Chapter 10

Optimising Sustainable Hydropower Development on the Mekong: What Direction Should Lao PDR Take?

Anoulak Kittikhoun
Sophearin Chea
Sopheak Meas
Ly Thim
Peeti Ngamprapasom

This chapter should be cite as:
Kittikhoun, A., S. Chea, S. Meas, L. Thim and P. Ngamprapsom (2024), 'Optimising Sustainable Hydropower Development on the Mekong: What Direction Should Lao PDR Take?', in Phoumin, H. and A. Phongsavath (eds.), *Energy Security White Paper: Policy Directions for Inclusive and Sustainable Development for Lao PDR and the Implications for ASEAN.* Jakarta: ERIA, pp. 232-253.

1. Introduction

The Mekong River is intricately woven into the fabric of life across the countries it traverses. Its significance extends far beyond its physical presence, touching upon diverse aspects of food security, energy generation, economic prosperity, fisheries, and navigation. For millions of people residing in Cambodia, China, Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, and Viet Nam, this mighty river serves as a lifeline, or, as many describe, a hydrologic backbone or current of life that sustains livelihoods and shapes the socio-economic landscape of the region (Hudson-Rodd and Shaw, 2009; Jacobs, 2002).

Hydropower development is at the forefront of global renewable energy initiatives. It presents both promises and challenges in meeting the world's growing energy demands while striving for sustainability. Since its modest inception in 1878, hydropower has blossomed into a significant player in the global energy landscape. Today, it accounts for approximately 16% of the world's total electricity generation and is the third-largest source of energy, following coal and natural gas (IHA, 2023).

Within the Mekong region, this trend is particularly pronounced. As the most upstream country, China has erected 11 mainstream dams along the upper reaches of the Mekong River within its territory. In the Lower Mekong River Basin, plans for a cascade of another 11 mainstream dams are in various stages of development, with 2 operating and 3 under construction in Lao PDR. The tributaries of the Mekong River are contributing to this surge in hydropower projects, hosting another 122. Of these, 88 projects are operational, 20 are under construction, and 14 are in the planning phase. The installed capacity of operational dams stands at over 13,257 megawatts (MW), with the potential to double to 27,302 MW if all planned dams are completed.[1]

Amidst the fervour for hydropower development, a host of challenges and concerns have emerged, however. Environmental degradation, alteration of river flows and ecosystems, and socio-economic impacts have cast a shadow over the perceived benefits of hydropower. Efforts have been introduced to address these challenges; at the same time, the global community has turned towards embracing alternative energy sources. This shift reflects the growing recognition of the necessity for a diversified and sustainable energy portfolio, ensuring a more resilient and environmentally friendly future for generations to come.

In this chapter, the complex terrain of sustainable hydropower development on the Mekong River is examined, with a focus on guiding the direction that Lao PDR – a member of the Mekong River Commission (MRC) and the host to its headquarters – may consider taking. By examining the current energy landscape and hydropower initiatives in the Mekong River Basin and in Lao PDR, this chapter seeks to provide practical policy recommendations, ensuring the sustainability of hydropower development, optimising energy resources, and bolstering water–energy security.

[1] MRC (2021b), MRC Hydropower Database, https://archive.iwlearn.net/mrcmekong.org/programmes/Hydropower/hydropower-database.htm

2. Evolution of Hydropower

2.1. Origins

Hydropower emerged from humble origins to rapidly proliferating around the globe, with technological advancements that made it a cornerstone of today's renewable energy landscape. In 1878, the world saw its first hydropower project lighting up a single lamp at Cragside country house in England – known at the time as the 'palace of the modern magician' (BBC, 2013). Just 4 years later, Wisconsin launched the first hydropower plant to serve both private and commercial customers, sparking a proliferation of hundreds of hydropower plants worldwide within a decade.[2] Germany pioneered its first three-phase hydroelectric system in 1891, while Australia unveiled the first publicly owned hydropower plant in the Southern Hemisphere in 1895. In Asia, China joined the movement in 1905 with a hydropower station on the Xindian River near Taipei, which boasted an installed capacity of 500 kilowatts (kW).

As the 20th century unfolded, hydropower facilities underwent rapid innovation and transformation. In the 1930s, United States (US) President Franklin Roosevelt's New Deal spurred the construction of multi-purpose projects like the Hoover and Grand Coulee dams, which boosted hydropower to 40% of the country's electricity generation by 1940. From the 1940s to the 1970s, driven by post-war economic growth, state-owned utilities in Japan, North America, the Soviet Union, and Western Europe embarked on significant hydropower projects. This period saw low-cost hydropower supporting the rise of energy-intensive industries like aluminium smelters and steelworks. In the latter half of the century, Brazil and China emerged as hydropower leaders. The Itaipu Dam, inaugurated in 1984, stood as a testament to Brazil's hydropower expertise (jointly with Paraguay) with a capacity of 12,600 MW, later expanded to 14,000 MW. China's Three Gorges Dam, boasting 22,500 MW, became the world's largest.[3]

However, the late 1980s witnessed a slowdown in hydropower capacity growth, followed by a decline in the 1990s. Financial constraints and mounting concerns over environmental and social impacts halted many projects globally. International financial institutions, notably the World Bank, curtailed lending and support in the late 1990s, impacting hydropower construction in the developing world (IUCN, IBRD, World Bank, 1997).

Towards the end of the 20th century, increased global awareness of environmental and social impacts prompted a re-evaluation of hydropower's role in national development. In 2000, the World Commission on Dams published a major report (WCD, 2000), and the World Bank also implemented environmental and social safeguards for hydropower projects to ensure responsible development and to minimise negative impacts on ecosystems and local communities. The International Hydropower Association, established in 1995 under the United Nations Educational, Scientific, and Cultural Organization (UNESCO), began crafting the Hydropower Sustainability Guidelines in 2004, which later laid the groundwork for the Hydropower Sustainability Assessment Protocol.

[2] IHA, A Brief History of Hydropower, https://www.hydropower.org/iha/discover-history-of-hydropower
[3] *Ibid.*

Shortly after the dawn of the 21st century, hydropower development surged, especially across Asia and South America. Between 2000 and 2017, the global installed capacity for hydropower grew by nearly 500 gigawatts (GW), a remarkable 65% increase. In terms of energy contribution, hydropower surpassed nuclear by 55% and exceeded the combined output of all other renewables, including wind, solar, bioenergy, and geothermal (IEA, 2021).

Currently, hydropower fulfils the majority of electricity demand in 28 developing nations, with a total population of 800 million, by offering an economical means to enhance electricity accessibility (IEA, 2021). On a global scale, approximately half of the economically feasible capacity of hydropower remains untapped, with emerging and developing economies exhibiting particularly high potential for it. Significant untapped hydropower potential indicates that a substantial portion of the sector's expansion will likely occur in Africa and Asia.

Because of its numerous advantages and contributions, hydropower is projected to continue as the leading renewable energy source globally for the foreseeable future. To 2020, the global installed capacity of hydropower reached 1,308 GW, accounting for 16% of the world's total electricity generation and making it a crucial component of the global energy mix (IHA, 2020). This positions it as the third-largest source of energy, following coal and natural gas. The International Energy Agency suggested that to achieve the primary energy-related objectives of the Sustainable Development Goals, such as fulfilling the Paris Agreement's target of limiting global warming to below 2°C, approximately 800 GW of extra hydropower capacity must be added in the next 20 years (IEA, 2021). Nevertheless, the increase of hydropower capacity cannot solely rely on market forces; governments must devise mechanisms that incentivise flexibility to maintain system balance (IHA, 2023).

2.2. In the Mekong Region

With its basin hosting approximately 70 million inhabitants, the Mekong River serves as an economic artery. It sustains the livelihoods of millions across the region by providing vital resources including energy, food, water, and income (Hudson-Rodd and Shaw, 2009; Jacobs, 2002; MRC, 2019c). As the population continues to grow and various factors such as rising incomes, urbanisation, industrialisation, and increased electrification take hold, the demand for electricity in the region is poised to experience significant expansion in the future (Han, Meas, An, 2021).

Further, with demands for energy in the Lower Mekong River Basin continuing to escalate at a rate of 6%–7% annually, these riparian countries are increasingly turning to hydropower as a solution. With its extensive and intricate network of tributaries, the Mekong River system has been recognised as an important source of hydroelectric power generation since the 1960s (Soukhaphon, Baird, Hogan, 2021). Today, the basin is a key site for large-scale hydropower development that has helped shape the energy landscape and economic development of these nations over the years.

Hydropower development on the Mekong River began in the early 20th century and started to intensify in the 1990s to 2000s (MRC, 2019a). The Mekong Committee (the predecessor of the MRC), with the support of the United Nations, US, and others, promoted hydropower development from a basin-wide perspective in the 1960s–1980s with the objectives of meeting the needs of all Mekong countries (Kittikhoun and Kittikhoun, 2022; Mekong Secretariat, 1989). Yet the ambitions for multiple dams in the basin, especially on the mainstream, were impeded by Cold War conflicts, resulting in many projects remaining unrealised (Sneddon, 2015). When peace returned to the region in the 1990s, hydropower development re-emerged due to rising energy needs driven by economic growth, population expansion, and migration from rural to urban areas, as well as a transition from public financing to collaborative ventures between governments and private enterprises, resulting in the infusion of capital for dam initiatives (Grumbine, Dore, Xu, 2012; Kondolf, Rubin, Minear, 2014; Pearse-Smith, 2012).

An initiative to harness hydropower began in north-eastern Thailand with the construction of the Nam Pung Dam in Sakon Nakhon Province in November 1965 (Hirsch, 2010). The Nam Pong Dam emerged in the Upper Chi River Sub-basin in Khon Kaen Province and was operational in March 1966. The Ubol Ratana Dam was then completed, followed by the Lam Pao Dam by 1968. Subsequent developments included the Sirindhorn Dam in the Mun River Basin in Ubon Ratchathani Province in 1971 and Chulabhorn Dam in 1972. The Nam Ngum Dam, the first significant dam in Lao PDR, was completed in 1971; it was one of the few hydropower projects completed from the Indicative Basin Plan of the Mekong Committee (Mekong Secretariat, 1989).

Primarily due to Cold War tensions, significant progress in hydropower dam development was then stalled until the Pak Mun Dam was constructed on the Mun River, a key tributary of the Mekong River, in Ubon Ratchathani Province in 1990 (Foran and Molle, 2009). Throughout the 1990s, the Government of Thailand embarked on the construction of several medium and large irrigation dams under the Khong–Chi–Mun Interbasin Transfer Project (Sneddon, 2003). Concurrently, Lao PDR resumed dam construction in the mid-1990s with foreign investment, which led to the Houay Ho Dam in southern Lao PDR and the Theun-Hinboun Dam in central Lao PDR (Whitington, 2019). In China, the inaugural dam on the Upper Mekong Basin, which the Chinese call the Lancang River, was erected during the 1990s, culminating in the completion of the Manwan Dam in 1993 (Baird, 2013; Whitington, 2019). Meanwhile, in Viet Nam's Central Highlands, the construction of the Yali Falls Dam commenced in 1993 and concluded in 2001 (Ang et al., 2024; Wyatt and Baird, 2007).

However, the 1997/98 Asian financial crisis led to the cancellation of several planned hydropower projects, with others either delayed or reduced in scale (Soukhaphon, Baird, Hogan, 2021). As a result of decreased market demand for hydropower and ongoing financial challenges, limited progress was made in hydropower development within the Lower Mekong River Basin during the early 2000s. Furthermore, the World Commission on Dams findings from 2000 dissuaded major institutions from financing new large-scale dam projects during this period. Nevertheless, hydropower projects persisted in the Upper Mekong River Basin in China (Wouters, Daza-Clark, Devlaeminck, 2024). Then, in 2005, the World Bank approved the Nam Theun 2 Hydropower Project, with 1,075 MW installed capacity, in central Lao PDR. At the time, this was the largest dam ever constructed in the entire Mekong River Basin. This project became operational in 2010. In the 2010s, hydropower dam development then increased dramatically, particularly in China and Lao PDR.

Today, China has 11 operational dams – 2 of which are large storage dams (i.e. Nuozhadu and Xiaowan) – in the Upper Mekong River Basin that make up the cascade along the mainstream (MRC, 2021b). The country has more than 23,000 large hydropower dams and approximately 50,000 smaller ones (Sun et al., 2019). By the end of 2019, China's total hydropower installed capacity reached approximately 356 GW, which includes 30 GW of pumped storage capacity with an annual generation capacity of around 1,300 terawatt-hours, the highest in the world (Bin, 2021). In comparison, Brazil is ranked second with 109 GW, while the US is ranked third with 102 GW (IHA, 2020). China added 4,170 MW of new hydropower capacity in 2019, slowing down its rate of installation. This placed China in the second position globally, with Brazil taking the lead by installing 4,919 MW of new capacity in the same year (IHA, 2020).

A large portion of China's hydropower comes from rivers within its borders, but some dams are connected to rivers that cross into other countries. These include rivers like the Amur, Brahmaputra, Mekong, and Salween, many of which hold a lot of untapped potential for hydropower (Xiao et al., 2023).

In Myanmar, the first dam on its Mekong River tributaries was commissioned in 2017, and there are plans for at least six more small storage dams (MRC, 2024b).

In the Lower Mekong River Basin, a cascade of another 11 mainstream dams has been planned or in operation (Table 10.1). Two of the dams are in Cambodia, while nine dams are in Lao PDR, with two already operational (i.e. Xayaburi and Don Sahong). In Cambodia, construction of the tributary Lower Sesan 2 Dam commenced in 2014, marking it as the largest dam project undertaken in the country up to that point. The project reached completion in 2018. Additionally, studies have been undertaken regarding the potential development of the Sambor Dam on the mainstream Mekong River. However, recent reports indicated that the Sambo and Stung Treng mainstream projects are postponed for at least a decade (Kijewski, 2020; Prak, 2020).

Table 10.1. Hydropower Projects in the Lower Mekong Basin by Country

Country	Mekong			Tributaries			Total
	In Operation	Under Construction	Planned	In Operation	Under Construction	Planned	
Cambodia			2	2		9	13
Lao PDR	2	1	5	65	20	5	98
Thailand			1	7			8
Viet Nam				14			14
Total	**2**	**1**	**8**	**88**	**20**	**14**	**133**

Lao PDR = Lao People's Democratic Republic.

Source: MRC, MRC Hydropower Database, https://archive.iwlearn.net/mrcmekong.org/programmes/Hydropower/hydropower-database.htm

On the tributaries of the Mekong River, there are another 122 hydropower projects, of which 88 are operational, 20 are under construction, and 14 are planned (Table 10.1). The installed capacity of operational dams stands at just over 13,257 MW (Table 10.2). However, this number could possibly double to 27,302 MW if all planned dams are built and all ongoing dam construction is finished. This includes 14,403 MW from tributary dams and 12,899 MW from the 11 dams on the mainstream.[4]

Table 10.2. Total Installed Capacity of Hydropower Projects in the Lower Mekong Basin by Country
(megawatts)

Country	Mekong				Tributaries				Grand Total
	In Operation	Planned	Under Construction	Total	In Operation	Planned	Under Construction	Total	
Cambodia		4,000.00		4,000.00	401.00	1,110.00		1,511.00	5,511.00
Lao PDR	1,545.00	4,865.00	1,410.00	7,820.00	7,959.39	265.00	1,315.70	9,540.09	17,360.09
Thailand		1,079.00		1,079.00	744.68			744.68	1,823.68
Viet Nam					2,607.00			2,607.00	2,607.00
Grand Total	**1,545.00**	**9,944.00**	**1,410.00**	**12,899.00**	**11,712.07**	**1,375.00**	**1,315.70**	**14,402.77**	**27,301.77**

Source: MRC, MRC Hydropower Database, https://archive.iwlearn.net/mrcmekong.org/programmes/Hydropower/hydropower-database.htm

Today, hydropower remains a crucial component of the energy mix in the region. China has continued to be a global leader in hydropower development, with projects along the Upper Mekong River Basin contributing significantly to the country's renewable energy capacity. While Thailand and Viet Nam have already developed most of their tributary sites, three other countries – Cambodia, Lao PDR, and Myanmar – currently possess the greatest potential for hydropower development. In addition, the four MRC Member Countries – Cambodia, Lao PDR, Thailand, and Viet Nam – have been exploring other alternative energy sources to meet energy demands and to help decarbonise their countries and the region (MRC, 2024a, 2024b).

3. Hydropower Development in Lao PDR

Lao PDR boasts significant geographical advantages for hydropower development, with abundant water resources and topographical features conducive to dam construction. Despite the promise of hydropower, however, several challenges must be addressed to ensure sustainable development. Uncertainties in hydrological flow and climate change pose significant risks to hydropower projects, necessitating adaptive strategies to manage seasonal variability in water availability. The need to balance energy demand with water resources management priorities underscores the complexity of hydropower development.

According to the *Lao National Power Development Strategy, 2021–2023*, and its data on electricity generation capacity, as of 2020, the nation's power infrastructure comprises a total capacity of 10,091 MW and an annual output of 53,196.94 gigawatt-hours (GWh) (MEM, 2021). The same source noted that the majority of electricity generation stems from hydropower, constituting 80.41% of the total capacity, followed by coal-fired plants at 18.61%, with renewable energy sources such as biomass and solar accounting for a modest 0.98%. Furthermore, the distribution of electricity usage reflects significant reliance on hydropower for both domestic and exportation purposes. Specifically, 72.00% of electricity generated from hydropower plants is directed towards exportation, while domestically, hydropower remains the primary source, contributing to 91.49% of the total energy consumed. Coal-fired plants and renewable energy sources, including biomass and solar, collectively contribute 3.17% and 5.34%, respectively, to the domestic energy supply.

The country's energy strategy emphasises the need to balance the security of supply, affordability, and sustainability (Keokhoungning, 2024). This strategy entails leveraging hydropower resources while exploring opportunities for investment and collaboration in solar, wind, energy storage, and electric vehicle infrastructure. Outlined within the energy strategy are several key objectives:

(i) develop potential power sources in the country with mixed power generation for domestic use and export;
(ii) target mixed power generation for domestic use from hydropower at 75%, coal-based power plants at 14%, and renewable energy at 11%;
(iii) reach electrification rate targets of 95% for 2020, 98% for 2025, and 100% for 2030;
(iv) promote power generation for export and power exchange amongst neighbouring countries;
(v) promote electricity exportation for the ASEAN Power Grid; and
(vi) promote the use of electric vehicles, targeting these comprising 15% of total vehicles in country by 2025 and 30% by 2030 (MEM, 2021).

The importance of regional cooperation and synchronisation amongst neighbouring countries is crucial to achieving clean energy goals and to promoting renewable energy adoption. This entails fostering joint projects, sharing resources, and developing common policies to facilitate energy trading between Lao PDR and Thailand, China, Cambodia, Malaysia, Myanmar, Singapore, and Viet Nam. Currently, cross-border power trading between Lao PDR and its neighbours stands at 6,000 MW with Cambodia, 600 MW with China, 300 MW with Malaysia, 600 MW with Myanmar, 4,000 MW with Singapore, 10,500 MW with Thailand, and 5,000 MW with Viet Nam (Keokhoungning, 2024).

3.1. Context and Challenges

Approximately 90% of Lao PDR is located in the Mekong River Basin, giving it abundant water resources and hydropower development potential. In the Lower Mekong River Basin, 133 projects with a total installed capacity of 27,302 MW were identified at different stages of development. Of these, 98 projects with an installed capacity of 17,360 MW are in Lao PDR, representing 64% of the total installed capacity in all stages (MRC, 2021b; 2024b).

Positioned downstream of China and Myanmar, Lao PDR contributes about 41% of the annual flow to the Mekong (MRC, 2016). This suggests that any water resources development in the territory – including water infrastructure projects like hydropower – may impact the Mekong River's environment and, in turn, society. Furthermore, the development of water infrastructure projects upstream – particularly in China – impacts the river system, including changing the flow regime and sedimentation, thereby potentially affecting hydropower operation and production in Lao PDR.

The basin's climate is projected to be changing. Future scenarios show higher temperatures and the potential for more extreme floods and droughts (MRC, 2018). It was reported that the overall basin water yield could either increase or decrease, with the range of annual river flow varying between –59% and +27%, and the dry season minimum 1-day flow changing between –65% and +35% at Chiang Saen in Thailand by 2060 (MRC, 2018).

Climate change, coupled with the uncoordinated operation of water infrastructure on the river, is expected to have serious impacts on the hydrology of the Mekong River, its environment, associated economies, and vulnerable communities. As highlighted in the *Sustainable Hydropower Development Strategy*, hydropower development has a number of risks including the loss of livelihoods, reduced yields of capture fisheries, declining sediment flows, disrupted ecosystems, and loss of wetlands and forests (MRC, 2022b). To mitigate these potential impacts and to address sustainable hydropower development, the MRC aims to achieve a balance between the benefits of hydropower development and the preservation of the Mekong River's ecological integrity.

3.2. Sustainable Hydropower Development in Lao PDR

Lao PDR is one of the signatory members of the MRC and is, therefore, bound by the 1995 Mekong Agreement and associated procedures and guidelines. In supporting sustainable hydropower development and water resources management, the MRC plays a crucial role as an instrument for regional cooperation and collective action to address challenges and to realise the shared vision of sustainable development in the Mekong River Basin. This intergovernmental organisation has indeed been a force for peace, forum for dialogue, repository of knowledge, and platform for conflict resolution and water diplomacy (An, Kittikhoun, Meas, 2020; Sok, Meas, Pheakdey, 2023).

By adopting a balanced approach to energy development, leveraging geographical advantages, and addressing key challenges, Lao PDR can unlock the full potential of its hydropower potential while promoting regional energy security and sustainability. Some considerations for making hydropower development sustainable in Lao PDR are as follows.

Look for joint investment with other Mekong countries. Joint investment projects between two or more countries offer a strategic approach to harnessing the collective strengths and resources of multiple countries for mutual benefit. They are the ultimate realisation of the aspirations of 'One Mekong, One Spirit' as well as 'shared river, shared future'. By pooling financial resources, technical expertise, and infrastructure, these projects enable economies of scale and optimise the utilisation of shared water resources. Moreover, joint projects facilitate the coordination and management of transboundary water systems, fostering greater participation of relevant stakeholders and meeting multiple objectives for a more sustainable Mekong (MRC, 2024a; 2024b).

The Pak Chom and Ban Khoum projects are transborder hydropower projects between Lao PDR and Thailand. Pak Chom is expected to generate 1,079 MW, while Ban Koum is expected to generate 1,872 MW (ICEM, 2010). Both projects, which are in the early stages of planning and study, hold significant potential to benefit the region. However, these projects are currently under study by private companies. If these projects could become a joint project between the governments of Lao PDR and Thailand, they could enable the sharing of resources and expertise, leading to more efficient project planning, implementation, and operation. Both countries can leverage their respective strengths and capabilities to optimise the feasibility study, design, construction, and management of the hydropower facilities, thereby maximising the benefits while minimising risks and costs. The MRC Secretariat can offer facilitation and early technical support to improve project quality as well. This proactive involvement is preferable to later participation during the Prior Consultation process, a formal 6-month procedure under the Procedures for Notification, Prior Consultation, and Agreement (PNPCA). Overall, if Pak Chom and Ban Khoum can become bi-national joint hydropower projects, they will serve as models of regional cooperation and integration that can demonstrate how joint initiatives can yield mutual benefits.

Moreover, the MRC is currently working with Member Countries to carry out Proactive Regional Planning, expecting that an initial adaptive basin plan be available by the end of 2024, in which several joint investment projects will be recommended. It is expected that many joint investment projects will be identified as those in 'grey' or 'green' infrastructure and be undertaken jointly, with cost- and benefit-sharing agreements by two or more of the six basin countries. Investment projects may include river regulation structures, dams, multi-purpose storage, flood-warning systems, and systems for monitoring of water flow.

Joint investment projects, such as multi-purpose dams and hydropower ventures, are exemplified globally. Notable instances include the Columbia River projects between the US and Canada (Muluye, 2021); the Sambangalou project involving Mali, Senegal, and Mauritania (Choplin and Lombard, 2014; Gakusi, Delponte, Houetohossou, 2015); and the Itaipu venture shared amongst Brazil, Paraguay, and Argentina (Gwynn, 2023). These initiatives stand as remarkable transformations of conflict into cooperation.

Implement alternative and complementary cost-effective energy/water system integration options. Modification of the flow on the mainstream is expected to continue with further development of mainstream and tributary hydropower projects. Through an ongoing study under Proactive Regional Planning, there is potential for more inter-seasonal storage for optimisation of hydropower generation and improvement of water security as well as for supplementing energy with the development of alternative energy options for water-related infrastructure, including pumped storage hydropower (MRC, 2024a; 2024b).

Implementing complementary cost-effective energy/water system integration options involves a multi-faceted approach aimed at enhancing the resilience and sustainability of energy and water systems in the context of hydropower development. One of the options is integrating various renewable energy sources into power development plans, which presents opportunities for synergies between water resources management and energy production.

The Government of Lao PDR recognises that there are emerging issues related to the use of run-of-river conventional hydropower plants, with excess electricity being generated in the wet season, while generation is potentially only just meeting current demand during the dry season. Various strategies are being considered to address these challenges, including (i) installing solar, and taking advantage of the complementary nature of solar and existing conventional hydropower (e.g. supplying daytime needs, thus allowing conventional hydropower plants to 'reserve' their limited dry season capacity for evening peaks); (ii) installing pumped storage hydropower facilities and/or large-scale batteries; as well as (iii) instituting demand management approaches, and increasing electricity exports during the wet season (DEPP, EDL, LNMCS, 2023).

Pumped storage hydropower is a unique form of hydropower technology that utilises the principles of energy storage and regeneration. During off-peak hours, when electricity demand is low, these systems pump water from a lower reservoir to an upper reservoir, effectively storing potential energy. During peak demand periods, the stored water is released through turbines, generating electricity as it flows back to the lower reservoir. This cycle can be repeated continuously, making pumped storage hydropower a flexible and efficient means of managing fluctuations in energy demand. Blakers et al. (2020) showed that Lao PDR has over 5,500 potential sites that may be suitable for pumped storage hydropower development, with a total potential storage capacity of 188,156 GWh.

Floating solar photovoltaic systems also offer an innovative approach to harnessing solar energy. These systems consist of solar panels mounted on buoyant structures that float on the surface of water bodies, such as reservoirs, lakes, or human-made ponds. These systems offer several advantages, including reduced land requirements, improved energy efficiency due to the cooling effect of water and the potential for co-location with existing hydropower facilities (Majumder et al., 2023).

Over the last decade, the cost of producing electricity with renewables, including wind and solar, has decreased rapidly (Gilfillan and Pittock, 2022). The decreasing cost of renewably generated electricity is a key driver of the growing use of renewables-based generators as is the need to reduce electricity sector emissions. Investing in new and diverse renewable energy could create a more secure and affordable energy supply in both domestic and regional markets.

Apply MRC strategies, procedures, tools, and guidelines. The *Integrated Water Resources Management-based Basin Development Strategy* and *Sustainable Hydropower Development Strategy*, approved by the MRC, recognise the opportunity to develop hydropower to meet the clean energy and development needs of riparian countries while contributing to flood and drought management and a low-carbon economy (MRC, 2021; 2021a). Both provide guidance on procedures, guidelines, tools and mechanisms necessary to make hydropower development responsible, optimal, and sustainable, without significant adverse impacts, especially transboundary impacts.

In terms of procedures – especially PNPCA – there are specific requirements for hydropower development. Projects on tributaries must be notified, while those planned on the mainstream require a more detailed process known as Prior Consultation. During Prior Consultation, the project's studies, data, and design must be shared with MRC Member Countries and the public, and they are subject to independent review. The process then continues with dialogue, exchange, monitoring with the MRC, and adaptive management (MRC, 2003). Five mainstream hydropower projects in Lao PDR have undergone the PNPCA Prior Consultation, including the Don Sahong, Luang Prabang, Pak Beng, Pak Lay, and Xayaburi. A sixth project, Sanakham, is in Prior Consultation, while a seventh, Phou Ngoy, has been notified for Prior Consultation.

After Prior Consultation, based on the recommendations of the MRC, the Xayaburi hydropower project undertook design adaptation or change for fish passage, navigation, and sediment transport facilities as well as investigation of seismic risk (MRC, 2019b). Best practices from Xayaburi were used in the development of the Luang Prabang hydropower project, particularly regarding fish passage and sediment management based on its monitoring programme.

The post-Prior Consultation process for Don Sahong yielded the development of MRC Joint Environmental Monitoring, which focusses on hydrology and hydraulics, sediment, water quality, ecological health, and fisheries (MRC, 2022a). To date, Joint Environmental Monitoring methods and protocol have been integrated into the MRC Core River Monitoring Network, an arrangement of monitoring stations and associated infrastructure designed to collect scientific data on various aspects of the Mekong River Basin.

Furthermore, the Prior Consultation processes for Pak Beng, Pak Lay, and Luang Prabang were concluded with agreed on statements by the four MRC Member Countries, outlining measures to optimise project benefits, and to avoid, minimise, and mitigate potential transboundary adverse impacts. To implement these statements, the MRC Joint Committee agreed on a Joint Action Plan (JAP) for each project to be executed as part of the post-Prior Consultation process and to involve the continuous exchange of data regarding the project's design, construction, and operation. The JAP provides opportunities for the government to engage with experts from the MRC with a view to enhancing existing measures to avoid, minimise, and mitigate the potential for transboundary impacts, and to enhance the benefits of the project via adaptive management.

Besides the above procedures, several guidelines also exist to make hydropower development more sustainable. Preliminary Design Guidance for Mainstream Dams (PDG), established by the MRC, serves as the standard for developers and participating countries. This framework encompasses criteria essential for effective dam design and operation, including parameters related to flow management, water quality, dam safety, and the provision of passage systems for both fish and sediment as well as for navigation and the preservation of river-based livelihoods (MRC, 2023b). Mainstream hydropower developers in Lao PDR, including those involved in projects such as Pak Beng, Pak Lay, Luang Prabang, and Sanakham, have used the PDG during their feasibility studies.

Other MRC guidelines related to the development of hydropower dams include the Rapid Basin-wide Hydropower Sustainability Assessment Tool (RSAT), and the Transboundary Environmental Impact Assessment (TbEIA) guidelines. These provide a basis for a hydropower project that is profitable, environmentally friendly, and socially responsible. The RSAT is a multi-stakeholder dialogue and assessment tool designed to assess hydropower development and management issues at a sub-basin level (MRC, ADE, and WWF, 2014). It helps identify gaps, risks, and key institutional responses and management strategies that can be adopted for sustainable hydropower development in the tributary.

The TbEIA guidelines, approved in 2022 as a voluntary application, were designed as a supporting tool applicable in compliance with different national environmental impact assessment legislation systems in MRC Member Countries (MRC, 2023a). The TbEIA actively supports national systems by facilitating environmental impact assessments for projects with potential significant transboundary impacts. Collaboration with neighbouring countries enhances the efficacy of this process, fostering regional cooperation and ensuring better environmental assessments. It is a useful tool in the early design phase of projects to avoid any significant environmental impacts. Lao PDR used these guidelines for the Sekong A hydropower project with the technical support of the MRC and in dialogue with Cambodia and Viet Nam. As a result, Cambodia and Viet Nam expressed appreciation to Lao PDR for sharing data, listening to their concerns, and committing to improvement of the project.

In summary, through the utilisation of various MRC procedures and guidelines, as well as active engagement with other MRC Member Countries and stakeholders during the PNPCA process, Lao PDR is optimising project benefits while also avoiding, minimising, and mitigating potential adverse transboundary effects. This approach consequently fosters basin-wide cooperation amongst riparian countries.

Work toward coordination of basin management operations. Realising that the basin is becoming more developed and regulated by dams, coupled with heightened vulnerability to extreme weather events induced by climate change, a pressing need is arising for more data and information sharing and transboundary coordination of operations regarding flow management, sediment management, management of emergencies, and design and management of hydropower cascades (MRC, 2023c). Coordination of dam operations is crucial, considering the number of dams operated by various operators to ensure energy optimisation and good management of other issues such as sediment transport, water flow, and emergencies.

The increasing number of tightly linked cascades of dams within the Mekong system presents both opportunities and challenges for integrating water resources and energy resource/demand planning. Coordinated operation allows for the management of seasonal flows, enabling downstream projects to benefit from regulated water releases and increased energy production. For instance, for dams in northern Lao PDR, such as those from Pak Beng to Sanakham along the mainstream, storage operation in both the Upper Mekong River Basin and the Nam Ou tributary can enhance the efficiency of energy production. Different developers/operators of the mainstream hydropower projects in Lao PDR have indicated that they would benefit from MRC's coordination with both these individual projects and the Chinese dams.

Achieving effective coordination requires a high degree of cooperation amongst stakeholders, including dam developers and operators, as well as amongst governments. Challenges arise when projects are owned by different entities with varying interests and priorities. These differences may complicate the timing and quantity of water release, particularly if developers aim to cater to diverse markets and customers with different demand patterns. Therefore, integrating water resources and energy resource/ demand planning is essential for optimising the benefits of hydropower development while mitigating potential conflicts and ensuring sustainable management of the Mekong River Basin. By aligning water release schedules with energy demand patterns and considering the broader implications for water availability and ecosystem health, countries can achieve a more balanced and coordinated approach to hydropower development that maximises benefits.

As a consequence, national regulations, procedures, and platforms to establish a dam coordination and management centre to facilitate data and information sharing amongst different dam operators need to be in place, especially in Lao context. The Compagnie Nationale du Rhône, a French electricity generation company, has a coordination and monitoring centre concept, which should be revived and enhanced. Such a centre could help support coordinated operation and management for energy and water as well as related issues like sediment, floods, and droughts, bringing together the Ministry of Energy and Mines and Ministry of Natural Resources and Environment.

Also, as one of the MRC Member Countries, not only is it crucial but also beneficial that Lao PDR continues to work with the MRC as it has the mandate to work with other riparian countries, including China, to exchange dam operational data to improve information sharing and transboundary coordination in the basin regarding management of flow, sediment, and emergencies.

4. Conclusion and Policy Recommendations

To navigate the challenges and to fortify Lao PDR's journey towards sustainable hydropower development, four strategic actions and policy directions are proposed.

4.1. Identify and Implement Planned and New Options for Joint Investment Projects

The development of proposed mainstream hydropower dams planned along the border between Lao PDR and Thailand (i.e. Ban Khoum and Pak Chom) should be elevated as national joint projects with the Government of Thailand, so that both countries can work together, with the technical support of the MRC, at the pre-feasibility and feasibility stages to ensure quality reports and studies that illustrate clear impact assessments and mitigation measures. This pre-Prior Consultation engagement with the MRC Secretariat will be helpful regarding the submission and application of the Prior Consultation process within the MRC framework.

Moreover, the work with the MRC and other Mekong countries should be reinforced to identify potential new joint investment projects in the MRC Adaptive Basin Plan, which the MRC is working with Member Countries to formulate under the Proactive Regional Planning to be fully completed in 2027. These projects can be jointly invested, operated, or managed by two or more riparian countries to cope with floods and droughts, optimise energy production, and secure food production for the Mekong River Basin and region.

4.2. Identify and Implement Alternative and Complementary Cost-effective Energy/water System Integration Options

More opportunities in alternative renewable energy sources, like solar and wind, should be identified and implemented. Aligning with Lao PDR energy development plans and leveraging advancements in technology, these alternative energy sources offer the potential for reduced investment and greater energy resilience as well as preserving the river environment for future generations. Embracing such diversification also addresses the pressing challenges posed by climate change to water security for Lao PDR's arsenal of hydropower dams.

Alternative energy options for water-related infrastructure, such as floating solar, and pumped storage hydropower development to supplement energy supply available from existing hydropower projects should also be explored.

4.3. Strengthen and Apply MRC Procedures, Tools, and Guidelines

The early and effective application and utilisation of the MRC procedures, tools, and guidelines – as well as data and studies, such as PNPCA – should be incorporated into national process of hydropower project development with targeted capacity building to relevant line agencies and companies. This will support Lao PDR in conducting quality feasibility studies and reliable environmental and social impact assessments as well as proposed mitigation measures to avoid, minimise, and mitigate potential adverse impacts at both national and transboundary levels.

The implementation of the post-PNPCA process should be further strengthened, including JAPs agreed on at the completion of the PNPCA Prior Consultation process of the hydropower projects. These plans are considered a mechanism for dialogue amongst the MRC Member Counties and other stakeholders, as they keep them informed of the development of hydropower projects. Improvement of plan implementation will demonstrate Lao PDR's commitment towards openness and transparency; in return, Lao PDR will gain more trust and support for its future hydropower development.

4.4. Work towards Coordinated Water Infrastructure Operation and Communication in the Mekong River Basin

National regulations and platforms to establish a dam coordination and management centre to facilitate data and information sharing amongst different dam operators should be developed, building on the current momentum. Good data and information sharing is crucial, due especially to various dams that are operated by different operators. A coordination and monitoring centre could support coordinated operation and management for energy (and water) optimisation as well as back up the disaster mitigation and management efforts. The centre can be hosted by the Ministry of Mines and Energy with active participation of the Ministry of Natural Resources and Environment and connection to the MRC.

The Government of Lao PDR should continue and even advance its efforts in sharing the operational data of hydropower dams amongst MRC Member Countries and other basin countries to improve data and information sharing and transboundary coordination regarding the management of flow, sediment, and emergencies. This can be done under the MRC cooperation platform to enhance regional collaboration, ensure sustainable water resource management, and mitigate the impacts of hydrological events.

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