reducing these costs.

Reduced System Operating Costs

Hydropower and PSH plants reduce the overall power system operating costs and the average cost of electricity generation. Being a renewable energy resource, hydropower utilizes water as fuel, thus reducing the need for thermal generation and the use of fossil fuels. The run-of-river hydropower plants reduce the need for operation of baseload thermal generation, while peaking hydropower plants reduce the need for generation from expensive peaking thermal units.

The value of hydropower in reducing the cost of electricity generation can be determined using the avoided cost approach, by running two cases, with and without hydropower and PSH plants in the system. The differences between these two cases in thermal power generation and fuel use can provide the value of hydropower in reducing electricity generation costs.

Increased Energy Security

As a domestic renewable energy resource, hydropower has a positive effect on energy security. Not only does it displace imports but can mitigate electricity price volatility by diversifying the portfolio of fuels used to produce it. On the other hand, regions/countries with very high percentage of hydropower in their electricity generation portfolio might be vulnerable to price spikes during drought events. This is especially important for countries with limited primary energy resources which have to rely on imports for a significant share of their energy needs. In addition to reducing the need for imported fuels in the power sector, hydropower and PSH plants can also have positive impact on reducing the imported fuels in other sectors of the economy as well. For example, with the greater electrification of the transportation sector, the electricity produced by hydropower and by hydropower-supported variable renewables can provide a significant amount of electricity to be used in the transportation sector, thus offsetting the use of fossil fuels.

4.5 Attributes of Hydropower, Fixed and Variable Speed Pumped Storage

Hydropower generation has three basic forms in terms of providing energy services; storage hydropower[4], fixed-speed pumped storage and adjustable-speed pumped storage. However, the attributes of each type can vary, based on their design and operation mode, but in general each provide numerous benefits:

- Significantly reduces system operating costs (production cost of electricity)
- Reduces cycling and ramping of thermal generating units
- Reduces curtailments of variable renewables (wind and solar)
- Provides a large amount of operating reserves
- Increases the stability and reliability of the power system
- Reduces transmission congestion and allows for transmission deferral

[4] Hydropower projects nominated as «run of river» may also contribute as they often have at least diurnal storage

The value of each type of storage hydropower to the power system increases with the higher penetration of variable renewables in the system.

Indeed, the maximum amount of intermittent, non-programmable sources that a power system can tolerate is generally considered to vary between 20 and 30% of installed capacity. Above 30%, storage capacity, particularly Pumped Storage Plants, are considered necessary to allow further intermittent energy development.

Some key differences between general hydropower plants, constant-speed (CS-) and variable-speed (VS-) pumped-storage hydropower plants (PSH) in terms of the energy services they provide are summarised in Table 4.1

	Generating Mode	Pumping Mode			
		AFC	Range of pumping operation	Output response speed	
				Normal operation	Transient operation
General Hydropower	All three types can provide AFC, spinning reserve, non-spinning reserve and load following functions.	×	×	×	×
CS-PSH		×	△ Only constant input possible	○ 0 - 100%／60 sec	×
VS-PSH		○	○ Variable within this range 70 - 100%	○ 0 - 100%／60 sec	○ 20MW ／0.1 sec

Table 4.1: Operating Capability of General, CS-PS and VS-PS Hydropower Systems

[Legends] ○: Possible
×: Impossible
△: May be possible under certain conditions

It should be noted that:

- In the generating mode, there is no difference among the three types because they can all provide ancillary services in the form of auto frequency control (AFC), spinning reserve, non-spinning reserve and load following.
- General hydropower plants have no pumping mode. Differences between CS-PSH and VS-PSH in the pumping mode are as follows:
  - CS-PSH does not have the AFC function in the pumping mode whereas VS-PSH does.
  - For the range of pumping operation, CS-PSH has only 100% constant input whereas VS-PSH has a variable pumping range from 70 to 100%.
  - For the output response speed, both CS-SPH and VS-PSH can reach full-capacity operation within 60 seconds at normal operation. However, at transient operation, CS-PSH has no ability to change the output whereas VS-PSH can change the output at the rate of 20MW per 0.1 second.

Therefore, VS-PSH can be operated more flexibly in the pumping mode and provide a wider variety of ancillary services than the other systems.

The balance of this section discusses the values, or the "ancillary service values," of the three types of hydropower systems, as operated in Japan.

Currently in Japan, there are no markets for ancillary services, so their costs are recovered in the wheeling charge. Japanese electricity utilities must apply for the government's examination and approval of the ancillary service costs. Appendix A2 shows evaluation results of the three types of hydropower plants currently operated in Japan, namely, general, constant-speed and variable-speed pumped-storage hydropower plants, in terms of the ancillary services they provide. The evaluation was made based on the disclosed wheeling charges that electricity utilities submit to the government for approval.

Ancillary services provided by general hydropower plants include frequency control by AFC operation, spinning reserve and non-spinning reserve.

Constant-speed pumped-storage hydropower plants (CS-PSH) are evaluated to have higher value than general hydropower plants in the ancillary services they provide. The reason is, in addition to AFC, spinning and non-spinning reserves, they have the effects of reducing fuel spent at thermal power plants by substituting thermal operation and increasing highly efficient thermal operation time.

Ancillary services provided by variable-speed pumped-storage hydropower plants (VS-PSH) have even higher value than CS-PSH because of their flexibility in service provision that is made possible by frequency control functions at pumping operation, adjustable pumping input and the ability to produce power at the highest efficiency at a given water level and input conditions. They are also evaluated to have higher fuel reduction effects than CS-PSH. Based on the assumption that costs and effects are of equal value, cost-based values of ancillary services provided by VS-PSH are higher because they are more flexible. In other words, a VS-PSH system has greater "flexibility value" than other systems.

As mentioned earlier, there are no ancillary service markets in Japan. However, opinions are currently being invited by General Transmission Utilities on the bidding methods of "peak adjustment power" that is necessary for frequency control and supply-demand balancing (as detailed in Appendix A2).

Based on one proposal of the bidding method, CS- and VS-PSH owned by one Transmission Utility are evaluated to have different values. Currently in cost evaluation, their differences are clear. Therefore, future possibilities are that CS- and VS-PSH will be evaluated to have different values.

VS-PSH systems are thought to be applicable not only to large-scale projects but also to small-scale hydropower generators.

Since VS-PSH has higher ancillary service values (meaning that the ancillary services provided by VS-PSH have higher cost-based values) and flexibility values, one possible way to make ancillary services available at reasonable cost in the future may be to add variable speed pumps alone to the existing general hydropower plants. This method may be applicable to small head hydropower generators in irrigation channels and water supply facilities.

4.6 Allocation of the Value of Energy Services

Valuing energy services provided by hydropower plants has been covered in this Section. In general terms, energy services provided by any specific project are allocated based on the plants capability and the requirements of the energy system.

5 VALUATION OF WATER MANAGEMENT SERVICES & OTHER SOCIO-ECONOMIC CONTRIBUTIONS

5.1 Introduction

Water Management and Other Socio-Economic Services from hydropower projects are acknowledged in planning and design but seldom quantified and valued explicitly or in full. Such services include:

- Water quantity management (flood/drought protection and groundwater stabilization),
- Water quality improvements (temperature control, oxygenation, trash cleansing)
- Catalyst effect for other water uses and ecosystems through increased availability of freshwater such as:
  - Domestic water supply
  - Navigation / transport
  - Irrigation /agriculture
  - Recreation / tourism
  - Aquaculture
- Catalyst effect for energy intensive industries
  - Water supply for aluminium, pulp and paper, aviation, shipyards, etc.
- Catalyst effects for broader socio-economic development
  - Regional development (improvement of infrastructure and services, employment, etc.)
  - Human development indicators

Enhanced understanding of water management and other socio-economic services engenders consideration of the value of those services, as well as the potential trade-offs to manage, but also how to allocate project development and operation costs related to providing those services.

The starting point for the valuation of these water management services for multi-purpose reservoirs should be at the planning and design stages of project development. This will allow the project to be optimized based on the total value of the project, and not on a single or a few of its principle purposes. This valuation should include the value of both direct and indirect economic benefits

It should be noted that regulations might introduce a dis-location of benefits and costs, in that regulated river flows may enable more water users to fulfil their water requirements, or allow more water users to develop their water needs. However, regulation might make access to water for other water users less reliable in that:

- Existing water uses might have a higher degree of security of supply, and new water users might use the opportunities of the regulated flow (e.g. change agriculture from rain-fed to irrigated lands). At the same time, some water users might have a less secure supply of water, as e.g. the water might be fully consumed/used by other water users
- Spatial dislocation of the benefits. Regulation might introduce a geographical change in the access of water, as those close to the regulation typically have a more secure access to water, while other users further away (far downstream, or in the tail end of a canal) might have less water than before the regulation. As such, the regulation might affect the internal competition for water between actors within the same sectors (some farmers might benefit, some might lose)

Where several goods and services have the potential to be available simultaneously, for example when a hydropower reservoir enables water availability for other purposes, transaction costs can be reduced. This should be considered in economic analysis.

This Annex focuses on the identification and valuation of services as well as on the existing modalities to apportion the costs related to providing the various services to different stakeholders. Investigation of public and private investments, regulatory frameworks and market mechanisms which facilitate or hamper the full deployment of non-energy services from hydropower are beyond the scope of this Summary Report.

5.2 Task Objectives

Hydropower projects with freshwater storage capacity, when properly designed and managed, can play an important role in catalysing sustainable development in many countries, as well as providing climate change mitigation and adaptation.

However, this potential is often not recognized. A lot of attention is generally paid to managing the negative environmental impacts of hydropower projects adequately, while the positive environmental, social and economic effects are either taken for granted or are not taken into account at all. For example, under pressure from environmental interest groups most large and storage hydropower projects are currently excluded from premium markets (e.g. carbon credits, CDM, renewable energy credits or favourable feed-in tariffs) which does not necessarily set encouraging signals for further investments. There are a number of small hydropower projects participating in the CDM, but other financial benefits vary greatly in different regions.

Thus, many public and decision-makers are not aware about the full range of services provided by hydropower to the energy sector (e.g. energy services favouring increased deployment of intermittent renewables and the potential to electrify transport in a climate-friendly way). In addition they provide non-energy services, such as flood management, water supply, groundwater stabilization, and help foster regional development through enhanced opportunities for transportation, agricultural yields, industrialization, recreation and fisheries.

Documenting such information in a credible, scientific way through the IEA protocols will help to improve the understanding of the cross-sector nature of multipurpose hydropower and how regulatory or market uncertainties can hinder sustainable resource management in the water and energy sector. Enhanced knowledge about non-energy services provided by hydropower will allow providing factual arguments in the context of a licensing/relicensing process or in the context of implementing water management and climate change adaptation policies, as well as in implementing renewable energy action plans.

Hydropower with freshwater storage capacity is not only at the nexus of water and energy issues, but can also be a driving force for regional development. The study was designed to gather information on the socio-economic contributions which are currently made, or could potentially be made by hydropower projects, mainly those with some storage. Case studies and estimations from different countries could be gathered using the following domains (each sub-item is considered to be a sub-task):

- *Flood Reduction*
- *Navigation/Transport*
- *Recreation*
- *Irrigation*
- *Water Supply*
- *Aquaculture*
- *Socio-economic Contributions*
- *Water Quality*

The objectives of Task 2 are to:

Identify the water management services and environmental and socio-economic contributions created by hydropower developments and their spatial and temporal distribution

Estimate the economic values associated with these water management services and environmental and other socio-economic contributions provided by hydropower projects.

5.3 Review of Published Literature

1. Oak Ridge National Laboratory's (ORNL) project on *"The Economic Benefits of Multipurpose Reservoirs in the United States-Federal Hydropower Fleet (Bonnet, 2015)*

Of the 80,000 dams in the USA, only about 3% have hydropower facilities. These provide a variety of energy services that range from reliable power generation to load balancing that supports grid stability. Those with water storage capacity may have a main purpose beyond hydropower and support navigation, recreation, flood control, irrigation, and water supply, with each multipurpose benefit providing significant social and economic impacts on a local, regional, and national level. The ORNL project provides a base case for the economic benefits of U.S. federal multipurpose hydropower reservoirs. This is shown in Appendix B.1

Multipurpose projects are valued through a quantification of each service. This can be more readily achieved for energy-related services, where power is generated and sold in a regulated electricity market and monetization is achieved through a market-driven pricing mechanism. Energy service benefits can also be identified where their economic contributions are regulated. However, many non-energy-related services from hydropower multipurpose reservoirs are not valued. The project found that, when monetized their economic value could surpass that of power generation.

The ORNL project noted that within a multipurpose benefits valuation framework, each service is often identified and valued individually. The inherent challenge is where water is consumed both on-stream and off-stream, valued both explicitly and implicitly, and valuation metrics often not comparable across uses. Hydropower generation can often be monetized and quantified based on measurable units. Flood control benefits are valued based on the avoidance of costs or damages, although beneficiaries do not pay a direct price for the advantage of not incurring property loss during floods.

2. EDF's project on *"Value Creation at Hydropower Projects: Developing a Methodology for Systematic Assessment and Benefit Sharing"* (Branche, 2015)

The EDF project provides a systematic check-list and tool for hydropower operators to analyse created values and to engage with local stakeholders about future development, with four main objectives:

- Identification of created and destroyed socio-economic and environmental values related to the hydropower installations
- Analysis of the contribution of the hydropower operator
- Evaluation in qualitative, quantitative and, if possible, monetary terms
- Development of didactic ways to present values and to facilitate discussion with stakeholders

In 2014, a draft assessment guide was developed and tested at three sites in France. In 2015, the iterative development work continued with two more challenging cases at the Durance in France and at Nam Theun 2 in Lao PDR.

3. CEATI's project on *"Quantifying the Non-Energy Benefits of Hydropower* (CEATI 2010)

Hydropower project owners and operators have historically competed with moderately priced carbon-based energy from oil, coal, and gas. At the same time, they have suffered increasing energy and non-energy trade-offs, with little recognition for their economic values or impacts.

In addition to their power dispatch characteristics, greater demands are placed on the use of hydropower resources, such as providing tangible social and environmental benefits in areas such as water supply, fisheries, recreation, navigation and irrigation. The impact to hydro power comes from lost opportunities and generally higher power costs to consumers.

The CEATI project notes the role of hydro projects value to net social welfare and equity is an important objective achievable through the explicit monetization of project benefits and associated values.

4. ORNL's Report on Multipurpose Hydropower Project Benefit and Cost Allocation: Methodology Review and Current Issues (Uría-Martínez, 2014)

Most dams and reservoirs in the USA do not include hydropower facilities. On the other hand, many that have been built for hydropower were planned to include water resource multipurpose infrastructure and provide energy and water management services. The value associated with some of these services can be monetized (e.g., by selling electricity, grid services or water, or collecting a toll from the ships that use the navigation locks). In other cases, the value manifests itself as an avoided cost which is spread over the entire society and cannot be monetized. For instance, flood control provides savings by reducing the frequency of and damage from flood events. ICOLD's Bulletin 171 on Multipurpose Water Storage (MPWS) - Essential Elements and Emerging Trends (ICOLD, 2016)

This ICOLD Bulletin on Multipurpose Water Storage (MPWS) was prepared using information from 52 case studies globally. The scope provides a view on the dynamics of MPWS projects with the findings and reflections stemming from the review of case studies and presented as recommended "essential elements" and "emerging trends" for planning and management rather than in the form of a guideline. The focus is therefore on what is being done, how and by whom.

Essential elements represent a considered set of checklists for implementation of a MPWS scheme. Emerging trends are a snapshot of the current "state of the art" of MPWS projects; a state that has been evolving significantly in the recent few decades, and that is expected to further evolve as innovative approaches emerge in search of optimal sustainable solutions. It is considered that presentation of different ways of dealing with planning and management of MPWS projects in different part of the world will provide useful material to planners, developers and operators of such projects for improving their business and integration with society and the environment.

Key areas of the Bulletin that align with this Summary Report include water storage, the water-energy nexus, the economic cost of no-project options (see Section 5.5), cost allocations and emerging trends.

provides a summary of purposes and methodologies commonly utilized to quantify their value.

Off-stream flows are typically used for consumption or production activities (residential, commercial and industrial demands as well as irrigation). The value of water consumption by residential or commercial customers is typically assessed by regression analysis that estimates their water demand curves. As for water used as input in the industrial or agricultural sectors, its value can be estimated using a netback method in which the cost of all non-water inputs is subtracted from the value of the final industrial or agricultural product. This approach results in an upper bound estimate. In general, more attention is paid to irrigation than industrial water demands as irrigation is, by far, the largest consumptive use of water. Among industrial users, thermal power plants are the largest consumers of water. The interdependency between water and energy demands is being currently acknowledged under the energy-water nexus research area.

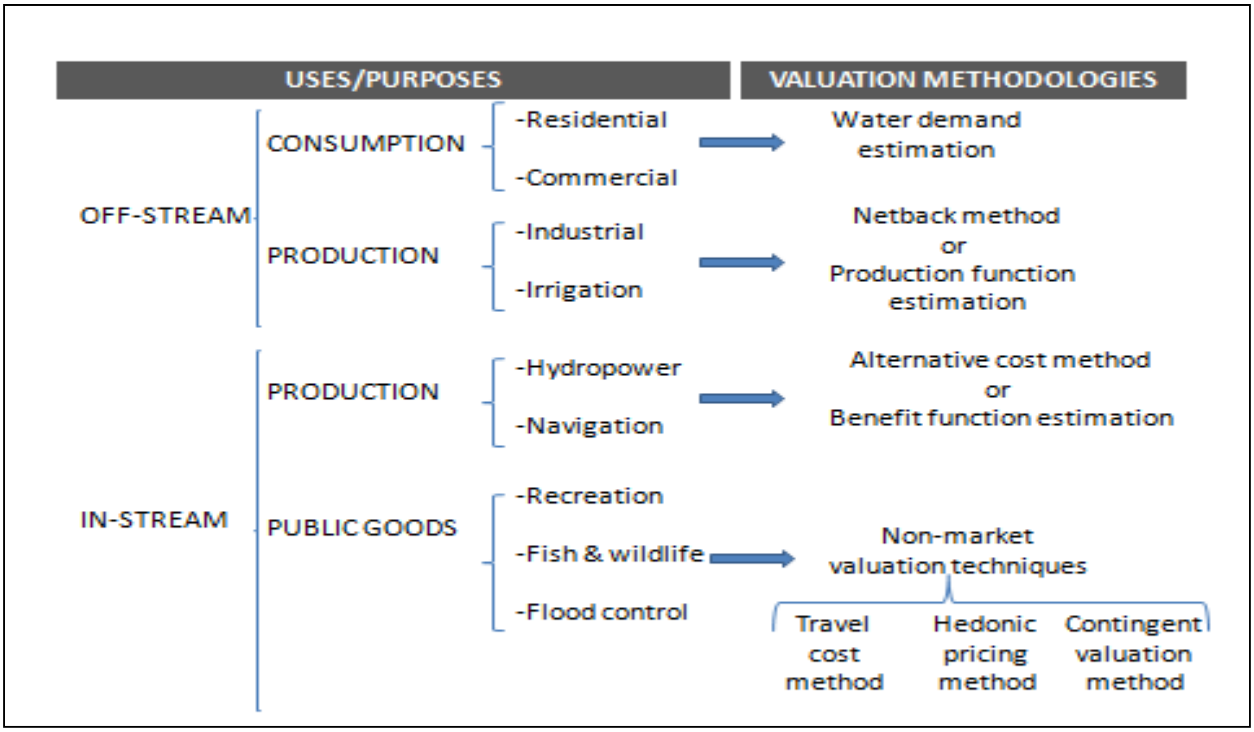

Figure 5.1. Hydro project purposes and corresponding typical valuation methodologies

The non-consumptive purposes of in-stream flows (e.g., hydropower, navigation, recreation, fish and wildlife, flood control) require a different set of valuation methodologies. A further classification between public and non-public uses helps mapping each of these purposes to adequate valuation methodologies. Non-public uses like hydropower or navigation (when it involves transit through navigation locks in exchange for a toll) are typically evaluated using an alternative cost method. The alternative cost method can be applied when the cost of the hydropower plant or navigation lock is less than the cost of the next best project that would provide the same output or service.

Non-consumptive uses that can be characterized as public goods (i.e., where people that have not paid for the service cannot be excluded from using it and where use by one individual does not prevent another individual from also using it) which require non-market valuation techniques. The most commonly used alternatives to appraise the value of these uses/purposes are the travel cost method, the hedonic price method and the contingent valuation method. The travel cost method is used to value recreation uses. Hedonic pricing methods assess the value of a particular attribute or purpose of the hydropower project by estimating the difference in prices of a related good that embodies different levels of that attribute. As an example, the value of a reduction in flood risk can be estimated from the differences house prices being within or outside a flood-prone area. The benefits from flood control can also be estimated from the avoided damages caused by floods in a given area. Contingent valuation method estimate value based on responses from carefully designed surveys about willingness to pay for a given improvement or worsening in an ecosystem service. For instance, the benefits of ecosystem restoration along a river were considered through abundance of game fish, water clarity, wildlife habitat, allowable water uses and ecosystem naturalness.

5. ICOLD's Bulletin 171 on Multipurpose Water Storage (MPWS) - Essential Elements and Emerging Trends (ICOLD, 2016)

This ICOLD Bulletin on Multipurpose Water Storage (MPWS) was prepared using information from 52 case studies globally. The scope provides a view on the dynamics of MPWS projects with the findings and reflections stemming from the review of case studies and presented as recommended "essential elements" and "emerging trends" for planning and management rather than in the form of a guideline. The focus is therefore on what is being done, how and by whom.

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Key areas of the Bulletin that align with this Summary Report include water storage, the water-energy nexus, the economic cost of no-project options (see Section 5.5), cost allocations and emerging trends.

5.4 Economic Valuation Approaches for Water Management Services and other Socio-Economic Contributions

There are many water management services and socio-economic contributions linked to hydropower. In most cases, energy is the primary service and the most easily valued. On the other hand, the other services and contributions are less easily monetized. However, all market and non-market services should be acknowledged as they represent the total value of the hydropower project.

As noted previously, one of the most important aspects is assessing the value of all water management services for multi-purpose reservoirs is to ensure that a new project is optimized from the outset based on the total value of the project, and not on a single or a few of its principle services

Different organizations in different jurisdictions take varying approaches to the valuation of water management services and other socio-economic contributions. Some examples of these are described for specific services, such as:

1. **Flood Control:** Dams that provide storage to prevent and/or lessen the severity of flood flows and damage to human and physical resources within a flood basin.
2. **Navigation:** Operation and control of locks to facilitate the transportation of goods via inland waterways.
3. **Recreation:** Use of water bodies (reservoirs or rivers) for physical and recreational activities (boating, fishing, swimming, etc.).
4. **Water Supply:** Public and private withdrawals of water used for domestic, municipal and industrial needs.
5. **Irrigation:** Diversion and use of water to provide crop and plant irrigation and enhance growth and production.

6. **Aquaculture:** Provision of a stable environment (water level, temperature etc.) for the rearing of fish.
7. **Socio-Economic Contributions:** Improvement of infrastructure, services, employment and human development
8. **Water quality:** Improvements to water quality, such as temperature control, oxygenation and debris/trash removal

The various water management services and environmental and other socio-economic contributions provided by multipurpose hydropower development are closely related to the operations of the reservoir, which can be classified as:

1. Drawing down the reservoir to create storage
2. Diverting water from the reservoir surface or at depth
3. Maintaining stable reservoir surface levels

The most effective reservoir operation scenario for each of the main water management services are indicated on Table 5.2

Water Management Service	Reservoir Drawdown	Reservoir Diversion	Stable Reservoir Levels
Flood Control	✓ Storage space reduces magnitude of flood		
Navigation			✓ High and stable water levels provide safer and efficient transportation
Recreation			✓ Stable water levels enhance range of recreation opportunities
Water Supply	✓ Storage provides reliability of supply in low flow periods	✓ Diversions normally from intakes to provide hydraulic head	
Irrigation	✓ Storage provides temporal availability of supply	✓ Diversion normally from reservoir surface to maximize spatial coverage	
Aquaculture			✓ High and stable water levels provide most efficient production

Table 5.2 Effective reservoir operation scenario for each water management service

For a multipurpose reservoir that provides one or more service other than hydropower, the use of the water resource has to be balanced between competing interests. Understanding the value of the services that can be provided by the reservoir is a key input for the planning, design and operational stages. Decisions and choices between competing interests may involve considerations of willingness to pay at both the capital and operational levels. This in turn can affect the selection of overall design parameters and reservoir operating rules.

5.4.1 Flood Control

One of the services provided by multipurpose dams is flood mitigation for downstream areas. Flood control is provided in the reservoir behind the dam by capturing the peak inflows in the space provided by reservoir drawdown. The value of flood control benefits are derived from the avoided costs of flood damage less the costs of providing storage space.

During an extreme flood event, peak inflows are retained in the storage space and flood waters released by the dam discharge facilities (spillways, sluices, outlets etc.) over a longer time period. The amount of reservoir drawdown and hence storage space is based on factors including the volume and peak discharge of the design flood, the capacity of the discharge facilities to pass this design flood without threatening the security of the dam and the population and infrastructure at risk downstream.

The magnitude and frequency of occurrence of flood events are probabilistic in nature and the design flood is selected to meet the requisite criteria. This flood could occur once, multiple times, or not at all over the design life of the project. The likelihood of the flood event may also vary considerably in different seasons of the year, For example, seasonal variability can be based on a monsoonal climate or a combination of an extreme precipitation event on a fast-melting large snowpack. An added complexity in calculating the economic value of flood/drought control comes from the fact that the probability of these events might not stay constant during the life of the project due to climate change.

Storage space can be provided by a reservoir drawdown below normal operating level or allowing temporary flood surcharge through such measures as spillway flashboards or dam raising. The costs of additional storage space can be optimized against reductions in potential flood damage. While there will be costs associated with providing this extra storage space, there may also be benefits from a reduced spillway size.

To understand the value of flood control benefits it is necessary to estimate the damage costs avoided, but which would have occurred as a result of an extreme flood event without the flood control measures in place. These costs are normally derived from estimates of damage or loss to properties, infrastructure, arable land and services in areas that would otherwise have been inundated. This allows a monetary value of potential damages to be determined for the project

The damage and loss reductions provided by the flood control measures has to take into account the likelihood or probability of the event occurring, usually referred to as the return period. From this an annual risk cost can be determined, which is considered as the benefit of the flood control measures. This is then compared with the PV of the costs of providing the reservoir storage space to determine the value of the selected flood control measures.

The costs associated with providing the reservoir storage has to include the physical costs of the structures and any special provisions. This could include any structures to provide temporary raising of the normal operating levels and water intake structures with low level apertures. Other costs to be included are lost opportunities to generate power at normal operating levels (rated hydraulic head), though this can be complicated where the same storage space is shared between flood control and levelling out large fluctuations in seasonal inflows.

The evaluation of value becomes more complex when the river basin has a number of multipurpose reservoirs, providing different services and owned by different entities.

The corollary of flood control is drought relief, which covers securing water for power production, water supply, irrigation, environmental flows, etc., in times of water scarcity. This can be achieved through reservoir storage from the wetter to the dryer season, which is different to reservoir operation to reduce the risk of flooding. This can be achieved on a site specific basis where storage space is provided for flood control at certain periods of the year, and made available to store water during other periods, within acceptable downstream risk thresholds.

5.4.2 Navigation

Inland navigation can be provided by maintaining stable reservoir levels and providing ship and boat passage past dams, normally using ship locks or ship lifts. It is also important to increase water releases during the dry season. This will enable longer navigable reaches downstream from the dam. Inland navigation serves a vital role in the transportation of goods in many countries of the world with a positive economic benefit. This benefit is demonstrated as the savings for ship owners who send commodities by inland barge (the lowest cost shipping option) rather than by truck or rail (the second lowest cost option).

An estimate of the value of this navigation benefit can be determined by the tonnage passed through a powered ship lock multiplied by the average value of the savings for ship owners, with units in currency per tonne. As a typical shipment passes through multiple locks care must be taken to avoid double counting over the total journey. This is an example of “cost based valuation methods”

5.4.3 Recreation

Reservoirs are popular destinations for a wide variety of recreation activities, with this sector including sports fishing, boating, camping, swimming, water sports, and wildlife observation.

Three common procedures are available to estimate the value of recreation services. Two are based on non-market valuation estimates using various forms of either contingent valuation methods (CVM), which covers survey-willingness to-pay techniques or travel cost models (TCM), which rely on survey and other data sources. These CVM and TCM estimates attempt to simulate market-like transactions, where willingness-to-pay can be measured for various recreation activities. With either method, the value to be determined is an expression of net value (consumer surplus) to those participating in the activity. The third method is based on unit day values

- The CVM method relies on direct survey questions that ask an individual their willingness to pay for recreation activities (for which they are not currently paying) at a given location.
- TCM models assume the travel and time costs spent by visitors to get to a reservoir increase with distance. A demand curve is derived that values the reservoir using travel and time as ‘price’ surrogates.
- The unit day value approach assumes the total benefit of the reservoir can be estimated by multiplying the number of visitors to the reservoir by the average amount spent per visitor per trip. Visitation data is produced from surveys and regional economic and population models, while spending profiles are generally obtained via direct survey

To estimate the economic value of recreation at a reservoir, most agencies in the USA rely on the unit day value approach, with visitor counts to reservoirs and related recreation areas obtained through an agency survey or provided by park services. Common spending amounts (2015) are reported to range from US$10/visitor/day for local visitors participating in day use activities, to US$40/visitor/day or more non-local visitors participating in or multi-day recreation activities, including water sports and overnight camping.

5.4.4 Water Supply

Many multipurpose reservoirs assign a percentage of their total storage to water supply and are equipped with facilities to release or withdraw stored water. In the USA about 17% of surface and groundwater withdrawals are used for public, municipal, and industrial uses.

A basic approach to value water supply services from a reservoir is to multiply the total amount of water supplied by an average price of water, yielding a monetary value per volume of water. Included into this value is the cost of procuring an alternative water supply, and the cost of maintaining and building infrastructure to deliver a potable water supply to the end user. In some cases, the location of water withdrawal may be from the river downstream of the multipurpose reservoir. In this case, the value is provided by the storage and hence flow regulation service

A specific example is the supply of industrial cooling water, especially for thermal or nuclear power generation. Industrial cooling water may have the same point of withdrawal as a municipal pump station, but it will not necessarily require treated potable water. In this case, the value will be based on that for municipal water, but without the costs of treatment and urban distribution.

An example of valuation approaches used by the USBR for their rate setting process covering municipal and industrial (M&I) water users covers four methods

- M&I Fixed Rates
- M&I Cost of Service Rates
- M&I OM&I Rates
- M&I Adjustable Rates

M&I Fixed Rates

The water rates specified in original long-term water service contracts. Fixed rates are not adjustable to reflect changing O&M and capital costs and over time, have generally been insufficient to recover annual O&M and interest costs, and timely repay allocated capital costs.

M&I Cost of Service (COS) Rates

The rate is the charge per volume necessary to recover the cost of delivering the water to each individual contractor.

M&I Operations, Maintenance, and Interest (OM&I) Rates

The rate is the rate per volume necessary to recover the annual cost to of operating and maintaining project facilities, plus interest based on outstanding capital and deficit balances as of the most recent fiscal year.

M&I Adjustable Rates

Irrigation and M&I adjustable rates are specialized rates subject to periodic adjustment(s) based on specific provisions of individual long term water service contracts

5.4.5 Irrigation

Most irrigated farmland lies in arid regions, having lower than average rainfall. To enhance crop production, irrigation systems are developed using infrastructure such as pumping stations, diversion dams, and canals. These systems are much more effective if they can access water stored in multipurpose reservoirs at optimum times in the growing season.

The economic benefits of irrigation services have been developed in different ways:

1. Simply quantified by multiplying the irrigated area of land by the incremental value of crops grown, over what could have been produced without the irrigation water.
2. The increased value of land under irrigation as determined by the capital land price difference between the irrigated and non-irrigated ground.
3. The market value of the sale of water rights transfers
4. The average net value (return) to ownership of the land assigned to irrigation water.

An example of valuation approaches used by the USBR for their rate setting process covering irrigation water users covers four methods

- Irrigation Fixed Rates
- Irrigation Cost of Service Rates
- Irrigation Full Cost Rates
- Irrigation Adjustable Rates

Irrigation Fixed Rates

These are water rates specified in original long-term (40 years) water service contracts and are not adjustable if needed to reflect changing costs over the term of these contracts.

Typically, fixed rate contracts are insufficient to recover O&M and capital costs of the project. Newer contracts such as the interim renewal contracts require annually adjusted cost of service (COS) rates. Contracts with fixed rate provisions will eventually all be replaced by contracts having annually adjustable COS rates.

Irrigation Cost of Service (COS) Rates

The rate is the charge per acre/foot necessary to recover the cost of delivering the water to each individual contractor and are designed to recover each contractor's share of their allocated:

- Annual O&M costs
- Capital costs over the authorized repayment period
- Deficit costs over the repayment period

Irrigation Full Cost (FC) Rates

These are similar to the COS rates, except that full cost rates include interest on irrigation capital costs.

Irrigation & M&I Adjustable Rates

Irrigation and M&I adjustable rates are specialized rates subject to periodic adjustment(s) based on specific provisions of individual long term water service contracts

5.4.6 Aquaculture

Aquaculture is the farming of fish and other aquatic life in enclosures, ponds, lakes and reservoirs, as well as rivers and coastal waters. Freshwater reservoirs are especially suited to aquaculture in that they can provide a stable environment (water level, temperature etc.) for the rearing of fish over a protracted period. Aquaculture in reservoirs is a large and growing industry and is already extensively developed in China and other S-E Asian countries.

The success of an aquaculture enterprise is dependent on many factors including the selection of a suitable site and the design and construction of facilities that enable efficient and economic operation. However, with the rapid development of aquaculture in reservoirs, some negative effects on water quality and aquatic organisms are clearly emerging.

As this is a direct use of the reservoir water, valuation approaches based on the net commercial value of the fish are appropriate. This should take into account the capital costs to develop the aquaculture facility and the operations and maintenance costs of running the business

5.4.7 Socio-Economic Contributions

The contributions of hydropower reservoirs to socio-economic services can include general improvement to infrastructure, social services, employment and overall human development. For example, the impoundment of a reservoir could lead to the development of buildings and infrastructure along the shoreline, particularly if this results in recreation or employment opportunities. The effects on land management can be presented either as the capital value or annual lease value of the land affected by or controlled by reservoir development. A specific example is the development of access roads to the hydropower plant which can enhance access to markets for local villages and thus generally enhancing their economic development

Hydropower reservoirs can also contribute to direct environmental benefits that can be considered as services. In this case, the economic value of the environmental goods or services can be considered as a sum of the use and non-use values. Use values can be assigned to the extracted or non-extracted resources, such as timber which is available prior to inundation or through ready access following inundation. In this case, the value of the timber is related to its mode of use, or monetary value, but not its intrinsic value. On the other hand, its non-use value is the value that can be assigned to the timber resource, but without its exploitation.

Another important societal benefit attributable to hydropower is the ability to reduce emissions that are potentially affecting climate change. Using hydropower to provide power and energy services thus can reduce carbon emissions. The other main alternative is natural gas fired turbines, but they have few of the other benefits of hydro and have higher carbon emissions.

Valuation approaches for socio economic aspects are covered in general terms in Section 2.

5.4.8 Water quality

Water quality is affected when flowing water in rivers is impounded behind dams, both in the reservoir and the downstream reaches of the river. These water quality changes tend to be dependent on the retention time, with small run-of-river headponds causing little change.

Reservoir impoundment hastens the decomposition of any submerged organic matter in the flooded area, reducing oxygen levels and producing GHG emissions, particularly in the early years. Geographically, this is more often an issue in tropical regions. However, in many developments, reservoir clearing can be a mitigating approach to reduce the impacts.

When water is discharged through low-level outlets in the dam, it is usually cooler than river water inflows in summer and warmer in winter. On the other hand, surface water discharges are normally consistently warmer all year round. This can affect dissolved oxygen levels in the discharged water

Other water quality parameters that can be affected by reservoir impoundment, in addition to temperature and dissolved oxygen, include turbidity, nutrient enrichment, contaminants and dissolved and suspended sediments.

Water quality interests are closely related to water use, and conflicts can arise for reservoirs with multiple water uses. Hydropower and water supply may have conflicting water demands, but drinking water quality standards must prevail. Of the other water uses, fish and wild life conservation, irrigation and recreation are most dependant on water quality.

Valuation approaches for environmental aspects are covered in general terms in Section 2.

5.5 Economic Cost on No-Project Option

ICOLD (2016) notes that the economic assessment of Multipurpose Water Storage (MPWS) projects often underestimates or ignores the economic cost of the no-project option. For some projects the consequences of taking no action at all - the project not proceeding - may be wider than has traditionally been considered during the economic evaluation. This is particularly the case in the water sector, where lack of suitable infrastructure can lead to increased water stress over a large area. In this situation, a true economic appraisal should include the wider costs of the "no action" option, which might imply lost food production through lack of irrigation, diminished employment, flood damage and a general lowering in the level of economic activity. Similarly, there may be an economic cost to delaying action, which is urgently needed to support development. Much of the world's unexploited hydropower potential is in developing countries, many of whom are desperate for electricity and for water storage to support development. Similar considerations apply to flood protection and irrigation potential in developing countries. Yet these much-needed projects are typically subject to extensive delays both before and during construction, which add to their cost and impacts and threaten their sustainability.

6.0 POLICY DEVELOPMENT

6.1 Introduction

In most countries there is no clear policy or responsibility for the planning of multi-purpose hydropower projects. Public procurement, normally based on price competition and lack of income from the provision of energy and water management services, discourages private sector investment. The standard approach to EIA is to consider mitigation of negative impacts rather than searching for shared benefits and maximizing positive impacts. As an example, the failure to value the benefits of storage could lead to a situation where storage capacity may be reduced by a developer in order to lower the risk of the project without understanding the economic value of this storage to the electricity network and economic development opportunities. All this can result in sub-optimal development

6.2 Policy Issues

Regulatory frameworks, market mechanisms and business models can sustain or hamper the optimal deployment or development of multipurpose hydropower services.

Politicians, legislators, and regulators frequently undervalue or take for granted the benefits of hydro projects and do not consider the broad base that make them highly valuable assets and for some large dam projects may, in effect, dispute the financial/economic benefits. However, in many jurisdictions, this erosion of sound economic policy came from the period when hydropower was abundant and relatively inexpensive.

More recently, market reforms and legislation have led to an escalation of the costs of licensing, changing regulations and the diminishment of energy and capacity hydropower resources that are increasingly traded for social benefits. Issues that affect the recognition and quantification of hydro project benefits include (CEATI 2010):

- **Adequate Valuation and Monetization**

It is important that policy makers understand that many of the electrical energy services made available to the public have been traded for non-electrical services, but without a value being attributed to them. An effective means to value services is through monetization. Therefore it should be policy to provide an explicit quantification and careful accounting of benefits (and costs) to enable decision makers and resource managers to make sound business decisions.

- **Consideration of All Direct Net Social Benefits**

The most significant economic benefit from hydropower projects is electrical energy/power. Closely related are the supporting energy benefits referred to as energy or grid services.

Because most multipurpose hydropower schemes have the capability to store and divert water, hydropower can provide significant water management services such as irrigation, navigation and municipal water supplies. Reservoirs can also provide storage capability to control floods, though these benefits have to be traded with other services including power generation and downstream water quality. Hydropower also hosts a broad set of non-market societal benefits within the recreational and environmental sectors.

There are many societal values linked with hydropower and all market and non-market benefits should be included to represent the total benefits ascribed to the hydropower project.

- **Consideration of Electric Power Energy Benefits**

The versatile nature of hydropower capacity and energy makes it an unmatched resource for meeting variable demand conditions and scheduled and regulated loads, and a formidable back-up for unscheduled emergency conditions. With increasing power resource constraints and costs, the value of hydro project power products and services is becoming more apparent.

- **Misapplications of Water Resources Economics**

Many countries have regulations and mandates that hydropower developers and owners must meet. These covers protocols on economic valuation with the general approach that the power producer should cover the costs of all project energy and water management services. This approach tends to undervalue or erode power benefits and increase or overvalue mitigation costs.

Historically, hydropower has often been the “paying partner” in multipurpose hydropower development. One salient example in the United States is the development of irrigation projects by the U.S. Bureau of Reclamation in the Western U.S. Even though the primary purpose of those projects was irrigation, they were mostly financed through the power sales enabled by also installing hydropower generation at those projects (https://www.nps.gov/articles/6-hydroelectric-power-and-the-bureau-of-reclamation.htm).

- **The Cost of Inattention to Hydro Project Values**

The hydropower industry has challenges in effectively communicating the societal values, partly due to limited regulatory, political and environmental support and partly due to the complexity of the issues. To improve the position and acceptance of hydropower, stakeholders should be provided with an accounting of the societal benefits from both environmental and energy perspectives. However, it needs to be acknowledged that many of the economic benefits are regional or national, while many of the economic costs are localised.

To best enable an appropriate treatment of the value of energy and water management services, an effective process to provide input to policy development should include:

- An integrated and collaborative approach to valuing energy and water management services.
- A coordinated approach to communicating approaches to regulators and policy makers.
- Investigations into ways to stimulate private industry to consider multiple purposes when planning for new hydropower projects
- Initiatives to ensure the viability of private-public partnerships, taking multipurpose factors into account
- Development of frameworks needed to ensure sound economic investment decision making.

7.0 FAIR ALLOCATION OF WATER MANAGEMENT SERVICES

7.1 Introduction

Multipurpose reservoirs can provide a number of water management services, such as diversions for irrigation, storage capacity for flood or drought control, domestic and industrial water supply and regulation for recreation, navigable water ways and others. Each of these services receive significant benefits from the impoundments created by the reservoir, including reservoir storage and drawdown capability, raising of the water levels behind the dam to provide hydraulic head and the dam barrier itself that provides facilities for diversion. In most cases, the dams impounding the reservoirs are built and funded by one of the services receiving benefits with the other beneficial services making little or no financial contribution to development or during the life-cycle of the project. It is therefore appropriate that any costs associated with benefits received from use of the reservoir be shared in a fair and equitable manner amongst all beneficiaries.

Water allocation is a fundamental component of multi-purpose hydropower developments and with the interdependency of energy and water systems, forms an integral part of the water-energy nexus. The allocation of water, both quantity and quality, reflects social priorities and the role of water in maintaining life processes, through supporting livelihoods, economies and social arrangements. While water laws can establish clear entitlements to water through an allocation framework and licensing regime, they cannot always ensure the equity of allocation.

An overarching principal of the allocation of water management services is that, while taking into consideration economic, environmental and social drivers, approvals and priorities are the ultimate responsibly of the local, regional or national regulator.

7.2 Water Allocation Approach

It is very clear that in the development of new multipurpose hydropower developments or the management of existing ones, there is no certainty in the future with regards to climate and technology. Multipurpose hydropower developments last for many decades and it is possible that over such a long lifetime the optimal water allocation among the various purposes will change. Together with increased levels of water scarcity and variability in some regions, allocation is both important and complex in terms of decision making. One important question is to what extent flexibility in water allocation regimes should be allowed to maximize social value over the life of a project.

Key factors for effective water allocation regimes (Global Water Partnership; www.gwp.org) include:

- Clearly establish the conditions of entitlements of water and listing priorities especially during times of water scarcity;
- Ensure the allocation of water rights is consistent with ecological boundaries;
- Respect pre-existing allocation regimes and rights holders in any reform processes;
- Provide transparency and equity in the allocation of water rights to minimize potential social conflict.

The approach to allocation should include an understanding of the following important issues:

- Parties receiving water management services should be prepared to support the capital and operating costs associated with the provision of those services,
- Allocation agreements should be included in contractual documents to cover all identified variables. This is particularly important with project services funded by different finance groups
- Dispute resolution approaches should be agreed on to cover changes to water services or unexpected events
- An effective communications plan should be developed to explain benefits of water services provided by the project, to multiple stakeholders. This can improve likelihood of approvals
- Allocation approaches should ensure water service requirements for downstream users are included

Water allocation systems typically fall into three categories; public allocation, market-based allocation and user-based allocation. Within these categories there are two aspects to the fair allocation of the value of these services.

- Separating the value where they can be clearly allocated to the various users of water management services

- Allocating the value in proportion to expected benefits from the provision of each water management service

Allocation is made more complex as the services can be **complementary**; the release of minimum flows for downstream aquatic health, navigation and recreation or **competing**; foregoing hydroelectric generation to lower reservoir levels for flood storage or withdrawing irrigation flows or **inter-dependent**: generating with cool water from lower reservoir levels for use downstream in thermoelectric operations. Each of these services may have valuable inter-dependent economic benefit.

The complexities around allocation can also be compounded where a river basin has a number of multipurpose reservoirs, some providing different services and/or owned by different entities.

7.3 Review of Published Literature

1. EDF-WWC Framewor: *Multi-purpose Water Uses of hydropower Reservoirs. Sharing the Water Uses of Multi-purpose Hydropower Reservoirs: the SHARE Concept.* (Branche, 2015)

Multi-purpose hydropower reservoirs are designed and/or operated to provide services beyond electricity generation, such as water supply, flood and drought management, irrigation, navigation, fisheries, environmental services and recreational activities. The provision of these services can conflict at times, but are also often complementary. A major challenge with multipurpose reservoirs is sharing water amongst competing users. The EDF project has established a framework to manage tensions amongst users, address governance issues and provide financial/economic models to develop and operate such multipurpose reservoirs. This has been named the SHARE concept, representing five value propositions

- Sustainability approach for all users
- Higher efficiency and equity amongst users
- Adaptability for all users
- River basin perspective
- Engaging all stakeholders

2. Hydro Tasmania's project at Arthurs Lake, Tasmania, Australia in EDF-WWC Framework *Multi-purpose Water Uses of hydropower Reservoirs* (Branche, 2015)

Arthurs Lake was created in the 1920's with the main purpose of providing storage for hydropower, but with multipurpose attributes of recreation, fishing and more recently irrigation. To enhance recreation and fisheries, higher lake levels are maintained, with no cost recovery required as the costs were not considered as significant. However, the value of this service is high for the economies of regional communities. A major irrigation project was recently implemented, sourcing its water from Arthurs Lake. The water diverted for irrigation would otherwise have been used for the generation of electricity and agreement was reached for compensation equivalent to an estimate of the value of lost generation. The irrigation company recovers much of this compensation cost through its own small hydro plant and the benefits from irrigated land to local communities and the State are high. Lessons learned from this project include the appropriateness of existing legislative frameworks, the benefits of participative approaches around multiple uses of the water resource and a careful consideration of benefits and costs.

3. Bureau of Reclamation's *Cost Allocation Process* (USBR, 2012).

The USBR has a cost allocation phase of their annual rate setting process. Cost allocation is defined as the process of identifying and allocating the costs of a multi-purpose project among the various authorized project purposes. Cost allocations are performed on an annual basis for plant-in-service (construction) costs and of annual operation and maintenance (O&M) costs. The cost allocation phase updates (1) the respective repayment obligations of the reimbursable project functions (which include irrigation and M&I water supply and power) and (2) the costs allocated to non-reimbursable project functions including flood control, navigation, recreation, fish and wildlife and water quality improvement.

The method used to allocate plant-in-service costs is based upon the factors derived in the separable cost-remaining benefits (SCRB) allocation method. This is the standard economic method that Reclamation uses to allocate costs of multipurpose projects to authorized project purposes.

The method used to allocate O&M costs closely follows the plant-in-service allocation, although when O&M costs are not specifically related to particular plant in-service features, alternative factors are used for identifying costs to project purposes. The purpose of the annual cost allocations is to identify responsibilities for payment by project beneficiaries of reimbursable costs.

As background, annual cost allocations are based upon periodic cost allocation studies. The last comprehensive cost allocation study was completed in 1970 using the SCRB method. A "short-form" reallocation study using revised benefits and indexed costs was completed in 1975. The 1975 reallocation study did not include an evaluation of hydrologic operations, resizing, or re-costing of alternatives. An interim cost allocation study report was issued in June 2001 and approved for application. This was developed further for application at Shasta Lake (USBR, 2015)

4. ORNL's *Report on Multipurpose Hydropower Project Benefit and Cost Allocation: Methodology Review and Current Issues* (Uría-Martínez, 2014)

For the analysis of multipurpose hydropower project costs allocation, the distinction between separable costs and non-separable costs (those cost components that play a role in multiple purposes) is crucial. Separable costs are specifically related to a single purpose and include the added costs of a change in size or design due to inclusion of that purpose. For flood control, an emergency spillway would be a specific cost while increasing the height of the dam to ensure adequate flood control is separable but not specific. Non-separable costs are those related to components of the project which cover multiple purposes, for instance, covering land acquisition for the project site and facilities. This is shown in Appendix B.2

The Inter-agency Committee on Water Resources outlined three possible methods for cost allocation: (1) the separable costs, remaining benefits (SCRB) method, (2) the alternative justifiable expenditure (AJE) method and (3) the use of facilities (UOF) method.

SCRB has been the preferred method used for allocating the costs of multipurpose water reservoir projects in the United States with the non-separable cost allocated in proportion to each user's willingness to pay (after subtracting the separable cost). The AJE method, which distributes total project cost minus specific costs among all uses (rather than total project costs minus separable costs as in the SCRB method), is simpler, but less accurate. In the UOF method, non-separable costs are allocated based on physical criteria (e.g., storage space, water flow) rather than benefits and is acceptable when it is not easy to compute benefits. Figure 7.1 summarizes similarities and differences between the three traditional methodologies.

5. “Allocation of water consumption in multipurpose reservoirs” (Tor Haakon Bakken, 2016)

Studies assessing water consumption from electricity production show results ranging from very low to much larger than the other renewable technologies. This is partly explained by differences in the methodologies used, including shortcomings in the lack of guidance for allocating water consumption rates in multipurpose reservoirs.

This study covers the approach to evaluate, test and propose a methodology for the allocation of water consumption from such reservoirs. Different allocation methods were tested for the services provided by the reservoir, with volume allocation found to be the most robust approach for allocating water consumption between functions in multipurpose reservoirs. This to be based on spatial boundaries for the analysis consistent with hydraulic boundaries. It is further suggested that the findings of the studies are relevant for similar applications, such as allocating energy investments and green-house gas emissions from multipurpose reservoirs.

The purpose of this study was noted as:

1. Review common approaches for resource consumption from multipurpose reservoirs.

2. Use case histories with data sets to demonstrate various allocation approaches for water consumption and assess their appropriateness

3. Propose recommendations and guidelines for the operative use of the allocation procedure for water consumption in multipurpose reservoirs with hydropower production.

Table 7.1 shows an interesting depiction of the inter-relationships between volume, energy and economic allocation across the range of services provided by multipurpose reservoirs is shown below.

Water Management Service	Volume Allocation	Energy Allocation	Economic Allocation
Power Generation	Used for power generation	Power production	Value of power production
Water Supply	Diverted for water supply	Production lost due to withdrawal of water supply	Value of water supply or value of lost power
Irrigation	Diverted for irrigation demand	Production lost due to withdrawal of irrigation water	Income from increased agricultural production or value of lost power
Flood Control	Available for storage of inflow	Production lost due to sub-optimal reservoir operation	Value of reduced flood risk or value of lost power production
Navigation	Used to maintain water levels	Production lost due to sub-optimum operation of reservoir	Value of alternative transportation or value of lost power production
Aquaculture	Diverted or used to maintain water levels	Production lost due to withdrawals and sub-optimum operation of reservoir	Value of increased fisheries production or value of lost power production

Recreation	Used to maintain water levels	Production lost due to sub-optimum operation of reservoir	Value of recreational activities or value of lost power production
Environmental Flows	Released to downstream areas	Production lost due to release of environmental flows	Value of downstream ecosystems or value of lost power production

Table 7.1 Inter-relationships between volume, energy and economic allocation across the range of services provided by multipurpose reservoirs

7.4 Approaches to Estimate Fair Allocation

As noted, the two primary components of fair allocation of water management services are:

- Separating the value where they can be clearly allocated to the various users of water management services
- Allocating the value in proportion to expected benefits from the provision of each water management service

The distinction between separable and non-separable costs (those components that play a role in multiple purposes) is crucial for construction cost allocation purposes (Table 7.2). For instance, sluiceways and irrigation water intakes can be treated as separable costs to be allocated to flood control and irrigation respectively. On the other hand, land acquisition costs for the dam site would be an example of non-separable cost whose allocation is less straightforward

It is important to make a distinction between cost allocation and cost sharing. Cost allocation uses scientific methods to distribute costs among purposes. (Young, 1982) provides a comprehensive summary of various cost allocation mechanisms ranging from simple proportional rules to game theory approaches. Cost sharing (i.e., who pays) is often negotiated and, particularly in the case of state-owned projects, influenced by political considerations.

Allocating water management services between users is primarily decreed or negotiated during the planning and approvals stage of the project. This can be based on pre-conditions set by the regulator, lender or negotiated with stakeholders. It can also be an outcome of mitigation options emanating from the formal Environmental and Socio-economic Impact Statement. As such, these aspects, being site specific are beyond the scope of this Summary Report.

In terms of the multi-purpose hydroplant developer allocating a fair value for the provision of the water management service against the respective water user, it has to be confirmed that there are no contractual or negotiated agreements in place that guarantee this service at no cost. This Summary Report is based on the assumption that there are no external constraints to valuing services and allocating them against the beneficial user.

Cost Allocation Methodology	Cost base for allocation	Allocation criterion
Separable costs, remaining benefits **(SCRB)**	Total costs – separable costs	Proportional to benefits
Alternative justifiable expenditures **(AJE)**	Total costs – specific costs	Proportional to benefits
Use of facilities **(UoF)**	Total costs – specific costs	Proportional to physical criteria (e.g., storage space use, water flow use)

Figure 7.2. Traditional Cost Allocation Methodologies for Multipurpose Hydropower Projects

Following the identification of the water management services that the multi-purpose reservoir supports, it is appropriate to develop the proportional relationship between them. In this way, the stakeholder(s) who receive benefits can understand and manage these services and the cost/value that they provide.

Economic valuation methods for water management services and other socio-economic contributions were outlined in Section 5.4. The subsections below outline some of the approaches to be considered on how the costs of providing multiple services can best be apportioned between the various stakeholders and the suitability for each water management service

7.4.1 Value proportional to water-use/water footprint

For a number of water management services, the volume of water used is readily known. This would include hydropower generation, diversion flows for irrigation and cooling water and offtakes for municipal and industrial water supply. In some cases these flows are measured directly, alternatively they can be back-calculated. For a multipurpose project where the volume of water used for the various services is known, the values can generally be separated and allocated proportionally to that usage.

Most multipurpose projects have reservoirs with storage capability. Being able to capture and store inflows for later use when the demand, and hence value, is higher is one of the main attributes of this type of development. This added value needs to be taken into account when allocating value.

However, it should be noted that the availability of the water resources for a specific project is often highly dynamic. For medium to large watersheds with multiple projects, managing the water balance requires sophisticated hydrologic/watershed management systems. Determining water consumption and withdrawals can also be challenging

7.4.2 Commercial benefits from service provided or opportunity lost

For some water management services it is not realistic to clearly separate water use between the services. In this case, it may be possible to allocating value in proportion to their expected benefits. At an existing reservoir in Tasmania, Australia (Section 7.2-2) which stored seasonal flows for hydropower generation, a new user negotiated an agreement to divert some of these flows to an irrigation scheme. To compensate for the lost opportunity, an agreement was reached for reimbursement equivalent to an estimate of the value of lost generation. However, the irrigation company recovers much of this compensation cost through its own small hydro plant and the benefits from irrigated land to local communities and the State are high.

An interesting case is where reservoirs are used for extensive aquaculture (fish farming). In general, as the water resource is not consumed, it could be considered that allocation is not relevant. However, aquaculture development does have impacts on the reservoir in terms of water quality and potential restrictions for other reservoirs users and uses. This could include spatial restrictions on the reservoir surface and limitations to reservoir drawdown levels and rate of lowering. Therefore, it is considered appropriate to allocate a fair value for the provision of this water management service against the aquaculture development. Basing this on a proportion of the commercial value of the business is appropriate, taking into consideration the infrastructure and facilities provided and the provision of a stable water levels, reliable water availability and quality.

7.4.3 Non-monetary value of service provided

A number of environmental and social water management services fall into this category, including the provision of downstream environmental flows and the maintaining of flows or reservoir levels for ecosystems and habitat. For many of these type of water management services, costs are not assigned and cannot be apportioned between the beneficiaries. Maintaining high water levels for recreation in summer or limiting drawdowns to preserve fish stocks are examples that may be required by the water licence, but are also part of social responsibility. Some recreational sites may charge fees for camping or boat launching, and fishers may be subject to anglers licence fees, but these are unlikely to be credited to the reservoir developer. Most reservoir owners believe that providing some form of local benefit to regional communities has very positive intrinsic value and are quite willing to provide these at low cost to themselves, without consideration of monetary remuneration

7.4.4 Consensus

Reservoirs provide a number of water management services for existing users as well as opportunities for new users. With the recognition that access to water is a basic requirement for many users and uses, fair allocation can be challenging, especially if supplies are limited. One approach to allocation is through consensus, collaboration between stakeholders to develop an outcome that can be accepted by all.

An example of this are the Water Use Plans developed by BC Hydro in British Columbia, Canada. These Plans have the objective to balance allocations between competing uses of water, such as domestic water supply, fish and wildlife, recreation, heritage, flood control and electrical power needs, in ways which are environmentally, socially and economically acceptable to British Columbians. The Water Use Plans have been developed for most of BC Hydro's hydroelectric facilities through a consultative planning process involving government agencies, First Nations, local citizens and other interest groups.

The BC Government Regulator licences the use of surface water, including reservoirs, as well as levy fees based on usage. The rates vary based on the amount of water diverted or used and the purpose of use. It is the responsibility of the Regulator to review and approve the Plans under the provisions of the Water Act in consultation with Federal and Provincial agencies, First Nations, and holders of water licences who might be affected by the Plans. Once accepted, any operational changes, monitoring studies and physical works outlined in the Plans are implemented by BC Hydro (www.bchydro.com).

Another example cited is the use of a modified version of the Building Block Methodology (BBM), workshop-based with extensive stakeholder involvement to assess water allocation between competing sectors (Bakken, 2013). Using a “bottom-up” approach allows local sectors to participate in the decision-making strategy and the selection of priorities. This was demonstrated for allocation of water from a multipurpose reservoir in India used for irrigation, drinking water supply and hydropower production. Possible water allocation regimes were developed under existing hydrological conditions (normal and dry years) as well as under future climate change scenarios, characterized by increased precipitation in the rainy season, more frequent droughts in the dry season and accelerated siltation of the reservoir, thus reducing the storage capacity. The feedback from the stakeholders (water managers representing the various sectors) indicated a practical and useful approach to water allocation.

7.4.5 Summary

Approaches for the allocation of costs for the provision of various water management services between the various stakeholders are summarized in Table 7.3. These should not be considered as discrete, as in some specific cases one of the other approaches may be more appropriate. In some cases, these could be considered as multipliers for socio-economic contributions

Water Management Service	Proportional to water-use	Commercial benefits	Non-monetary value of service	Consensus
Flood Reduction	✓			
Navigation/Transport		✓		
Recreation		✓	✓	✓
Irrigation	✓	✓		
Water Supply	✓			
Socio-economic Contributions			✓	✓
Aquaculture		✓		

Water Quality			✓	✓

Table 7.3 Appropriate Approaches to Allocation for Various Services.

8.0 NEXT STEPS

The contributors to this Summary Report have indicated that there are certain aspects relating to valuing hydropower services that they would like to continue with, either in more depth or with a broader coverage.

8.1 Follow-Up from Summary Report

This Summary Report has presented the preliminary results on considering the economic value of energy and water management services provided by multipurpose hydropower projects. Some detailed aspects from the scope of the original Annex have not yet been addressed. This section will note topics that may be of interest for continued investigation:

- More detailed work on economic valuation methodologies for both energy and water services, with reference to a best practice example.
- Expand the synthesis of the valuation methods and where each is most applicable for the various energy and water management services.
- Investigate further the linkage between the storage created by reservoir drawdown and/or dam raising with both water management and energy services, which can both benefit from this capability.
- Further to the above, review the value of reservoir storage as both an energy and water management service. For energy this includes drawdowns to balance variable renewals and for water this covers storage to mitigate the effects of floods or even out irrigation supplies
- Investigate methods to distinguish the value of services between those added after impoundment and those incorporated into the design of a new multipurpose development.
- Consider the treatment of negative value, such as flooding valuable habitat for fish spawning or winter grazing. Also reductions in water quality by capturing pollutants or retaining sediments
- Undertake further investigations on valuing environmental and social services that have no market price, with evaluation by other means
- Identify good examples of institutional organizations designed to foster multi-purpose water development projects

8.2 Possible New Tasks

In addition to follow-up from the Summary Report there are other topics that have not been covered and which may be of interest for continued investigation:

- Consider the impacts of uncertainty in terms of the economic viability of the energy and water management services provided, through methodologies such as risk assessment, sensitivity, etc.

- Investigate model/analyse approaches and methodologies to optimize the use, costs and allocations of reservoir services to maximize the overall project value, as well as the value of each service
- Investigate allocation approaches for reservoir cascade systems and how they could be optimally operated to maximize the value of energy generation and services provided.
- Investigate the complexity of water availability in river basins with multiple reservoirs and competing water use, taking into consideration economic aspects and how these could be affected by operations of the multipurpose reservoirs.
- Investigate the ways to increase the operational flexibility of hydropower plants with limited or no storage (e.g., run-of-river plants), with the goal to enable them to provide certain types of energy services.

CEDREN's project on HydroBalance has a task to investigate how balancing as a service provided by hydropower may have a valuable role in electricity markets, with an assessment of economic opportunities and socio-economic considerations. This is in the context of Norwegian reservoirs providing this service primarily to balance the variable renewable generation in Europe. Next steps would cover following-up with CEDREN on the results of their investigations.

8.3 Possible Market Value Task

In Japan, under power sector reform, a base load power sources market is being reviewed with rules regarding interconnections. Concurrently, the creation of capacity mechanisms and a "value market of non-fossil power" are being discussed.

Creation of a "value market of non-fossil power" is an approach based on the "Act on Sophisticated Methods of Energy Supply Structure". An especially noteworthy point is that it is deemed as a way to prepare the retail market for the time when the electricity utilities will be obliged to sell a certain percentage of non-fossil power.

The "value market of non-fossil power," prices will probably be determined by the market mechanism. However, it will be timely to research and analyse the methods of evaluating similar approaches internationally, such as the Green Market in Scandinavian countries. Such values include, for example, the values of setting different electricity prices according to time zones and futures prices (that are supposed to be effective recovery means for hydropower investment costs), market rules to ensure fair trade, ancillary services and the ability of instantaneous response.

Appropriate evaluation methods for hydropower attract much attention especially for ancillary services including capacity mechanisms.

Japan's contribution will be to continue to provide information on the situation surrounding power sector reformation, "value market of non-fossil power" and "evaluation methods of ancillary services" currently under discussion. This could be complemented by the latest approaches operational and planned in other member countries.

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GLOSSARY OF TERMS

Adequacy

The ability of a bulk electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components.

Ancillary Services
Services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the transmission system in accordance with good utility practice. In this Summary Report, ancillary services only cover those defined by FERC

Area Control Error (ACE)
The instantaneous difference between a control area's net actual and scheduled interchanges, taking into account the effects of Frequency Bias (and time error if automatic correction for either is part of the system Automatic Generation Control).

Automatic Frequency Control (AFC)
AFC is the same meaning as LFC, Load Frequency Control, which is one type of the AGC, Automatic Generation Control. The word AFC is widely used in Japanese electric industries instead of LFC.

Automatic Generation Control (AGC)

Equipment that automatically adjusts generation in a Control Area from a central location to maintain the Area Control Error within the specified range.

Balancing Authority
In the United States, the responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a balancing authority area, and supports Scheduled Frequency in real time.

Blackout
The disconnection of all electrical sources from all electrical loads in a specific geographic area. The cause of disconnection can be either a forced or a planned outage.

Black start Capability
The ability of a generating unit or station to go from a shutdown condition to an operating condition and start delivering electric power without assistance from the electric system.

Blackstart Resource
A generating unit and its associated set of equipment which has the ability to be started without support from the electric system.

Bulk Power System
The electrical generation resources, transmission lines, interconnections with neighbouring systems, and associated equipment, generally operated at voltages of 100kV or higher. Radial transmission facilities serving only load with one transmission source are generally not included in this definition.

Bulk Power Market
A market in which large amounts of electricity at high voltages are exchanged, usually from one utility to another for the purpose of resale.

Cascading
The uncontrolled successive loss of system elements triggered by an incident at any location. Cascading results in widespread electric service interruption, which cannot be restrained from sequentially spreading beyond an area predetermined by appropriate studies.

Contingency.
The unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch or other electrical element.

Single Contingency – The loss of a single system element under any operating condition or anticipated mode of operation.

Most Severe Single Contingency – That single contingency which results in the most adverse system performance under any operating condition or anticipated mode of operation.

Multiple Contingency Outages – The loss of two or more system elements caused by unrelated events or by a single low probability event occurring within a time interval too short (less than ten minutes) to permit system adjustment in response to any of the losses.

Contingency Reserve
The provision of capacity deployed by the control area in case of an outage (contingency) in order to balance system generation and demand and return Area Control Error within the specified range. Contingency reserve is typically deployed within 10 minutes following an outage. Typically, at least 50% of Contingency Reserve is required to be Spinning Reserve, which automatically responds to frequency deviations.

Control Area
An area comprised of an electric system or systems, bounded by interconnection metering and telemetry, capable of controlling generation to maintain its interchanges schedule with other control areas, and contributing to frequency regulation of the interconnection.

Demand-Side Management (DSM)
The term for all activities or programs undertaken by a utility or its customers to influence the amount or timing of electricity they use.

Disturbance
An unplanned event which produces an abnormal system condition such as high or low frequency, abnormal voltage, or oscillations in the system.

Electric System
A combination of generation, transmission, and distribution components.

Emergency
Any abnormal system condition which requires immediate manual or automatic action to prevent loss of firm load, equipment damage, or tripping of system elements that could adversely affect the Reliability of the Electric System.

Energy Arbitrage
In general, storing energy when the electricity prices are low and generating when the prices are high. Typically refers to the mode of operation of pumped-storage hydropower plants in electricity markets when they pump during the hours with low electricity prices and generate during the hours with high electricity prices.

Federal Energy Regulatory Commission (FERC)
United States government agency that regulates the interstate transmission of electricity, natural gas, and oil.

Flexibility Reserve
A new type of reserve that is being introduced in some electricity markets, mostly to compensate the variability and uncertainty of variable renewable generation (e.g., wind and solar), and to correct Control Area exchanges (reduce energy imbalances).

Forced Outage.
The condition in which the equipment is unavailable for service due to unanticipated failure or the removal of equipment from service for emergency reasons.

Frequency Bias
A value, usually given as MW/0.1 Hz, associated with a control area which relates the difference between scheduled and actual frequency to the amount of generation required to correct the difference.

Frequency Control
Also referred to as Frequency Regulation, Frequency Control includes maintaining system frequency within the specified range by continuous regulation of system generation and loads. Typically, a three-stage frequency control procedure (primary, secondary, and tertiary control) is applied:

Primary Frequency Control – The automatic and immediate response of turbine governors and some loads to frequency changes, which assist in stabilizing system frequency immediately following a disturbance. Primary Control, also referred to as Frequency Response, occurs within the first few seconds following a change in system frequency.

Secondary Frequency Control – Balancing services deployed in the “minutes” time frame. Secondary Frequency Control is accomplished using the Automatic Generation Control and the manual actions taken by the system operator to provide additional adjustments. Secondary Control maintains the minute-to-minute balance throughout the day and is used to restore frequency to its scheduled value following a disturbance. Secondary Control is provided by both Spinning and Non-Spinning Reserves.

Tertiary Frequency Control – Actions taken to provide relief for the Secondary Frequency Control resources, so that they are available to handle current and future contingencies. Reserve deployment and reserve restoration following a disturbance are common types of Tertiary Control actions.

Frequency Regulation
The purpose of Frequency Regulation, also known as Frequency Control, is to maintain system frequency within the specified range. Frequency Regulation typically refers to both Frequency Response of turbine governors and to Automatic Generation Control. It is provided by online generating units with frequency responsive governors and by generation and demand resources that can respond rapidly to AGC requests for up and down movements to counterbalance minute-to-minute fluctuations in system load and to correct for unintended fluctuations in generator outputs.

Frequency Response
The ability of a system or elements of the system to react or respond to a change in system frequency.

Governor
The electronic, digital or mechanical device that implements Primary Frequency Response of generating units or other system elements.

Inertia
The property of a mass that resists changes in speed.

Inertial Response
The inertial resistance of the rotating mass of turbine generator that resists instantaneous speed changes.

Interconnected Power System
A network of subsystems of generators, transmission lines, transformers, switching stations, and substations.

Load Following
Increase or decrease in generating unit power output to follow longer term (hourly) changes in electricity demand.

Load Levelling.
Shifting the load from peak to off-peak periods, which results in a flatter Load Profile of System Load.

Load Profile.
A curve depicting aggregated System Load of all electricity consumers, typically over a 24-hour period.

Non-Spinning Reserve
The portion of Operating Reserve that is not connected to the system but is capable of serving the demand within a specified time (typically within ten minutes), or interruptible load that can be removed from the system within ten minutes.

North-American Electric Reliability Corporation (NERC)
A not-for-profit international regulatory authority whose mission is to assure the reliability of the bulk power system in North America.

Operating Reserve.
The capability above firm system demand required to provide for regulation, load forecasting error, equipment forced and scheduled outages, and local area protection. It consists of Spinning Reserve and Non-Spinning Reserve.

Primary Frequency Response
The immediate proportional increase or decrease in real power output provided by generating units and the natural real power dampening response provided by system load in response to frequency deviations. This response is in the direction that stabilizes frequency.

Ramp Rate (Ramping)
The rate, expressed in megawatts per minute, at which a generator changes its output.

Regulating Margin
The amount of Spinning Reserve required under non-emergency conditions by each control area to bring the Area Control Error to zero at least once every ten minutes and to hold the average difference

over each ten-minute period to less than that control area's allowable limit for average deviation (in the United States, as defined by the NERC control performance criteria).

Regulating Reserve
An amount of Spinning Reserve responsive to Automatic Generation Control, which is sufficient to provide normal Regulating Margin for Frequency Regulation.

Regulation Service
The process whereby one Balancing Authority contracts to provide corrective response to all or a portion of the Area Control Error of another Balancing Authority.

Reliability
The ability of an electric power system to meet the electricity needs of end-use customers, even when unexpected equipment failures or other conditions reduce the amount of available power supply. Reliability is a combination of Security and Adequacy and is a measure of the capability of the electric system to withstand sudden disturbances or unanticipated losses in system components, whether caused by natural or manmade events.

Scheduled Frequency
50.0 Hertz in Europe, 60.0 Hertz in North America.

Security
The ability of electric power system to withstand sudden disturbances such as electric short circuits, unanticipated loss of system components or switching operations.

Spinning Reserve.
The portion of Operating Reserve consisting of the generation that is fully synchronized to the system and available to serve load within the specified period (typically within 10 minutes) following a contingency event.

Stability
The ability of an Electric System to maintain a state of equilibrium during normal and abnormal conditions or disturbances.

Supplemental Reserve
The portion of Operating Reserve consisting of the generation that is capable of being synchronized to the system and available to serve the load within the specified period (typically within 10 minutes) following a contingency event, or the load fully removable from the system within 10 minutes following a contingency event. It is also referred to as Non-Spinning Reserve.

System.
The integrated electrical facilities, which may include generation, transmission and distribution facilities, that are controlled by one organization.

System Load
Total aggregated demand of all electricity consumers in an Electric System at a given time (e.g., instantaneous load, within a certain hour, etc.).

Transmission Deferral.
Deferral of transmission system investments or upgrades.

Voltage Collapse.
A power system at a given operating state and subject to a given disturbance undergoes voltage collapse if post-disturbance equilibrium voltages are below acceptable limits. Voltage collapse may be total (Blackout) or partial and is associated with Voltage Instability and/or angular instability.

Voltage Instability.
A system state in which an increase in load, disturbance, or system change causes voltage to decay quickly or drift downward, and automatic and manual system controls are unable to halt the decay. Voltage decay may take anywhere from a few seconds to tens of minutes. Unabated voltage decay can result in angular instability or Voltage Collapse.