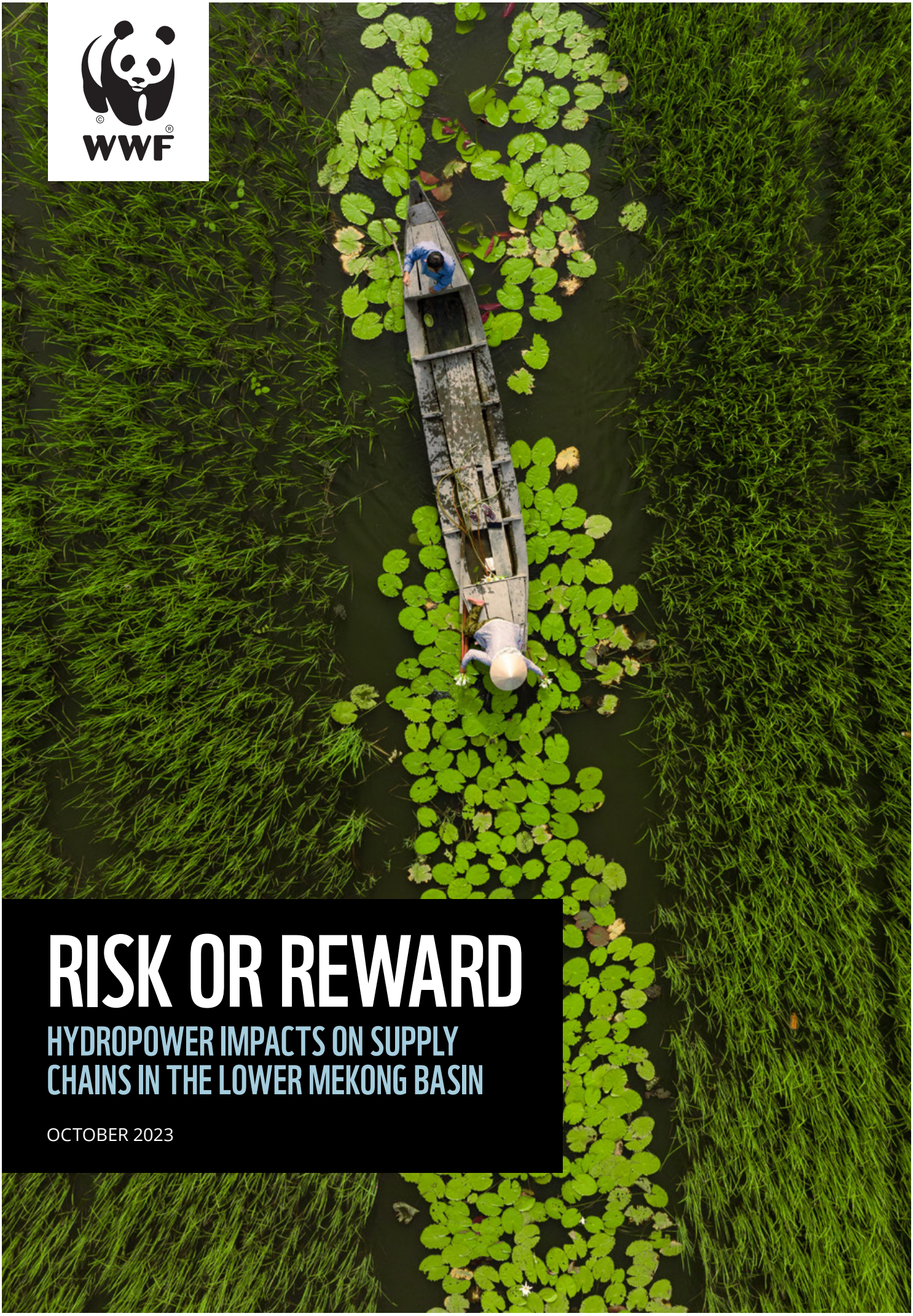


RISK OR REWARD

HYDROPOWER IMPACTS ON SUPPLY CHAINS IN THE LOWER MEKONG BASIN

OCTOBER 2023

AMPERES

Concept by Marc Goichot and Daphné Carliez (WWF-Greater Mekong)

Author and report development by AMPERES, prepared by Dr Amy Fallon, Dr John Sawdon, Ms Le Thi Ha Tien, and Mr Tarek Ketelsen. AMPERES is a mission-driven enterprise committed to finding integrated solutions for the entrenched sustainability challenges facing Southeast Asia, Australia and the Pacific. AMPERES has offices in Ho Chi Minh City (Viet Nam) and Perth (Australia) and uses evidence-based, deliberative processes and innovative technology to improve how society interacts with the environment.

A special thanks to Richard Lee (WWF) and Heron Holloway (WWF) and Klomjit Chandrapanya for their support throughout the development of this report.

Suggested Citation: WWF (2023) Risk or Reward: Hydropower impacts on supply-chains in the Lower Mekong report. Lead authors: Dr Amy Fallon, Dr John Sawdon, Ms Le Thi Ha Tien and Mr Tarek Ketelsen. Contributors: Marc Goichot, Daphné Carliez, Richard Lee, Heron Holloway and Klomjit Chandrapanya. WWF Asia-Pacific.

CONTENTS

© Shutterstock / Maxim Burkovskiy / WWF

EXECUTIVE SUMMARY

RISK OR REWARD? REWARDING THE PRESENT, RISKING THE FUTURE: ANALYSING THE HIGH-STAKES OF HYDROPOWER IN THE LOWER MEKONG'S SUPPLY CHAINS

Hydropower investments in the Lower Mekong region come with the promise of clean energy and positive projected economic value of up to US$33 billion (MRC, 2017), but the substantial threats posed to the Mekong's dynamic ecological system by dams calls these purported benefits into question. With multi-billion-dollar industries dependent on a healthy, free-flowing river, governments, investors, and businesses must consider the systemic threats posed by continued hydropower development to supply chains in the region, and ask: Is the reward worth the risk?

Although the Mekong region's economy has grown rapidly in recent decades, this economic growth has come with significant environmental and social costs; uncoordinated infrastructure development has fragmented and polluted the river's natural processes, undermining the basin's immense biodiversity and productivity, while communities have faced displacement and inequitable sharing of the economic benefits of hydropower.

OF THE NUMEROUS DRIVERS OF CHANGE FACING THE MEKONG, THOSE RELATED TO HYDROPOWER DEVELOPMENT ARE AMONGST THE MOST IMMEDIATE AND SEVERE.

Hydropower dams are significantly altering the river's flow of water, sediment, and nutrients - all of which are vital for a healthy river system and the food security of more than 50 million people. The Lower Mekong countries – Cambodia, Thailand, Lao PDR, and Viet Nam – all benefit economically from the river, with natural resource-based supply chains contributing to both domestic and global markets.

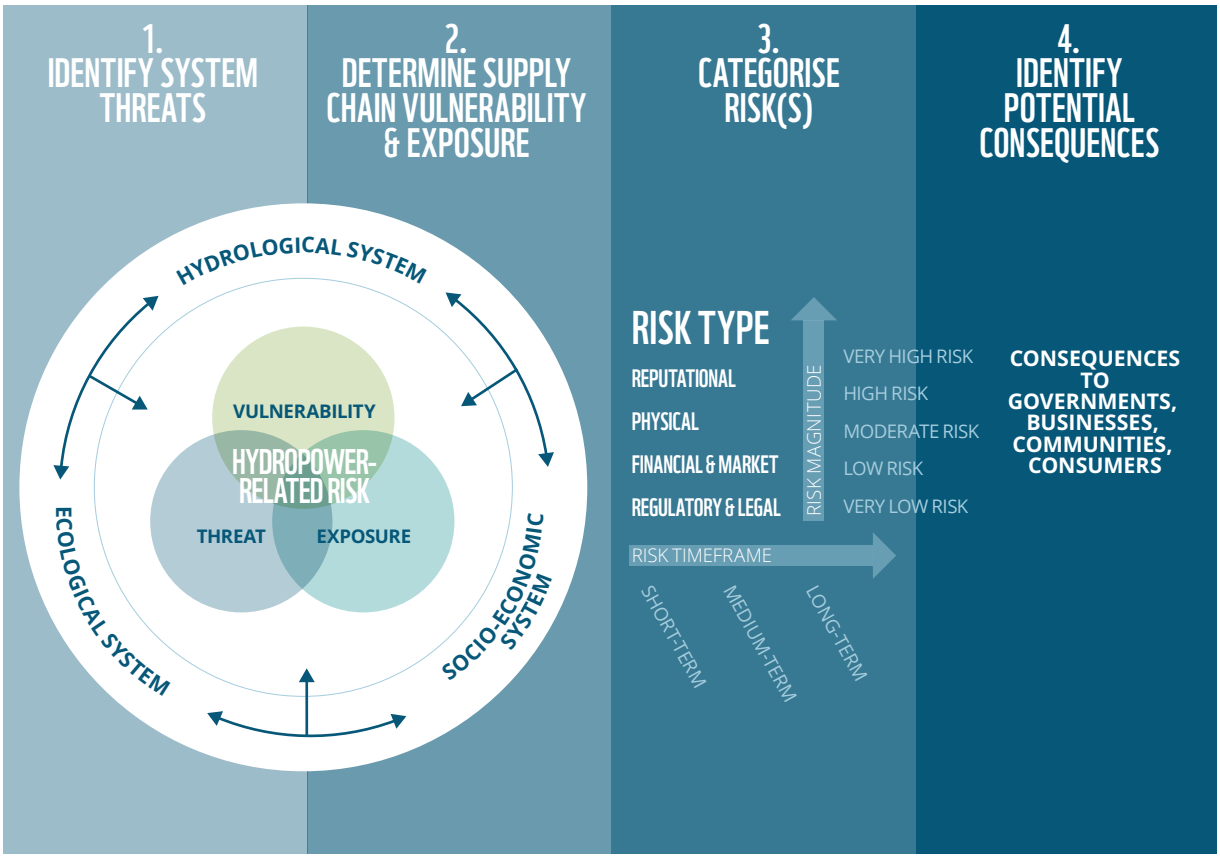
IN THIS REPORT, WE GO BEYOND THE WELL-ESTABLISHED ENVIRONMENTAL AND LIVELIHOOD IMPLICATIONS OF HYDROPOWER TO EXPLORE THE NATURE AND EXTENT OF HYDROPOWER-RELATED RISKS TO CRITICAL SUPPLY CHAINS ACROSS KEY GROWTH INDUSTRIES IN THE LOWER MEKONG BASIN (LMB).

Rapid growth in the economies of LMB countries has been a persuasive argument for the development of substantial hydropower in the basin. However, these arguments have been based on the purported benefits to the energy sector, with little consideration, or understanding, of the implications for other economic sectors. Using a hydropower risk framework developed for this analysis, we focus on five types of risk (physical, market, financial, regulatory, and reputational) for five key supply chains[1]: energy production; fisheries and aquaculture; rice production; sand and construction; and textiles and electronics. Risks to these supply chains are assessed as a function of their vulnerability and exposure to given hydropower-related threats via the basin's hydrological, ecological, and socio-economic systems.

THE FINDINGS PRESENTED HERE PROVIDE POLICYMAKERS, BUSINESSES, AND INVESTORS WITH A NEW PERSPECTIVE TO UNDERSTAND AND EXPLORE SUPPLY CHAIN RISK BEYOND CURRENT FRAMINGS, WHICH OFTEN NEGLECT THE SYSTEMIC, COMPLEX, AND LONG-TERM NATURE OF HYDROPOWER-RELATED RISKS.

With a broader understanding of risk, stakeholders will be better equipped to anticipate, prepare for, and mitigate these risks as they arise in the coming decades.

Fig 1 | High-level framework used to assess hydropower-related risks, which arise as a function of a supply chain's exposure and vulnerability to threats posed by hydropower to interconnected hydrological, ecological, and socio-economic systems.



1. These supply chains were selected due to their dependency on the Mekong River's natural resources and ecosystem services, as well as their importance to regional food security and economic development. Note, however, that the risks presented in this report may have cascading, long-term, indirect impacts on other supply chains in the region.

HOW DOES HYDROPOWER THREATEN THE LOWER MEKONG'S HYDROLOGICAL, ECOLOGICAL & SOCIO-ECONOMIC SYSTEMS AND DEPENDENT SUPPLY CHAINS?

FIVE KEY SUPPLY CHAINS DEPENDENT ON THE MEKONG'S NATURAL SYSTEM

- Fisheries & aquaculture
- Rice production
- Textiles & electronics
- Sand & construction
- Energy production

EXAMPLES OF POTENTIAL THREATS POSED TO EACH SUPPLY CHAIN

Hydrological system: *Timing and volume of natural flow regime is altered, weakening the flood pulse*

- Disruptions in breeding cycles for fish due to changes in flood pulse, reducing species diversity & abundance
- Reduced annual high flows isolates floodplains from annual flooding and sediment fertilisation processes
- Insufficient or irregular water releases from upstream, and flooding events
- Reduced transportation of sediment downstream
- Reduced or uncertain water flows for power generation during exceptionally dry years

Ecological system: *Dams act as physical barriers that block fish migration pathways & trap sediment & nutrients, with knock-on effects on riverbed incision, lower water levels & saline intrusion*

- **85-100%** Sediment reduction of 80% could lead up to 36% fish production loss
- **66%** Loss of nitrogen & phosphorus (natural fertiliser) transported from upstream
- Flooding impacts for assets, factories & infrastructure: Degraded water quality for factory processes (e.g., textile dyeing) due to saline intrusion
- **97%** Reduction of suspended sediment flux if all dams built, widening deficit in sand supply & extraction
- Silting of dams reduces electricity production capacity

Socio-economic system: *Marginalisation of river-dependent livelihoods, increased rural unemployment and outmigration, food insecurity for subsidence farmers; tighter regulations*

- **40%** Of household incomes in Tonle Sap area dependent on fish products under threat
- Labour shortages as people migrate towards urban areas
- Tighter regulations on factory operations in response to climate and water risks
- Tighter regulations on sand mining activities; Opposition from local communities in high-exposure areas
- Conflicts between riparian communities & hydropower developers, power companies

HYDROPOWER-RELATED RISKS FACING SUPPLY CHAINS IN THE LOWER MEKONG ARE...

CASCADING

One threat or risk triggers another, with a 'domino effect' across the system.

For example, the trapping of sediment by hydropower dams upstream reduces the amount of sediment transported downstream to the delta. This in turn increases riverbed incision rates, lowering water levels and increasing levels of saline intrusion in the delta. Rice's vulnerability to saline intrusion creates physical risks to crop productivity and therefore financial risk to farmers.

There is a growing body of scientific evidence documenting the cascading risks of hydropower on the hydrological, ecological, and socio-economic systems of the Mekong. However, the system is inherently complex, and there remains a multitude of connections that are poorly understood. As hydropower development grows, the cascading nature of its impacts could be wider and more significant than understood today.

COMPOUND

Multiple threats across the system combine to amplify the risk(s) facing a supply chain.

For example, capture fisheries in Cambodia's Tonle Sap Lake are not only under threat from hydrological changes from hydropower operations, but also from illegal and over-fishing, deforestation (shrinking fish habitats), water pollution, and alterations in the flood pulse due to climate change.

Maintaining the environmental integrity of the Mekong system has been overshadowed by an appetite for a narrow conception of economic growth. With development decisions proceeding at pace, often with limited or no integration or system-scale planning, the past 40 years have seen a major degradation of the Mekong, making the system weaker and more vulnerable to the multiple, compounding risks it is facing.

SYSTEMIC

Multiple cascading threats interact and are amplified through complex causal relationships across scales, resulting in system-wide impacts.

For example, there are multiple threats facing the Mekong's diverse hydro-ecological system, including over-extraction of sand by the mining industry, alterations to the river's flow and sediment transport downstream due to hydropower dams and other water-control infrastructure, water pollution due to industry and agriculture, and changes in the basin's flood pulse system due to changing land-uses and climate – all of which interact with and amplify one another in complex, often unpredictable ways across multiple time and spatial scales.

Table 1. Key definitions used in this report

TERM	DEFINITION
SUPPLY CHAIN	The sequence of processes involved in the production, sale, and distribution of a commodity or product, including the network of involved individuals, organisations, resources, activities, and technology.
THREAT	The result of social, economic, and environmental changes due to hydropower that may jeopardise a supply chain's value/profitability.
VULNERABILITY	The predisposition of a supply chain to be adversely affected by threats related to hydropower development.
EXPOSURE	The presence of a supply chain's operations in places and settings that could be adversely affected by hydropower.
RISK	A probabilistic concern with the consequences to a supply chain (e.g., operations/profitability) of a threat arising from hydropower, due to factors of exposure and vulnerability.
CONSEQUENCE	Potential outcomes for supply chains and actors involved (e.g., businesses, governments, and communities) if hydropower-related risks are not adequately mitigated.

WHAT ARE SOME OF THE KEY RISKS POSED TO THE LOWER MEKONG'S SUPPLY CHAINS?

Fisheries and aquaculture in the Lower Mekong have extremely high exposure to threats arising from hydropower development, and as such are estimated to face some of the greatest physical, financial and market risks, including financial losses of up to US$21 billion.

While aquaculture may mitigate some of these losses, it is unlikely to compensate entirely, and benefits will likely not reach those most dependent on capture fisheries for their food security. Cambodia's Tonle Sap Lake alone may face upwards of a 40–57 per cent decline in fisheries production by 2030.

The Mekong Delta is expected to face reduced rice productivity due to a combination of threats posed by upstream hydropower dams, putting farmers at increased financial and market risk in the long term.

Reduced sediment and nutrient transport (and pollutant flushing) from upstream, along with increased coastal erosion and saline intrusion, are expected to degrade soil quality and reduce freshwater availability for rice production in the Delta. These threats may also increase the need for inputs such as fertilisers and diesel/electric pump investments in the future.

Upstream hydropower dams cause cumulative, compounding physical and financial risks to sand and construction supply chains downstream in the Mekong Delta, while the cumulative impacts of hydropower dams and sand mining on mangroves is already apparent, reducing coastal resilience in a changing climate and increasing risk for all businesses involved or exposed.

Dams trapping bedload sand and unsustainable sand mining practices may cause aggregate shortages in the Mekong Delta (also contributing to riverbed incision, coastal erosion and saline intrusion) in the long term. Companies operating in the Delta may find that operations become less financially viable due to stricter regulations, creating further **regulatory** and **financial risks**, as well as broader impacts on the local economy if financial losses translate to job losses and construction delays. These may be compounded by high fuel prices and increasing taxes on river sand.

As hydropower dams create water-related risks for textiles and electronics factories due to reduced freshwater availability and increased frequency and intensity of floods, factories operating in high-exposure areas such as the Mekong Delta may face cascading financial, regulatory, physical and reputational risks.

Factories may have to source water from alternative sources (e.g., groundwater), with financial implications. Continued operations in high-exposure areas may also cause companies to face stricter government regulations, or the loss of their social license to operate, while floods and landslides have caused loss of physical assets and operational disruption in textile and garment factories.

The reliability of hydroelectricity is being called into question as other drivers of change, such as climate change, compound existing threats to the power sector.

Cambodia and **Viet Nam** are facing short-term **physical** and **market risks** related to hydroelectricity production due to the sector's vulnerability to drought. Meanwhile, **Lao PDR** is facing both regular dry-season power shortages and economically crippling **financial risk** due to mounting debts related to domestic hydropower development.

Table 2. Five types of risk facing supply chains

RISK TYPE	DEFINITION
PHYSICAL	Risk arising from material destruction or damage, causing disruption to supply chains. Potential physical risks include water scarcity, flooding, and ecosystem service losses.
FINANCIAL	Risk related to monetary losses caused by a threat (or multiple threats). Can also be a result of other risks or from costs of risk mitigation efforts (e.g., having to pump groundwater to compensate for reduced freshwater availability for production).
MARKET	Risk arising from movements or volatility in stock prices, interest rates, exchange rates, and commodity prices because of a given threat (or threats).
REGULATORY	Risk related to laws, policies, regulations, and court actions affecting supply chain operations (e.g., water license restrictions during drought, or polluter pays principle).
REPUTATIONAL	Risk related to a business, company, or government's image, brand, and public relations (e.g., social license to operate in a high-exposure area).

WHICH COUNTRIES FACE THE GREATEST SUPPLY CHAIN RISKS FROM HYDROPOWER?

The risks of hydropower development to Mekong supply chains are not evenly distributed amongst Mekong countries, reflecting national variations in both the resource-dependency of industry and the relative maturity of those supply chain industries. The risks posed by hydropower depend on a range of factors influencing supply chains' exposure (e.g., geographic proximity) and vulnerability (e.g., low capacity to adapt operations) to a given threat.

Supply chains in Viet Nam and Cambodia face the highest risks from hydropower due to the high exposure of supply chains to hydropower threats, such as sediment loss and river fragmentation, combined with relatively high vulnerability of these sectors.

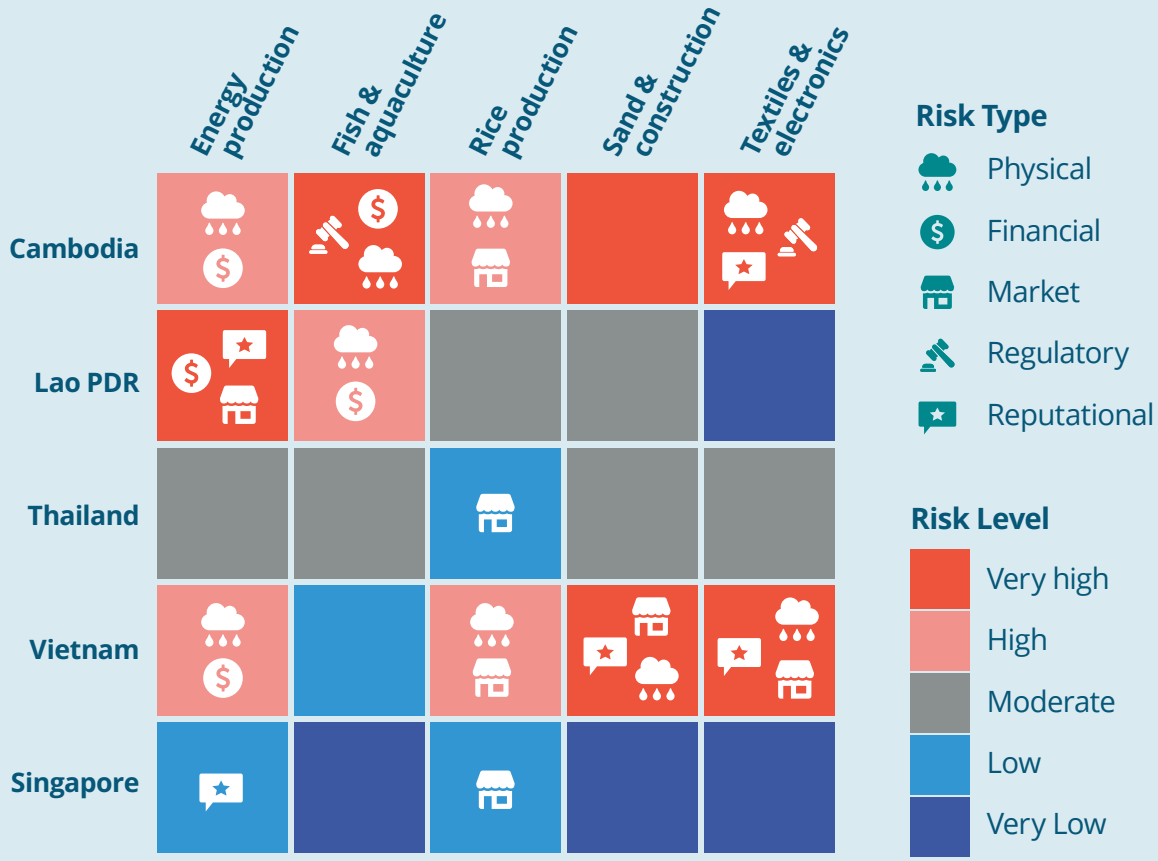
- For Viet Nam, these risks affect four of the country's main economic sectors – agriculture, textiles, electronics, and energy, which are compounded in the long term by high risks to the aggregates sector. With the Mekong delta a dominant geographical area for all these economic sectors, the risks posed by hydropower will have national-level economic implications. Businesses may face long-term reputational and regulatory risks with continued operations in high-exposure areas, such as the delta. Meanwhile, fisheries, aquaculture and rice supply chains face physical risks due to their high exposure to hydropower threats.
- For Cambodia, risks are highest for fisheries, aquaculture, and textiles sector, which are central to the country's economic development. High exposure and vulnerability of the Tonle Sap Lake's fisheries, which are critical for livelihoods and food security, put this sector at high physical and market risk, as well as regulatory risk in the long term as regulations on overfishing become tighter. In addition, Cambodia's rapidly growing agriculture and energy sectors also face high physical and market risks from hydropower, with impacts on the stability and fertility of agricultural fields, water availability for irrigation and operations, damage to agricultural production, and growing vulnerability of the nation's increasingly hydro-dependent power systems to the impact of drought.

Supply chains in Lao PDR and Thailand face relatively lower risks overall, largely due to their lower exposure and vulnerability to hydropower threats, though Lao PDR's energy sector faces high risks due to its increasing reliance on hydroelectricity and related domestic debts.

- Though Lao PDR's development of the electricity sector falls significantly behind its neighbours, the energy sector faces the highest risk of all Lao supply chains, primarily because of the dominance of hydropower in the nascent electricity system and the financial and market risks this dependency entails.
- For Lao PDR, most supply chain risks are low because of the low vulnerability of domestically important sectors, which are not exposed to the risks associated with hydropower. However, important areas of high vulnerability exist in Lao PDR in fisheries and aquaculture due to the magnitude and pervasiveness of ecological threats posed by hydropower, which are felt the most by vulnerable communities, due to high dependence on this sector for food and nutritional security. As the commercial fishery sector grows, so too will the scale of the risks.

Singapore, although not a LMB country, is increasingly turning to supply chains from the Mekong for natural resources in scarce supply nationally – particularly energy and food. At present, the risk for both rice and energy is moderate, though the country faces reputational and market risks in the long-term; recent ASEAN momentum to increase intra-regional trade is increasing the appetite for Mekong energy and rice in Singapore.

Fig. 2 | Overall hydropower-related risk for LBM+1 countries for five key river-dependent supply chains, with main risk types highlighted.



ARE HYDROPOWER INVESTMENTS IN THE LOWER MEKONG SUSTAINABLE?

Hydroelectricity provides a pathway for governments and businesses to meet decarbonisation targets and climate change mitigation goals, but there are serious and legitimate concerns surrounding the social and environmental externalities associated with hydropower development in the Mekong. Countries such as Singapore face increasing reputational risks with continued support for hydropower in the region, undermining their standing as a leader of sustainability in the ASEAN region and their commitment to international environmental agreements.

QUESTIONS FOR RETHINKING HYDROPOWER-RELATED RISK

Governments

- How can Mekong countries follow global trends and exploit their vast renewable energy resources (wind and solar) to reduce dependency on hydropower, and meet rapidly increasing demand for electricity?
- How can a broader understanding of hydropower-related risk be incorporated into national-level water, energy, and economic policy? And how can hydropower-related risks help establish processes and institutional structures to address systemic cross-cutting issues beyond sectoral siloes?
- How can governments enable a sustainable institutional and operating environment to attract responsible businesses and regulate/deter less responsible businesses?
- What support can governments provide to businesses in their assessment and management of supply chain risk, including capacity building tools?
- How can governments engage with the private sector in decision-making processes around national water and energy policy?

Businesses

- How can businesses move beyond simplistic framings of risk to consider risk both systemically and across longer, more appropriate timeframes?
- What are businesses' role in, and opportunities for, avoiding and mitigating hydropower (and related) threats themselves, moving beyond reducing supply chain vulnerability or exposure?
- How can businesses engage in public decision-making processes around river basin management, hydropower development planning and national energy policy?
- As a dominant driver of economic growth in the Mekong, what leadership and stewardship role can responsible businesses play, and how can these efforts be turned towards market advantage?

TEN ACTIONABLE RECOMMENDATIONS FOR RESPONSIBLE BUSINESSES AND POLICY MAKERS

01

Lower Mekong governments should better consider the trade-offs of further hydropower development, and assess alternative renewable technologies, such as wind and solar energy, for meeting the growing energy demands of the region as well as climate change mitigation and adaptation, and biodiversity conservation goals. **This includes reconsidering regional hydroelectricity investment plans, such as the recent Lao-Thai-Malaysia-Singapore (LTMS) regional hydropower trade agreement,** and considering alternative pathways for achieving climate change targets, while ensuring that cross-border electricity trade is both carbon-neutral and sustainable.

02

Foreign investors (including governments with plans to import hydroelectricity from the LMB, such as Singapore) should assess the true costs, including social and environmental externalities, of hydropower – as well as their impact on climate change adaptation measures – and weigh these against decarbonisation goals for climate change mitigation. Cost-effective, greener renewable energy alternatives are available so that hydropower is not the primary energy source but rather complements other technologies. Investors should take advantage of the dramatic cost declines of alternative renewable resources and ancillary technologies in recent years, together with the abundance of renewable resources in the Mekong and **consider these technologies as alternatives to hydroelectricity.**

03

Businesses sourcing their energy from LMB hydropower should consider shifting towards alternative renewable technologies to achieve their own sustainability and corporate social responsibility goals, especially as public awareness of the risks associated with hydropower increases.

04

Provide educational tools to businesses operating in the LMB so they understand the broader, systemic implications of hydropower on supply chain operations beyond water shortages and consider the potential consequences of reduced sediment and nutrient flow, saline intrusion, land subsidence, and riverine habitat fragmentation.

05

Businesses operating in high-exposure areas (e.g., the Mekong Delta) should conduct risk assessments for hydropower-related threats beyond short-term and localised threats, and analyse how they might reduce their vulnerability to these threats and act as leaders in responsible business practices in the LMB. This could be done through local business platforms such as the Mekong Delta resilient business network,[2] using tools and materials that are already established.[3]

06

Business leaders should work together to advance collective action on water and sand issues using established frameworks, so that the scale of action matches the scale of the issues being addressed.

2. See more about the Mekong Delta resilient business network at https://tuoitrenews.vn/news/business/20220506/mekong-delta-resilient-business-network-debuts-in-Viet Nam/66993.html
3. See, for example, the science driven targets developed by WWF: https://www.panda.org/discover/our_focus/freshwater_practice/water_management/science_targets_water/

07 **LMB governments should provide the enabling conditions for attracting responsible businesses through stricter environmental regulations and encouraging private sector engagement** (e.g., wastewater treatment requirements, water saving practices, and good regulatory frameworks to ensure compliance).

08 **Non-water related ministries in LMB governments** should increase awareness of hydropower-related risks across their sectors (e.g., ministries related to commerce and industry).

09 **Conduct further studies** on hydropower-related risks facing specific business supply chains in the LMB, particularly those with opaque business operations or complex chains of causality, such as those in the electronics, textiles, fisheries and rice sectors.

10 **Hydropower will be a part of a sustainable energy transition, but not repeating the role it has historically played in terms of electricity supply.** Governments should manage the hydropower sector fully cognizant of the damaging impacts that hydropower has on the region's natural and economic systems. Planning of new projects should carefully consider siting and use of hydropower as a supplementary energy source for the transition to other renewable energy sources, not a "complete substitute".

© Kelsey Hartman / WWF-Greater Mekong

INTRODUCTION

The Mekong River is the lifeblood of Southeast Asia and one of the most biologically diverse rivers in the world. The river's ecosystem services support the region's economy and the livelihoods and food security of more than 50 million people along its route from China's Tibetan plateau through China's Qin Hai and Yunnan provinces, Myanmar, Lao PDR, Thailand, and Cambodia, and through the Mekong Delta in Viet Nam before it meets the sea.

It is also one of the most vulnerable rivers in the world, with multiple threats posed by hydropower development, extractive industries, deforestation, overfishing, industrial and agricultural pollution, and climate change. These threats pose major, cumulative risks to the basin's society, economy, and the ecosystems upon which they depend.

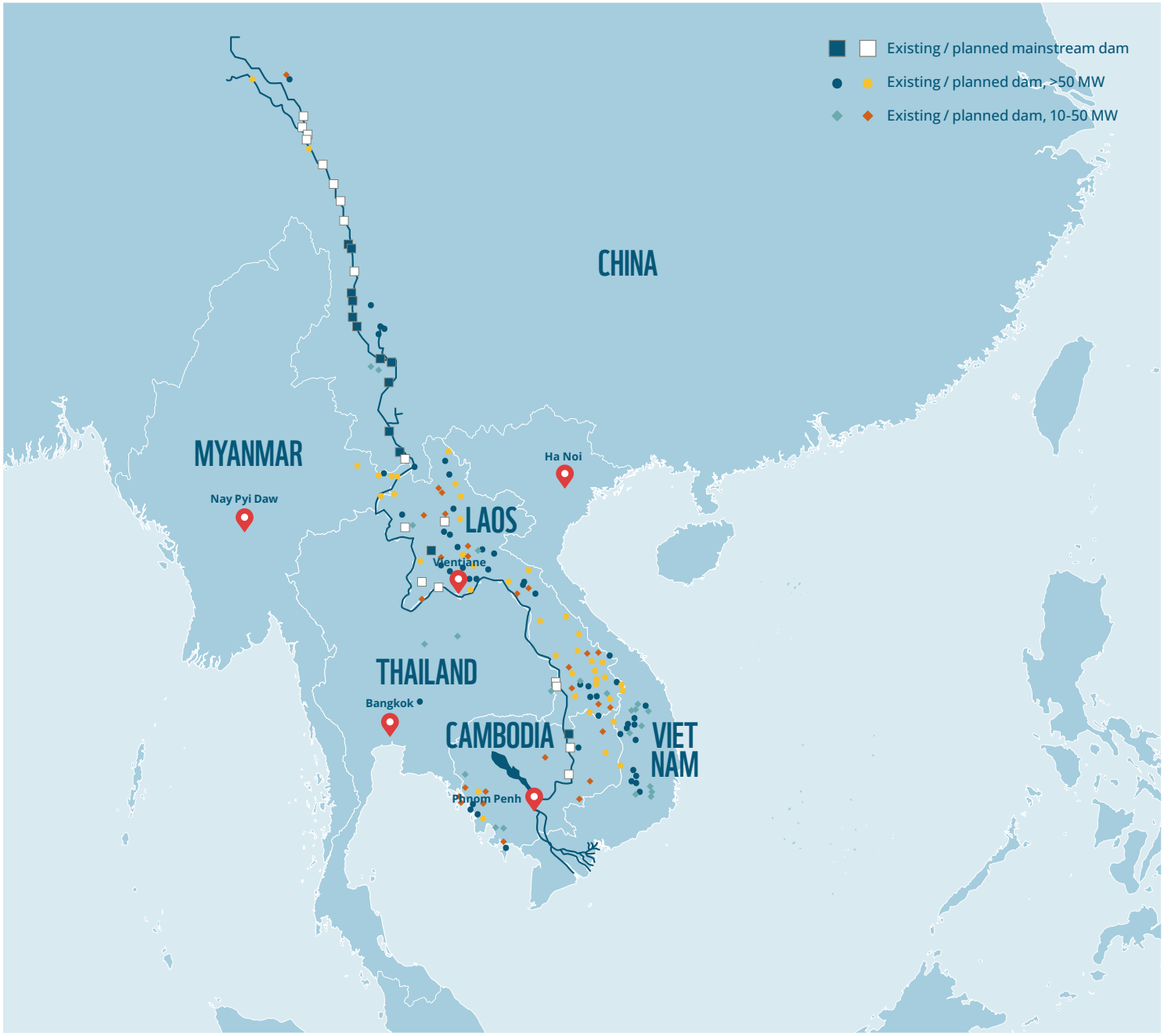
The Lower Mekong Basin (LMB) has seen rapid economic growth over the past two decades and an unprecedented expansion of water, energy, and industrial infrastructure. This has formed the basis for economic development; the combined Gross Domestic Product (GDP) of Cambodia, Lao PDR, Thailand, and Viet Nam increased from US$506.6 billion in 2010 to US$887.8 billion in 2020. Rapid economic growth, rising energy demands, and the need to decarbonise the power sector as well as the prospect of regional electricity trade via an ASEAN super grid, underpins the rationale for harnessing the Mekong River for power. Along with low-carbon energy, investing in hydropower also promises economic benefits to Lower Mekong countries of up to US$160 billion by 2040 (MRC, 2017), but these benefits come at great social, ecological, and economic costs.

A RIVER BASIN UNDER THREAT

The Mekong is no longer a free-flowing river, and of the threats posed to the Mekong, those stemming from hydropower development are some of the most urgent and severe (Arias, Piman, et al., 2014; Yoshida et al., 2020). Hydropower dams are fragmenting the river's connectivity, altering water flow and trapping sediments vital for the basin's ecological health. Large portions of the basin have low levels of connectivity[4] because of this fragmentation (including the Mekong's mainstem in Lao PDR and Thailand, and major sub-basins such as Nam Ngum, Mun-Chi, Nam Xuang, and 3S[5]).

Fig. 3 | Existing and planned hydropower dams in the Mekong Basin. Thirteen large-scale dams exist on the mainstem, with more than 30 more planned along tributaries.

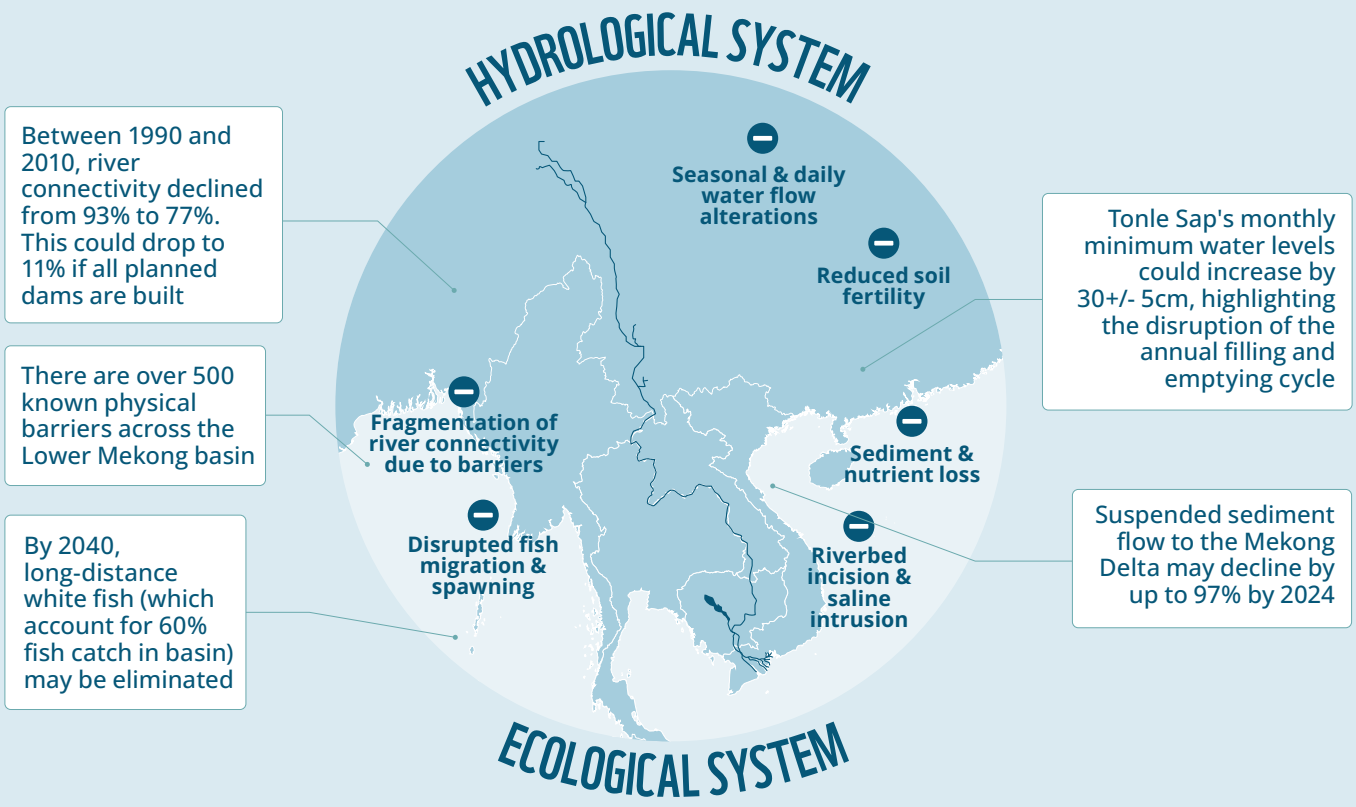
The LMB has up to 30GW hydropower potential, 10% of which has been realised (Intralawan et al., 2018. Map data source: M. Kallio, based on data from Mekong Region Futures Institute, 2021. Dataset on the Dams of the Greater Mekong, Bangkok, 2021. Mainstream data from OpenStreetMap and country borders from Natural Earth).



4. Connectivity is measured by the connectivity Status Index (CSI), produced by the Free-flowing River assessment for the lower Mekong region. The CSI is represented at the river reach scale and is composed of a weighted average of the six individual pressure indices DOF (degree of fragmentation), DOR (degree of flow regulation), SED (sediment trapping), USE (water abstractions), URB (urbanisation), and RDD (road infrastructure). See details at: https://free-flowing-lower-mekong.web.app

5. 3S Rivers include three large left bank tributaries draining the Annamite Ranges, the Sesan, Sekong and Srepok.

Fig. 4 | Key threats posed to Lower Mekong Basin's hydrological and ecological system due to hydropower development.



This fragmentation and alteration of the Mekong River's natural flow is threatening the basin's natural system in several ways (see Fig. 4) – for example, by blocking fish migration pathways, altering the Tonle Sap's flood pulse system, and causing the sinking and shrinking of the Delta. What these threats mean for key economic sectors and supply chains dependent upon the Mekong's natural system is not yet fully understood. This is due to the interconnectedness of these systems, the cumulative nature of hydropower impacts along with other threats such as climate change, and the complexity of supply chains themselves in terms of their exposure and vulnerability to these threats.

While businesses are becoming increasingly aware of nature-related risk (e.g., climate and water-related risks – see World Economic Forum, 2023), considerations of risks related to hydropower remain limited, typically focusing on (i) threats related to water flow (e.g., extreme flooding or drought) and quality, while underestimating ecological threats (e.g., habitat fragmentation and sediment trapping); (ii) operations-level physical risks, such as community displacement, rather than cumulative, cascading risks across the system; and (iii) short-term risks, rather than long-term risks. **As such, the benefits of hydropower as a low-carbon energy source for climate change mitigation are often grossly overestimated at the expense of long-term systemic risks posed by hydropower – not only in terms of environmental externalities, but also broader implications for society and economic sectors beyond the energy sector.**


© WWF-Viet Nam / Cham Team

PURPOSE OF THIS REPORT

This report provides an overview of the main risks[6] of hydropower development and their potential consequences for key supply chains[7] in the Lower Mekong Basin[8]. We focus on five key water-dependent supply chains: (i) fisheries and aquaculture; (ii) rice production; (iii) sand and construction; (iv) textile and electronics; and (v) energy production. These five supply chains were selected due to their reliance on the Mekong's natural system in terms of ecosystem services and raw materials and their contribution towards the region's food security, employment, and economic development.

This report is targeted towards governments and businesses of the Lower Mekong, as well as investors in hydroelectricity (such as Singapore) and other areas of development in the basin. It may also be of interest to policymakers in the water, energy, and agricultural sectors in the region. It is hoped that the report may provide the foundation for such groups to take a comprehensive, longer-term view of risk that captures the complex interdependencies of the Mekong's natural system and supply chains, and the ways in which hydropower development threatens to disrupt these linkages.

6. This report complements previous WWF work on the Mekong River's economy (Baleta et al., 2016. Mekong River in the Economy), WWF Water Risk Filter (www.riskfilter.org/water), Biodiversity Risk Filter (www.riskfilter.org/biodiversity), and WWF's work on Supply Chain Risk (www.supplyrisk.org).

7. Here, 'supply chain' refers to the network of interacting functions regarding a commodity, from the raw resources or manufacturing to the final product that ends with the consumer. Key actors in a supply chain include businesses, consumers, and governments, each of whom plays important roles across the following key stages: production, processing, trade, and consumption.

8. See Annex 1 for methodology, which followed 4 steps: (i) identify key hydropower-induced threats to the Mekong's natural system; (ii) characterise supply chain's vulnerability and exposure to these threats; (iii) categorise hydropower-related risk in terms of type, magnitude, and timeframe; and (iv) identify potential consequences to supply chains and key actors.

SUPPLY CHAIN 1:

ENERGY PRODUCTION

The benefits of hydroelectricity, in terms of providing a low-carbon energy source and tool for climate change mitigation, must be carefully weighed against the substantial and complex social and environmental externalities associated with hydropower dams in the Mekong, as well as the wider implications of these costs along other supply chains. The energy sector itself is also vulnerable to other cumulative threats in the basin, such as drought, revealing the vulnerabilities of hydroelectricity.

HIGHLIGHTS

- The region's power sector faces significant physical, financial, and reputational risks due to hydropower. In Cambodia and Viet Nam, recent dry years have shown the vulnerability of hydropower to drought and low water flows, with the potential consequence of energy shortages (especially in urban areas in Cambodia) and financial losses in the power sector.
- Benefits of hydropower development in the LMB are skewed geographically, ultimately with big electricity consumers benefiting the most (i.e., Thailand, Viet Nam, and Singapore), although the hydropower sector, particularly in Lao PDR, is likely to capture the largest share of intermediate benefits.
- The Lao government is experiencing significant financial debt domestically due to its own investment in hydropower. This debt has the capacity to induce a significant financial crisis in the Lao economy.
- Thailand has decreased its hydropower-related risks for the power sector (e.g., reducing its reputational risk by halting any further domestic hydropower projects), though this may be undermined by its continued investment in projects overseas, which externalises the environmental and social costs of hydropower.

WHAT IS HYDROPOWER'S ROLE IN THE LOWER MEKONG'S ENERGY MIX?

The development of hydropower in the LMB provides energy-hungry importing countries with a low-carbon energy source shielded from fluctuations in international energy markets. Energy demand in the LMB is expected to grow at between 6 and 7 per cent per year over the next decade, and electricity demand is expected to grow even faster, with Cambodia, Lao PDR and Viet Nam expected to experience a growth rate more than twice that of GDP. Demand for electricity is likely to grow in the long term as decarbonisation of economies drive increased electrification of economic sectors, such as transport.

Each country in the LMB has a power sector with very different dynamics, reflecting the size of its market, its natural resource base for power generation, and its stage of development. Viet Nam is now the largest market in the region, overtaking Thailand in around 2015. It has relied heavily on domestic hydropower in the past, with natural gas playing a bigger role after offshore fields were developed in the 1990s. Thailand is a more mature market, with much lower growth in demand, and imports a significant amount of hydropower from Lao PDR. Meanwhile, the power systems of

Cambodia and Lao PDR are an order of magnitude smaller. Cambodia has largely been dependent upon imported oil, moving in the late 2000s towards imported coal and domestic hydropower, which have come to dominate the energy mix. Lao PDR represents a significant contrast, being almost wholly reliant upon hydropower for its electricity generation and as a central component of the country's economic development strategy – especially via hydroelectricity exports to Thailand.

The LMB has considerable potential for the generation of electricity through hydropower, with up to 30 GW of potential identified in the region. However, this is unevenly distributed within the basin. As of 2021, the LMB had a total of 88 hydropower projects with a combined installed capacity of 12,600 MW, the majority of which are in Lao PDR. Given countries' plans to continue building hydropower in the LMB, it is possible that hydropower capacity will exceed 30,000 MW by the year 2040 (MRC, 2022b). Though detailed figures are not available, it is estimated that the gross value of the power generated from hydropower in the LMB in 2015 was US$ 2.1 billion (MRC, 2018b). New MRC estimates suggest that hydropower could be worth up to US$ 160 billion by 2040 – although this does not consider the negative impact of hydropower on other sectors. Moreover, these benefits are not evenly distributed between riparian countries. Even before the construction of new plants in Lao PDR, the country was estimated to capture over 53 per cent of these economic benefits, Viet Nam 34 per cent, Cambodia 9 per cent, and Thailand 4 per cent (ibid.)[9]. Nor are these benefits evenly distributed within society.

OVER-RELIANCE ON HYDROPOWER INCREASES RISKS POSED TO REGIONAL ELECTRICITY SUPPLY

While hydroelectricity has benefited the LMB economically and in terms of providing a low-carbon alternative to fossil fuels, it also comes with numerous **physical, financial, and market risks**, often due to ad-hoc planning and governance. In Lao PDR, for example, domestic hydropower development has saddled the country with major debt, while its over-reliance on hydroelectricity means too much is produced during the wet season and not enough during the dry. **Over-reliance on hydropower as an electricity source also increases the supply chain's vulnerability to climate change and water-related risks.** Power systems are likely to experience national and local outages in drier-than-usual years, as seen in 2019 and 2023. This situation has been exacerbated by climate change and associated extreme dry weather conditions in the region. Short-term power shortages (days to weeks) could extend the impact to neighbouring countries after the realisation of regional grid interconnection and trade agreements.

Like Lao PDR, the Cambodian power sector has also faced **physical and financial risks.** Despite the commissioning of the Lower Sesan 2 project, the Cambodian power sector was ravaged with blackouts due to a dry hydrological year in 2019–20 because of the country's dependence on hydropower (accounting for around one-third of the country's electricity supply in 2019), with financial consequences for many businesses in urban areas.

Thailand, on the other hand, has been relatively immune to such risks due to its large energy reserve margin of around 40 per cent, and instead faces an issue of generation overcapacity (IEA, 2021). The Thai government has, however, faced **reputational risks** around hydropower, and so has pursued a policy since 2000 of not building any new domestic hydropower dams because of social protests relating to their adverse environmental and social impacts.

9. Ultimately consumers benefit from more reliable, cheaper electricity supplies than would otherwise be the case. However, the calculation of the economic benefits of hydropower by the MRC looks at the benefits calculated based upon the cost of alternative supplies for the same quantum of electricity, rather than consumer benefits.


© Adam Oswell / WWF-Greater Mekong

In Viet Nam, hydropower has a changing role in the country's energy supply mix, with its current role largely as priority dispatch during wet years because of its cost-effectiveness. Hydropower is also financially important in Viet Nam, with the country suffering financially during dry years, but performing well during wet years. This dependence on sufficient reservoir levels indicates a certain level of **financial risk** that may accompany dependence on hydroelectricity in the region, which may feasibly increase as the impacts of climate change manifest in coming decades. Reliance on hydropower significantly increases the vulnerability of power supply chains due to hydropower's exposure to hydrological variability.

Fig. 5 | Overall hydropower-related risk levels posed to the power sector in LMB+1 countries.

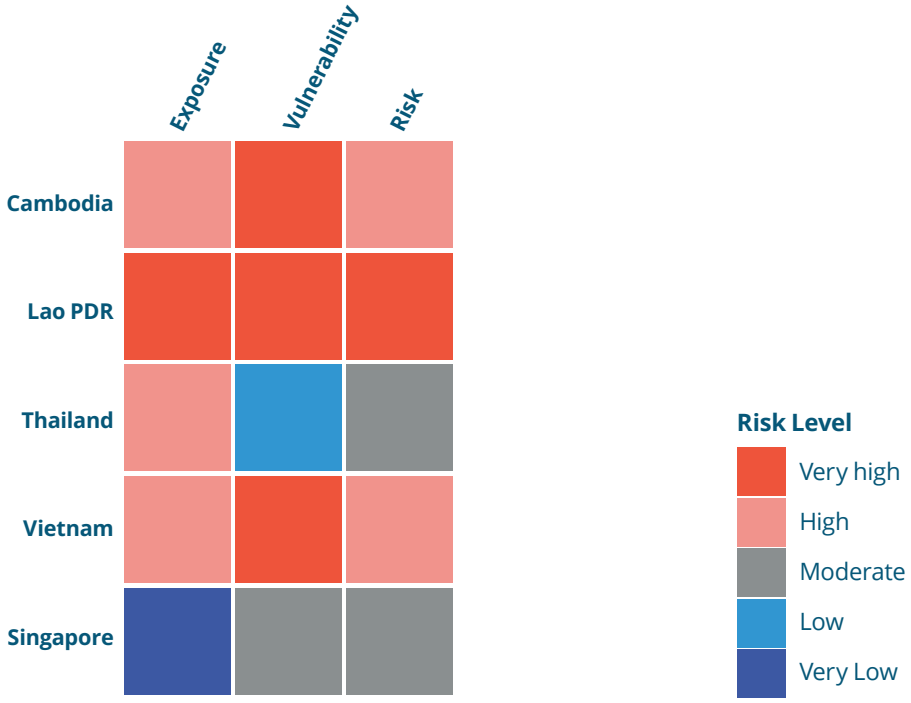


Table 3. Summary of threats, risk, and consequences for electricity sector associated hydroelectricity dependency in the Lower Mekong Basin

Changes induced by hydropower development:

HYDROPOWER DOMINATING THE POWER SYSTEM OF A LOCAL AREA/NATION

THREATS	AFFECTED STAKEHOLDERS	RISK TYPE	CONSEQUENCES	FURTHER POTENTIAL IMPLICATIONS
Over-reliance on hydropower to supply electricity making the power system prone to drought events	Hydropower developers/ generators	Financial risk Reputational risk	• Opposition from hydropower-impacted communities • Reduced power generation during drought years • Climate change will carry on and worsen this trend in the future • Reduced revenue	• Overarching impact on the whole economy when power outages happen • Potential upstream/ downstream transboundary political tensions due to unequal impacts of hydropower on natural systems
	Transmission/ Distribution entities	Financial risk	• Need to search for alternative power supplies • Need to expand/upgrade the transmission grid to connect with alternative power sources	
	End-users	Physical Risk Financial risk	• Disruption to the whole economy. • Loss of income (particularly power-intensive industries) • Reduced health and well-being (as drought-induced power shortages usually happen in dry, hot weather, which is also when power for air conditioning is the most essential for physical and mental health)	

© Thomas Cristofoletti / WWF-UK

CASE STUDY: REGIONAL POWER TRADING AT THE EXPENSE OF SUSTAINABILITY?

Electricity trading is expected to continue expanding between Lao PDR and its neighbours through bilateral as well as multilateral agreements, despite concerns around the sustainability of continued hydropower development in the Lower Mekong. In 2016, Thailand entered a Memorandum of Understanding (MoU) with Lao PDR to buy from a total of 9,000MW of electricity capacity. In 2021, this capacity was expanded to 10,200MW (Praiwan, 2021). Viet Nam also has a power trade MoU to purchase 3,000MW from Lao PDR by 2025 and 5,000MW by 2030. The purchase capacity is expected to reach up to 8,000MW in recent planning documents. Up to now, a capacity of 2,689MW has been approved to be exported from Lao PDR to Viet Nam (Luong, 2023). Meanwhile, although electricity trade between Lao PDR and Cambodia is currently limited to 445 MW, it is also expected to surge to 6,000MW by 2030 (Jha, 2023).

Lao PDR and Thailand are involved in the first multilateral trade under the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP), part of the ASEAN Power Grid programme. Phase I of this project (2016–2020) included a 100MW capacity agreement between Lao PDR, Thailand, and Malaysia, through which a total of 30.2GWh was supplied from hydropower plants in Lao PDR through Thailand to Malaysia. This agreement was recently upgraded to 300MW, while Singapore also joined and started to import electricity from Lao PDR through this system in 2022 (ASEAN Center for Energy, 2020; Ng, 2022). With its strategic location, Thailand aims to become the power trade hub of the region. Although grid interconnection is promoted in the region (and worldwide) to flatten out the intermittency of renewable energy, the current power trade agreement under LTMS-PIP has been criticised as unsustainable due to its reliance on hydropower, which comes with considerable social and environmental impacts (Do & Burke, 2023).

© Susanna Manu / WWF

SUPPLY CHAIN 2:

FISHERIES & AQUACULTURE

Of all the supply chains in the Lower Mekong Basin facing hydropower-related threats, capture fisheries and aquaculture supply chains face some of the greatest direct physical, financial, and market risks, with up to US$ 21 billion in financial losses projected across the sector if planned hydropower dams go ahead. This may have profound implications across the basin, including longer-term unintended consequences such as increased land and water requirements to make up for lost fish protein with resource-intensive livestock in Cambodia and Lao PDR.

HIGHLIGHTS

- Mekong fisheries may decline by 30–40 per cent in the coming decades, with financial losses of up to US$21 billion across the sector. Cambodia's Tonle Sap Lake alone faces upwards of 40–57% in production losses by 2030.
- Fishing supply chains in the basin face very high physical risks due to their exposure to and dependence on a healthy, free-flowing Mekong River for sustainable fish stocks.
- Hydropower-related risks will not be burdened equitably, with local consumers (i.e., subsistence fishers and those who buy fish on local markets) facing the greatest financial and market risks.
- While aquaculture may mitigate some financial and market risks facing national and international markets (e.g., in Viet Nam), the benefits are not likely to reach the poorest and most vulnerable households dependent on capture fisheries for food security and livelihoods – especially in Cambodia.
- Cambodia may see a loss of US$ 3-5 billion in annual GDP due to fish production losses if planned hydropower dams go ahead (MRC, 2018c). These losses amount to 11-18 per cent of Cambodia's GDP.
- Local consumers typically lack purchasing power to replace lost fish catch with alternatives on local markets, and alternatives are not likely to mitigate nutritional losses (e.g., protein-dense prahok paste in Cambodia, which relies on the at-risk fish, trey riel).
- Fishers in some areas may also face regulatory risks associated with continued fishing if governments reduce fishing quotas or heighten regulations on overfishing (as is already being witnessed in Cambodia).

FISH IS ESSENTIAL ON LOCAL PLATES AND AN IMPORTANT EXPORT PRODUCT

The Mekong River system is home to one of the world's most abundant and varied freshwater fisheries. Freshwater fisheries are crucial for the food security, nutrition, and livelihoods of millions of people in the Lower Mekong Basin (including up to 80 per cent of animal protein consumption [Hortle, 2007]), while also supporting both small and medium-sized businesses in the region. The Mekong River and its fluvial flows provide the basis for healthy spawning habitats and migration pathways for fish and other aquatic animals. Even the marine fisheries of southern Viet Nam are reliant on the nutrient-rich coastal plume of the Mekong River.

Fishing in the LMB is conducted in the form of inland capture fisheries, integrated rice-fish farming, or aquaculture. A fisheries and aquaculture supply chain is a connected system of resources, actors, and their activities, designed to produce, process, transport, and distribute fish products from their origin to consumption. This involves numerous actors, including fishers, input suppliers, wholesalers, and middlemen, and three main markets for local, domestic, and international consumers. Total fisheries production in LMB countries (inclusive of marine and freshwater capture fisheries and aquaculture) was approximately 11.9 million tonnes in 2020 and has grown 2.8 per cent a year between 2012 and 2020. Capture fisheries account for around 52 per cent of total production in the basin, and aquaculture 48 per cent.

Viet Nam dominates fisheries production, with both capture and aquaculture production rapidly increasing; aquaculture is now one of the most important businesses for farmers in the Mekong Delta (Yoshida et al., 2020). In contrast, Thailand has seen some contraction of production over recent years. Capture fisheries production has also seen a modest decline in Cambodia, while aquaculture has begun to expand rapidly due to increasing investments in the sector. In the coming years, aquaculture production in Cambodia is projected to surpass capture fisheries production for the first time. Meanwhile, Lao PDR has seen limited growth in both sectors.

Fish and aquatic product exports are important for both Viet Nam and Thailand; Viet Nam has been the world's third largest exporter of aquatic products since 2014, exporting US$ 8.5 billion in 2020. This is largely composed of fresh and brackish water aquaculture products, primarily produced in the Mekong Delta. While there is an overall increasing trend in freshwater fish exports from LMB countries, the sector is vulnerable to hydrological variability, with production dropping significantly during drought and dry years – for example, as seen in 2011, 2015, and 2020.

The value of fisheries in the region goes well beyond their monetary value with over 50 million people depending on Mekong fisheries for food and livelihoods. Fish products provide around 80 per cent of dietary protein consumption for the population (Hortle, 2007). Beyond protein benefits, fish from the Mekong River basin provide significant micronutrient supplies to the region, especially iron and zinc (Golden et al, 2019). Studies have suggested that as many as two-thirds of households living in the LMB have some involvement in the fisheries sector, making it an important part of many livelihoods, cultures, and food security, particularly amongst upland populations where poverty levels are frequently the highest (MRC, 2018b).


© WWF / Greg Funnell

RISKS FROM HYDROPOWER DEVELOPMENT ARE SUBSTANTIAL AND ALREADY BEING REALISED

The development of hydropower dams poses important **physical risks** for both commercial and subsistence fisheries throughout the basin. The combined impacts of reservoirs and dams may cause a 30–40 per cent decline in Mekong fisheries, or 1 million tonnes per year, which could amount to financial losses of up to $21.7 billion (Intralawan et al., 2019). Further **financial risks** and uncertainties may arise in supply chains as governments begin to respond to declining capture fisheries with restrictions on fishing gear and stricter access rules – for example, as seen in recent crackdowns in Cambodia. While aquaculture may mitigate some **financial and market risks**, benefits accrued would likely not reach the most impoverished groups, who depend on capture fisheries for food security and livelihoods (ICEM, 2010; Intralawan et al., 2018, 2019).

Meanwhile, fresh and brackish aquaculture in the Mekong Delta faces a constant need to adapt as hydropower dams trap

sediment, worsening saline intrusion in the delta. The increasing salinity could reduce prawn growth rate, increase sensitivity to diseases, and make some areas unsuitable for farming certain types of aquatic species. As a result, **physical, financial and market risks** threaten all parts of the aquaculture supply chain.

Potential shifts towards alternative protein sources from livestock across the basin may lead to further trade-offs and consequences, such as land and water resource use intensification, with implications for the wider economies in the basin where competing water and land demands among different sectors and regions are already tense. For instance, 25–55 per cent more land and 29–64 per cent more water may be required to make up protein from fish losses in Cambodia alone due to the threats posed by planned mainstream dams on the LMB (Orr et al., 2012).

Table 4. Summary of threats, risks, and consequences for fisheries and aquaculture associated with hydropower-related fish stock declines in the Lower Mekong Basin

Changes induced by hydropower development:

A 30-40 PER CENT DECLINE IN FISH STOCK

THREATS	AFFECTED STAKEHOLDERS	RISK TYPE	CONSEQUENCES	FURTHER POTENTIAL IMPLICATIONS
Decline in fish capture	Fishers	Physical risk Financial risk	• Reduced fish catch • Increased investment in better fishing gear • Reduced overall income • Unsustainable fishing (catching immature fish, use of illegal fishing gear) that affect future fish stocks	• Increase in poverty rate • Increase in unemployment rate • Out-migration from rural to urban areas, placing a burden on urban infrastructure. • Livestock farming expanding to replace fish-sourced protein losses, thereby requiring additional (potentially intensive) land and water inputs • Degraded community health, including child malnutrition, due to loss of nutritional benefits of fish (e.g., calcium content of small fish)
	Middlemen	Market risk Financial risk	• Reduced fish supply • Buying fish at higher prices • Expansion of purchase areas is required to reach alternative sources of supply • Reduced income	
	Local consumers	Physical risk Market risk Financial risk	• Buy fish at higher prices • Loss of fish in daily meals that have nutritional/cultural values • Need to purchase alternative protein sources • Malnutrition	
	Subsistence fishers	Physical risk Financial risk	• Loss of fish in daily meals that have nutritional/cultural values • Need to find alternative protein sources with likely higher prices • Malnutrition	


© Thomas Cristofoletti / WWF-UK

CASE STUDY: CAMBODIA'S TONLE SAP LAKE AND ITS FISHERIES ARE SHRINKING

The fisheries sector in Cambodia plays a crucial role in the country's economy (contributing 12 per cent of Cambodia's GDP) and food security. However, the country is expected to account for up to 75 per cent of capture fishery losses in the Lower Mekong, owing to hydropower development (Yoshida et al., 2020), and could face US$ 3–5 billion in losses in annual GDP (MRC, 2018a) or 40–57% in production losses by 2030. This poses substantial risks to fishing supply chains, with the highest risks posed to those dependent on fishing for food security and employment.

This issue is most pronounced in the Tonle Sap Lake – a unique ecosystem with enormous hydrological, biological, nutritional, and cultural values to Cambodia (Arias, Cochrane, et al., 2014). The lake's ecosystem supports spawning and rearing habitats for one of the world's largest freshwater capture fisheries. The Tonle Sap is often referred to as the "beating heart" of Cambodia due to its unique annual flood pulse.

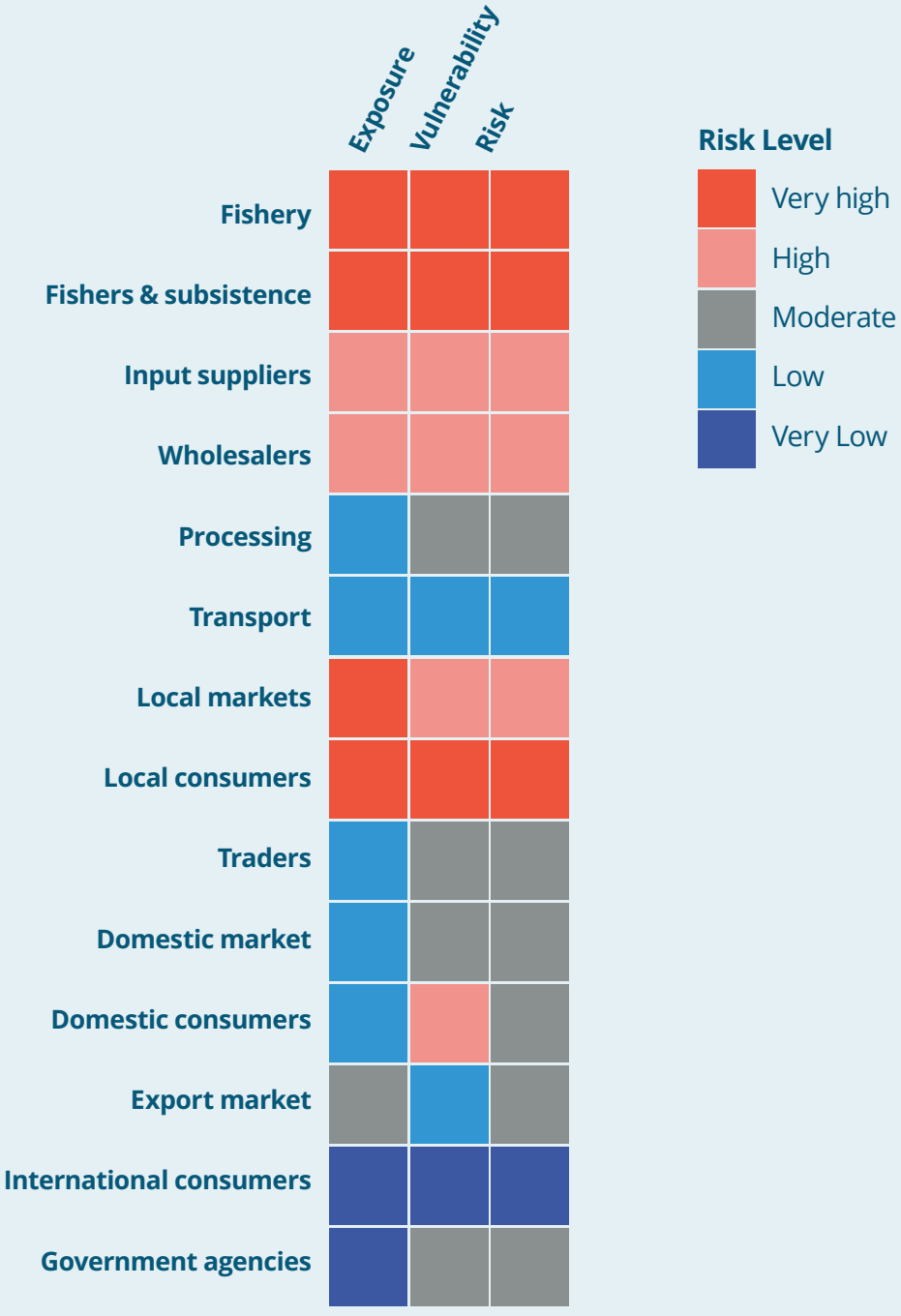
Hydropower dams are already altering the Tonle Sap's water flows; recent observation during the dry seasons in 2019–2021 showed that the drop in Tonle Sap water flow is associated with the reduction in fish abundance and biomass (MRC, 2022a). At the same time, the lake's fisheries face high **physical risks** due to the complex interaction of drivers of change in addition to hydropower development, including climate change, deforestation and land use change, other water-control infrastructures fragmenting fish migration pathways (e.g., irrigation infrastructure), and unsustainable fishing practices.

Communities living on and around the Tonle Sap Lake are highly dependent on capture fisheries for subsistence and livelihoods, and face high physical and financial risks due to their high exposure and vulnerability to alterations in the Tonle Sap's flood pulse. Many fishing households do not have the resources needed to adapt to fishery declines (e.g., capital for investing in better fishing gear),

which has also led to consequences such as debt traps for those who have to take out loans to do so (Middleton & Un, 2017). Fishers also face **regulatory risks** as regulations are tightened in response to declining fisheries.

Many Cambodians also **face financial and market risks** due to the loss of migratory fish, such as trey riel – an important fish for the nutrient-dense fish paste prahok, for which there are few adequate alternatives. The price of prahok on local markets has almost doubled in recent years, and many local consumers do not have the purchasing power to find alternatives in commercially available products (Bond, 2015), with significant implications for food and nutritional security.

Fig. 6 | Exposure, vulnerability, and resultant risk levels across Cambodia's fishing and aquaculture supply



© WWF-Viet Nam / Cham Team

SUPPLY CHAIN 3:

RICE PRODUCTION

Hydropower development in the Mekong is threatening the Lower Mekong's rice supply chains, which account for over a fifth of global rice exports by value. Reduced flow of sediment and nutrients over the next 50 years could result in losses of up to 2.4 million tonnes in the Mekong delta in Viet Nam and 430,000 tonnes from annual rice production in Cambodia – equivalent to a total annual loss of US$ 1.1 billion (Intralawan et al., 2018; Ministry of Natural Resources and Environment, 2015). This places the basin's rice supply chains at high physical, financial, and market risk. The consequences of these risks, including price fluctuations, have implications for the stability of domestic, regional, and global rice markets and the food security of millions dependent on affordable rice.

HIGHLIGHTS

- **Hydropower dams trap sediment and regulate water flow, both of which are needed for the fertility and stability of floodplain and delta environments supporting rice production in the basin.** Compounded by other threats to the natural system, such as sand mining and climate change, this is a particular concern for Viet Nam's Mekong Delta, which contributes 15 per cent of global rice exports.
- **Hydropower development in the basin could reduce rice production in Viet Nam and Cambodia by 2.3 per cent and 3.7 per cent respectively, largely due to changes in sediment load** (VMNRE, 2019). Adverse impacts on rice productivity could have knock-on effects along domestic and regional supply chains from farmers to distribution and export markets.
- **Viet Nam's highly productive Mekong Delta, which accounts for most of the country's rice exports, is particularly at risk.** Mounting pressures on the delta from increased incidence of drought, saline intrusion and sea-level rise will be compounded by hydropower development, putting the already-vulnerable rice sector at further risk. Sediment trapping will likely intensify saline intrusion in the delta due to increased riverbed incision reducing water levels.
- The fragility of the global food system – brought into recent focus by events such as India's export ban on rice in attempts to control domestic prices in the wake of floods and the disruption of grain and fertiliser exports caused by the Ukraine conflict – highlights the importance of key regional links in rice supply chains and the global significance of risks posed to the productivity of the rice sector in the Mekong by hydropower.

Rice comprises the main dietary staple of 3.5 billion people globally. The Mekong region is an important net contributor to global rice exports, with Thailand and Viet Nam being the second and third largest rice exporters globally. However, rice producing regions in the Mekong are increasingly vulnerable to the impacts of climate change, such as extreme floods and droughts as well as sea level rise, which hydropower development threatens to worsen.

While the agricultural sector only accounts for 14 per cent of the region's GDP, the sector provides employment for 60 per cent of the labour force and directly contributes to the livelihoods and food security of the 74.4 million people living in the basin. Rice production in Thailand and Viet Nam is dominated by commercial production, while the sector in Cambodia and Lao PDR is still predominantly subsistence production, with most of the rice consumed by farming households.

The Mekong region is an important source of rice exports to the international market, and plays a critical role in determining food security – particularly in large importing countries such as Singapore, the Philippines, China, Ghana, and Malaysia. In total, more than 10 million hectares of land are used for rice production in the LMB, constituting 80 per cent of all agricultural land. In the Lower Mekong, Viet Nam is the largest rice producer, producing 48.9 Mt of rice in 2021, followed by Thailand (33.6Mt), Cambodia (11.4 Mt), and Lao PDR (3.9 Mt). Together, the LMB countries account for over a fifth of global rice exports by value; in 2021, Thailand exported 6.1 Mt of rice and Viet Nam exported 4.6 Mt, ranking them the second and fourth largest rice exporters respectively (with Viet Nam rising to the third-largest exporter in 2022). The Mekong Delta alone contributes around 15 per cent of the world's rice exports (Yoshida et al., 2020).

Rice production in Viet Nam and Thailand has been generally stable over the last decade. By contrast, rice production in Cambodia has grown rapidly over the last decade - by around 3 per cent per year - reflecting conversion of land to rice production, more intensive cropping patterns, expansion of the irrigated area, and an increased levels of inputs (fertilisers, agricultural chemicals, mechanisation etc.) which have accompanied the commercialisation of the sector. Stagnation in Laotian rice production, by contrast, reflects limited investment in the sector, limited modernisation, and the continued predominance of subsistence production.

HYDROPOWER PUTS RICE PRODUCTION ON THE MEKONG FLOODPLAINS AND DELTA AT RISK

Hydropower development presents new risks to rice production in the LMB, through threats posed to the natural system by altered flow regimes and reduced sediment transport to the floodplains and delta. These risks differ between subsistence and commercial rice production and between countries in the Mekong basin. Long-term market risks are likely to be felt most acutely within the commercial rice growing sectors of Cambodia and Viet Nam, with a loss of up to 2,400,000 tonnes and 430,000 tonnes from annual rice production in the Mekong delta in Viet Nam and Cambodia respectively if sediment reduction continues over the next 50 years – equivalent to annual losses of around US$ 1.1 billion (Intralawan et al., 2018; Ministry of Natural Resources and Environment, 2015).

The loss of floodplain rice productivity associated with reduced sediment loads and nutrient transport will increase the need for artificial fertiliser, contributing to farmers' financial risk due to the high costs of chemical inputs and increasing risks to the environment from increased chemical pollution. Farmers may face increased **physical and financial risks** due to potential loss of fertile land from increased erosion.

Alterations in the Mekong's hydrological regime may also reduce flushing of pollutants, salts, and acid soils particularly in the delta, which could cause further physical risk to rice crops and increase the need for agrochemicals (again, increasing **financial risks** of farmers and potentially leading to higher rice prices on the market). Subsistence producers in north-eastern Thailand and Lao PDR who still practice recession agriculture on riverbanks and floodplains are already being adversely affected by the development of dams in the Mekong mainstream, and these will tend to be some of the most vulnerable households in those areas. In Thailand, this also poses an important **reputational risk**, as political groups drawn from rural households have played an important part in Thailand's recent political instability.

HOW ARE OTHER THREATS EXPECTED TO COMPOUND THESE RISKS TO RICE SUPPLY CHAINS?

Rice producing areas in the basin are increasingly under threat from extreme drought and flood events, as well as saline intrusion in the delta and higher temperatures due to climate change. Most rice production in the LMB takes place in the fertile alluvial floodplains and deltaic areas of the basin. These floodplains benefit from a wealth of hydro-ecological services provided by the Mekong River's annual flood pulse, which sees an abundance of water, sediment and nutrients transported from the headwaters to the floodplains in support of significant ecological and agricultural diversity. While the Mekong's annual flood pulse is fundamental to this diversity, extreme flood and drought events cause extensive damage to crops and infrastructure (Hoang et al., 2022).

Climate change is expected to exacerbate these risks. Climate projections foresee increased intensity of wet-season rainfall resulting in more flooding and greater variability of rainfall leading to more frequent and more intense droughts. Higher ambient temperatures in the region are also expected to reduce rice production both through additional heat-stress to the plants and through compounding the effects of drought. Sea-level rise, combined with more frequent and severe droughts, is also expected to increase the frequency and extent of saline intrusion in the delta, again threatening large areas of rice production. **Meanwhile, other development pressures such as sand mining, water extraction and infrastructure development are threatening the bio-physical system which supports rice production in the LMB.**

These threats of climate change, sand mining and water extraction have a compounding effect on Mekong supply chains already degraded through the significant negative impacts from hydropower.

© WWF-Viet Nam / Cham Team

Table 5. Summary of threats, risk, and consequences associated with hydropower-related sediment and nutrient load declines in the Lower Mekong Basin

Changes induced by hydropower development:

LOSS OF 2/3 OF NITROGEN AND PHOSPHORUS TRANSPORTED FROM UPSTREAM AND DISCONNECTING FLOODPLAINS FROM THE RIVER

THREATS	AFFECTED STAKEHOLDERS	RISK TYPE	CONSEQUENCES	FURTHER POTENTIAL IMPLICATIONS
The floodplains receive low to zero nutrition from the Mekong system; water cannot reach key farming areas	Farmers	Physical risk Financial risk	• Reduced yield if there are no nutrient substitutions • Soil degradation • Increased use and cost of agricultural inputs (fertiliser) • Increased use and cost of (electric/diesel) pumps to irrigate the farming areas	• Increase in poverty rate • Increase in unemployment rate • Out-migration from rural to urban areas, placing a burden on urban infrastructure. • Food insecurity
	Middlemen / Processor / Trader	Market risk Financial risk	• Reduced rice supply • Buying rice produce at higher prices • Expansion of purchase areas is required to reach alternative supply markets • Reduced income	
	Local / domestic consumer / export market	Physical risk Market risk	• Increasing trend of rice price in short and long terms • Food insecurity (especially the rural/urban poor)	

CASE STUDY: WHAT ARE THE IMPLICATIONS OF HYDROPOWER DEVELOPMENT FOR RICE PRODUCTION ON THE MEKONG DELTA?

The physical and market risks to rice production in the Mekong Delta are particularly severe. Given the importance of the delta to global rice supply, the implications of hydropower development for the whole delta region are of the utmost concern, putting 24.8 Mt of rice production (Nguyen, 2022), and consequently exports worth US$ 2.96 billion in 2021,[10] at risk.

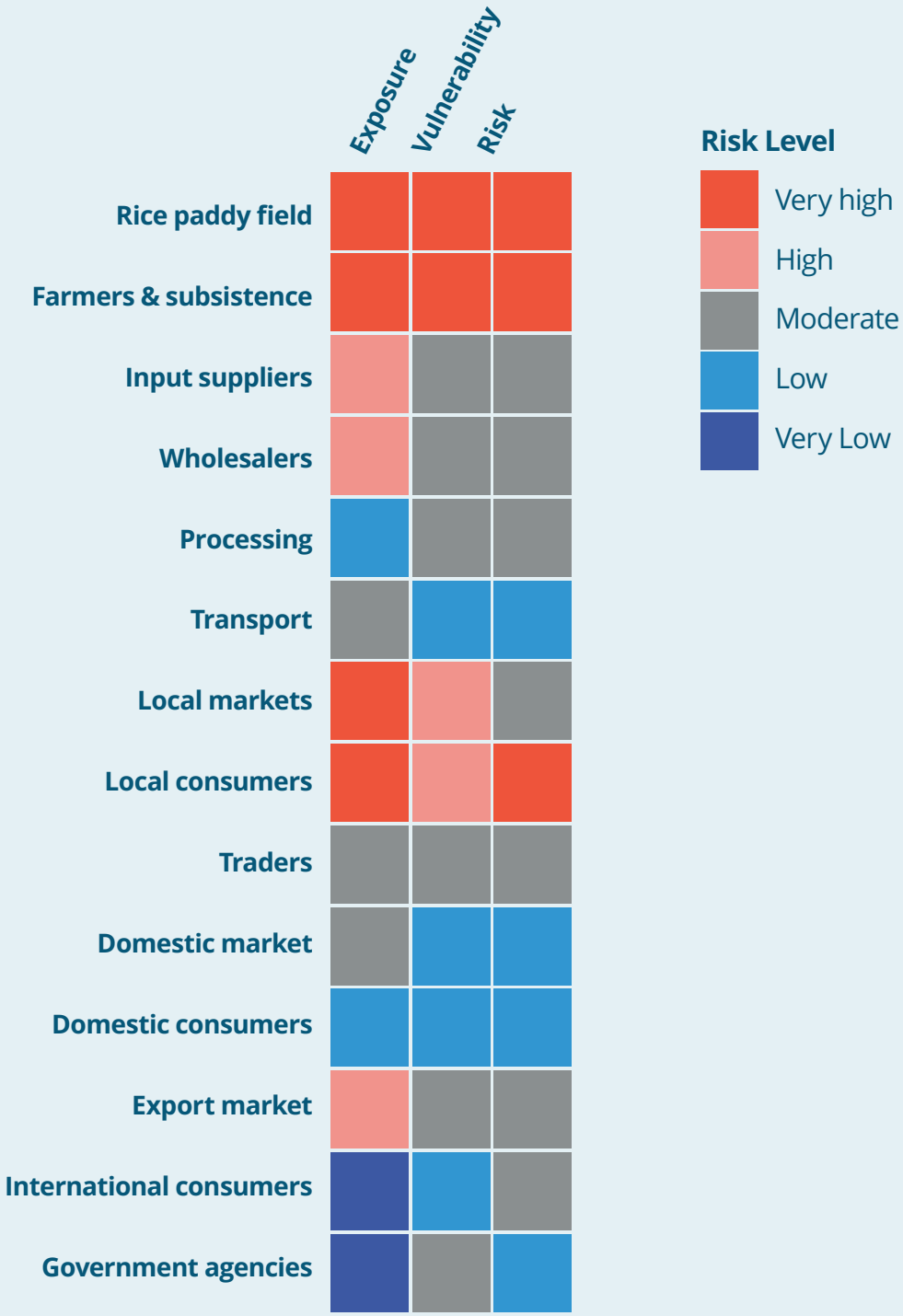
As with the rest of the basin, rice production in the delta will be placed at risk through the reduction in suspended sediment loads and nutrient transport to the rice growing areas of the delta. The loss of this important resource will reduce the productivity of these areas of the delta, forcing farmers to replace lost nutrients with artificial fertilisers (Hoang et al., 2022; Kondolf et al., 2014;

10. See The Observatory of Economic Complexity: https://oec.world/en/profile/bilateral-product/rice/reporter/vnm?redirect=true#:~:text=The%20main%20destination%20of%20Rice,d%27Ivoire%20(%24211M)

MRC, 2018b). This is likely to result in the loss of farm incomes, higher risks for farmers associated with greater input costs and higher rice prices overall, increasing both financial and market risks for rice supply chains.

River incision (a natural process by which the riverbed is eroded, leading to a deeper river channel) is accelerated by the loss of coarse sediment bed-loads in the river. Evidence suggests this is already taking place in the Mekong due to the over extraction of sand and aggregates from the river for construction. This is projected to increase with additional loss of sediment load reaching the delta due to hydropower development.

Fig. 7 | Exposure, vulnerability, and resultant risk levels across Viet Nam's rice supply



SUPPLY CHAIN 4:

SAND MINING AND CONSTRUCTION

Sand mining in the Mekong is growing rapidly, fuelled by growth in the construction industry of the basin and neighbouring countries. Present levels see sand mining extracted around three times the total natural annual sand load (prior to 1994) from the riverbed (Hackney et al., 2021) and about 20 times higher than the current annual load. These levels are already unsustainable, but the reduction in sediment loads due to sediment trapping by hydropower reservoirs has accelerated the imbalance between over-extraction and under-supply, shortening the timescales leading to the destabilisation of floodplain and delta environments. The cumulative, long-term impacts of sand mining and upstream hydropower development may exacerbate exposure of the Mekong floodplains and delta to water and climate risks, such as extreme flooding and sea-level rise. This may increase the vulnerability, and therefore risk, of other exposed sectors in the delta, including agriculture, aquaculture, tourism, and textiles.

HIGHLIGHTS

- Hydropower dams trap sediment and regulate water flow, both of which are needed for the fertility and stability of the Mekong's floodplains.
- Sand mining and construction supply chains may face **physical, market, and financial risks** in the long-term due to loss of sediment transportation because of hydropower dams trapping sediment, which may push operations to other regions or increase operational costs.
- There is a large gap between sand replenishment and sand extraction, and between sand extraction and sand demand in the Lower Mekong Region, which may continue to widen in the coming decades.
- Construction companies may face serious **reputational risks** and increasing opposition from local communities if operations continue in heavily depleted areas. Responses by governments may also result in **regulatory risks**.
- Construction industries in the Delta are already facing periods of sand shortages, causing delays for construction projects. This may have knock-on effects on urbanisation and economic development goals in the region and be a source of uncertainty for the sector.
- A reduction in sand causes higher levels of erosion, damaging instream infrastructure, causing riverbank erosion and collapse, and ultimately leading to the loss of land.
- The reduction of sand reaching the coast is compromising climate adaptation efforts against sea-level rise and contributing to the loss of mangrove ecosystems in the Mekong Delta.

THIRST FOR SAND IN THE LOWER MEKONG REGION AND BEYOND

The construction industry in the LMB has underpinned economic growth in the region, prompted by population growth, urbanisation, and infrastructure demand. The sector accounted for around 12.3 per cent of GDP in Cambodia in 2020, 6.1 per cent in Lao PDR, 4.1 per cent in Thailand and 8.2 per cent in Viet Nam, and collectively accounted for US$ 53.1 billion in 2020, or around 6 per cent of LMB GDP[11]. The LMB is an important source of sand and aggregates for construction materials. Much of the

11. Based upon figures from National Economic and Social Development Council of Thailand, General Statistics Office of Viet Nam, National Institute of Statistics of Cambodia and the World Bank.

extraction is not well regulated and monitored, and as such, placing a figure on extraction and trade from the basin is difficult. A 2013 study estimated 34.48 Mm3 (55.2 Mt)[12] was being extracted per year from the mainstream river (excluding tributaries), based upon interviews with sand miners – of this, 60 per cent was from Cambodia, 23 per cent from Viet Nam, 13 per cent from Thailand and 4 per cent from Lao PDR (Bravard et al., 2013). The employment of remote sensing techniques to monitor the mining barges recently revealed that annual sand extraction in Cambodia and Viet Nam could rise to 37 Mm3 (59Mt) and 47 Mm3 (75Mt) respectively by the end of the decade (Gruel et al., 2022; Hackney et al., 2021). These two countries were major sand exporters to Singapore until concerns over climate change and environmental issues led to bans on sand exports starting from 2017.

RISKS AND CONSEQUENCES OF HYDROPOWER DEVELOPMENT

Sand mining in the LMB is considered deeply unsustainable, as extractions rate have far exceeded replenishment of sand in suspended sediment and bedload. This gap is widening over time, both due to increasing trends in extraction and decreasing trends in replenishment (Bravard et al., 2013; Eslami et al., 2019; Gruel et al., 2022; Jordan et al., 2019). Sand[13] in the Mekong riverbed is replenished slowly through the transport of sediment in the river from upstream to downstream as suspended load and bedload, which are now trapped and disrupted by existing hydropower dams. While it is difficult to quantify the risks specifically posed by hydropower to sand and construction supply chains, hydropower dams contribute to, and compound, existing threats posed by unsustainable sand mining practices in the basin due to sediment trapping. Beyond the impacts on sand supply chains and related industries, this may pose risks to other supply chains discussed in this report because many economic sectors are dependent on construction and landfill; sectors' vulnerability to such threats depend largely on how economically viable transporting materials from further afield would be. The cumulative impacts of sand mining and hydropower on low-lying floodplains and deltaic areas also exacerbate the exposure to water and climate risks, from water supply (availability of surface freshwater) to floods and typhoons, thus posing physical risks to other sectors – notably, aquaculture, food and beverages, and tourism, as well as textiles and electronics – which may make many components of the economy less competitive compared to other regions.

In the long term, sand mining will likely come under much stricter control long before sediments come into short supply, which is likely to drive up the cost of aggregates from affected areas and drive suppliers to source them elsewhere, increasing financial risks. This may lead to a shift towards manufactured sand (which is potentially more labour intensive), or force operations to other areas, though this may prove difficult due to high costs associated with transporting sand over large distances.

Construction in the Mekong Delta faces long-term compound financial and regulatory risks as sand availability declines; sand prices in the delta have already increased recently due to a mismatch in supply and demand (noting the market price of sand does not reflect its true value), and high fuel prices, with impacts on business operations and delays in construction projects. Given the long time scales associated with hydropower impacts on sand supply to the delta, it is likely that businesses will therefore face regulatory, financial, and reputational risks associated with over-extraction on shorter time frames than those due to hydropower because of governance responses to unsustainable mining practices.

The delta's river bed lowered by 1.6m between 2008–2018, while annual riverbed incision between 2014–2017 could be up to 0.5m/year (Binh et al., 2021; Vasilopoulos et

12. Assume a density of 1.6ton/m3
13. Sediment particles between 0.063 – 0.500mm in size.

al., 2021). These structural changes may in turn exacerbate water and climate risks associated with issues with the wear and tear on in-stream infrastructure, river-bank stability and associated land and stranded assets, asset damage/insurance, and saline intrusion through deeper river channels (though additional research on these risks is needed). Furthermore, the reduction of sand reaching the coast is compromising climate adaptation efforts against sea-level rise and contributing to the loss of mangrove ecosystems in the Mekong Delta (Woillez & Espagne, 2022).

Table 6. Summary of threats, risk, and consequences for sand mining and construction associated with hydropower-related sand supply reductions in the Lower Mekong Basin

Changes induced by hydropower development:

REDUCED SAND SUPPLY FROM UPSTREAM MEKONG

THREATS	AFFECTED STAKEHOLDERS	RISK TYPE	CONSEQUENCES	FURTHER POTENTIAL IMPLICATIONS
Sand shortage	Sand miner	Physical risk Financial risk Reputational risk	• Reduced yield if there are no nutrient substitutions • Soil degradation • Increased use and cost of agricultural inputs (fertiliser) • Increased use and cost of (electric/diesel) pumps to irrigate the farming areas	• Increase in poverty rate • Increase in unemployment rate • Out-migration from rural to urban areas, placing a burden on urban infrastructure. • Food insecurity
	Sand trader	Financial risk Market risk	• Reduced rice supply • Buying rice produce at higher prices • Expansion of purchase areas is required to reach alternative supply markets • Reduced income	
	Private construction needs	Financial risk	• Increased cost of construction materials inputs • Delay in construction due to sand shortage	
	Developer and investor in major public/ private infrastructure	Financial risk Market risk Regulatory risk Reputational risk	• Increased cost of construction materials inputs • Delay in construction due to sand shortage, entailing increased labour and financial cost • Pressure from clients and increased risk of contract breaching • Declined entities' credit and reputation	
	Residents benefiting from public infrastructure under construction	Physical risk	• Delay in enjoying benefits from the public infrastructure	

© WWF-Viet Nam / Cham Team

CASE STUDY: SAND FOR INFRASTRUCTURE DEVELOPMENT IN VIET NAM'S MEKONG DELTA

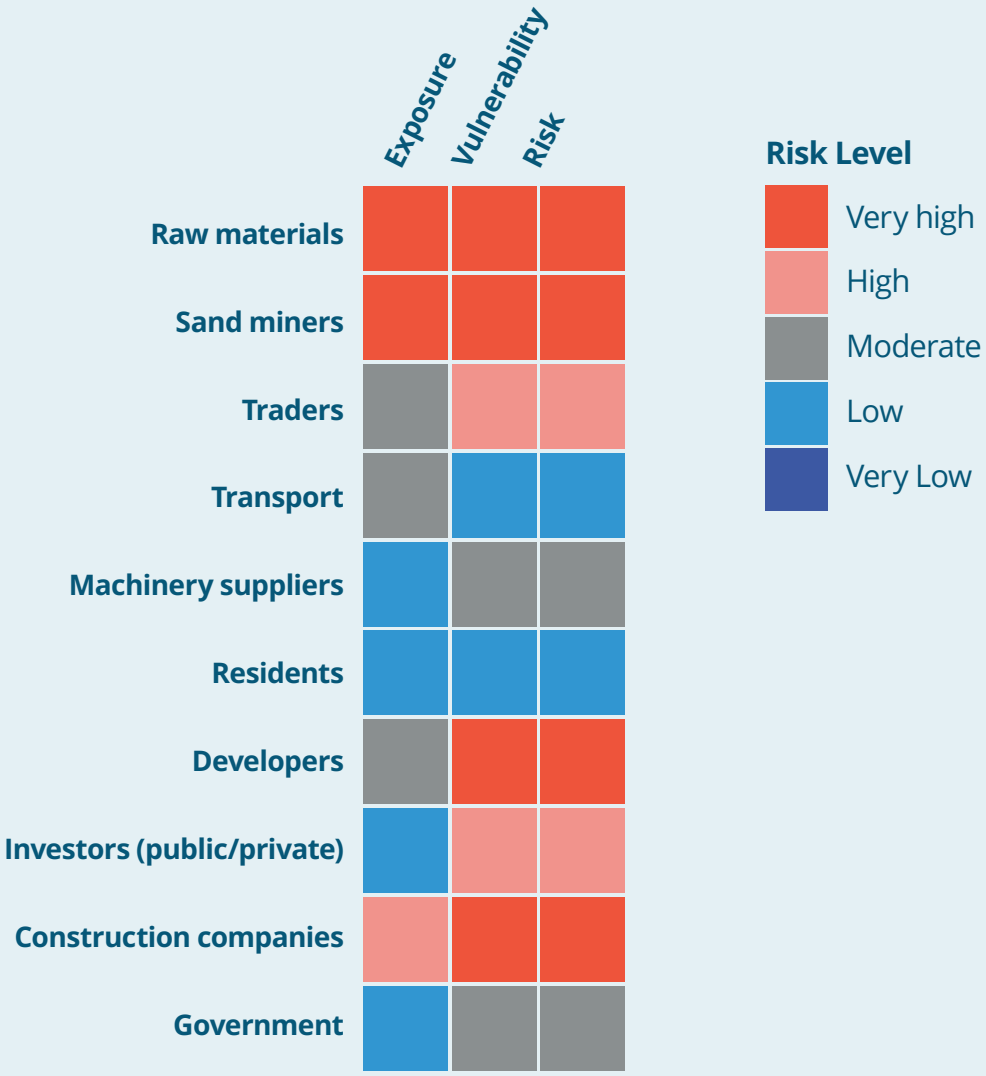
There is an enormous sand deficit between annual sand flux and extraction in the Mekong Delta. In 2018 alone, a total of 17.77 Mm3 of sand was reportedly extracted from the Mekong Delta. However, available statistics are somewhat contested, with estimates that the annual sand extraction rate in the delta could have been closer to 47 Mm3 in 2020 (Gruel et al., 2022; Hackney et al., 2020; Jordan et al., 2019). Meanwhile, it is estimated the delta receives around 6.18 Mt (3–4 Mm3) of bedload sand and suspended sand each year (Hackney et al., 2020), or only a fifth to a twelfth of the amount of sand extracted. By cutting the annual supply of sediment to the delta, hydropower development will continue to deepen this supply deficit in the medium-to-long term.

While sand is intensively dredged from the riverbed each year, the gap between sand extraction and sand demand continues to widen. Demand for sand for transport infrastructure development alone was estimated to be 47.81 Mm3 between 2021 and 2025 in the Mekong Delta (Tu, 2023), placing additional pressures on the sand budget. As of 2023, there are 66 active sand mining licenses in the Mekong delta, with a total reserve of 80 Mm3 and an annual capacity of 17 Mm3 (Khôi, 2023).

Sand shortages in recent years have led to significant price fluctuations and construction delays; for example, the price of sand for land reclamation extracted from An Giang and Dong Thap to supply projects in Ca Mau in 2022 doubled to 260,000 VND/m3 compared to 2020 prices (Tân & Thu, 2022). Responding to sand shortages and construction delays, authorities are acknowledging the impacts on rivers (speeding up riverbank erosion, riverbed incision, and saline intrusion in the delta) and are now considering a wider range of options to meet the demand.

The demand for sand in Viet Nam has strong implications for the Mekong's stability in Cambodia as sand exported to Viet Nam has resumed and gone up quickly in recent years, making Viet Nam the largest sand importer from Cambodia. In 2021, US$ 5.6 million, or equivalent to 0.8 Mt of sand was traded from Cambodia to Viet Nam according to data that was officially reported by Cambodia in the UN trade database (UN, 2023). Current sand mining in Cambodia (up to 37 Mm3 per year; (Hackney et al., 2020)) also contributes to the reduction of sand in the flow to the Mekong Delta.

Fig. 7 | Exposure, vulnerability, and resultant risk levels across the delta's sand and construction supply chain



© Ella Kiviniemi / WWF

SUPPLY CHAIN 5:

TEXTILES AND ELECTRONICS

Textiles and electronics are increasingly important to the Lower Mekong's economic development, and the region is becoming an important node in the global electronics supply chain. A large proportion of Cambodia and Viet Nam's export activities is located within the LMB and thus exposed to hydropower threats. Many more are located in the adjacent Dong Nai river delta which is hydrologically connected to the Mekong during flood and extreme flow events, and hence also exposed to Mekong and Dong Nai hydropower operations. Hydropower dams not only lead to physical risk to the production of raw materials, but compound existing climate and water-related risks facing these industries, including financial risks due to extreme flooding, and reputational risks as competition grows for water resources between sectors.

HIGHLIGHTS

- Upstream dams may reduce or inappropriately regulate downstream water flows necessary for factory operations and garment processing in textiles supply chains, leading to water shortages and degraded water quality. This may increase factories' financial risks and physical risk as they are forced to source water from elsewhere (e.g., via groundwater pumping) and asset loss and disruption due to flood and drought.
- The electronics sector is also vulnerable to physical risks stemming from a lack of water availability and flooding. The sector has large water demands, particularly for semiconductor manufacturing. As the floods in Thailand in 2011 demonstrated, capital intensive manufacturing industries can be vulnerable to flood events that cause significant damage to physical assets and widespread indirect economic damage through the disruption of employment and supply chains. Hydropower development is likely to compound these risks for facilities located in the LMB.
- If power sectors are dependent on hydropower for their electricity, periods of drought may cause electricity outages and again place financial risks on their supply chains due to production losses.
- Any financial losses faced along the supply chain due to power supply disruptions, water shortages, or damages due to extreme flooding (all of which are exacerbated by hydropower dams) may end up impacting the profitability of the electronics and textile sectors and create market risk. This may, in turn, increase the cost of consumer goods, impacting the market and reducing certain brands' competitiveness on the international market.
- Businesses may face regulatory risks if governments increase regulations around water use and waste treatment and disposal in affected areas. Non-compliance, or even continued operations in affected areas, may increase businesses' reputational risks and lead consumers to source goods from elsewhere.

HOW IMPORTANT ARE TEXTILES AND ELECTRONICS TO THE LOWER MEKONG BASIN?

In recent decades, countries in the Lower Mekong have pursued a path of export-led industrialisation, with light manufacturing exports becoming critical for economic growth and structural change in these economies. While this has been an important element of Thailand's industrialisation strategy, much of its production is located outside the Mekong basin. However, for Cambodia and Viet Nam, a large share of its manufacturing industry occurs in industrial centres in or adjacent to the LMB, and as such is likely to be vulnerable to hydropower-related threats in the basin.

The electronics sector is critical to the development of the economies of the LMB, and the region is becoming an increasingly important node in the global electronics supply chain. Thailand accounted for approximately 1.5 per cent of the global trade in electronics in 2021 and Viet Nam approximately 5 per cent, while Cambodia and Lao PDR have a relatively small role to play. Viet Nam has become a globally important exporter of both textiles and electronics, accounting for 5.8 per cent and 5.2 per cent of global exports respectively in 2020 (and ranking 12th globally for electronics export value in 2019). This growth is expected to continue as international producers try and diversify away from reliance on China for electronics. Electronics production is dominated by large international firms including Apple, Samsung, LG, Canon and Foxconn, although small and medium sized domestic enterprises also play important roles. Electronics now represents Viet Nam's largest export sector, accounting for 41 per cent of exports in 2021, and is a major employer. This includes the design and engineering of integrated circuits, which are an increasingly critical input into the global economy.

Cambodia has seen similar trends in export development (albeit on a smaller scale, reflecting the smaller size of Cambodia's economy and population). Textile sector exports (including garments and footwear) accounted for approximately 52 per cent of Cambodian exports, worth approximately US$ 11.8 billion in 2020. Unlike Viet Nam, Cambodia accounts for a small portion of global supply in textiles, which are likely to be marginal to overall global production, although the sector provides employment for 45 per cent of the country's manufacturing labour force (Vanderbyl & Pham, 2021).

Textile supply chains can be complex, starting with growers of raw materials such as cotton, silk, or linen, which is then sent for processing (e.g., dyeing, printing, weaving, or spinning) and cutting/sewing to make specific garments, often in factories. The products are then distributed by wholesalers and retailers (often with the support of logistics providers), and sold either domestically or on the export market, eventually reaching customers via shops or markets. Other actors include factory workers, manufacturer or merchant exporters, suppliers, and retailers. For electronics, precious minerals, and raw

materials (e.g., silicones, plastics, and metals) are first mined and collected, refined, then sold on the commodity market before being purchased by suppliers and manufacturers for manufacturing processes in factories for specific products (e.g., mobile phones, televisions). These are then sold via distribution centres to retailers or on the export market, before reaching consumers. Additional steps may also be involved after use if any components can be recycled via e-waste collection.

CASE STUDY: HYDROPOWER MAY EXACERBATE WATER AND CLIMATE RISKS POSED TO TEXTILES AND ELECTRONICS SUPPLY CHAINS IN THE LOWER MEKONG

Threats posed by hydropower to textiles and electronics supply chains are complex, uncertain, and long-term. Unsuitable upstream water flow releases at dams may lead to water shortages and reduced water quality for factor processes. Water scarcity due to degrading water quality may also be worsened by saline intrusion in the delta (exacerbated by hydropower dams blocking sediment and nutrient flow, and related riverbed incision). Responses within supply chain operations to water scarcity may have further unintended consequences – for example, groundwater extraction due to increased pumping to meet water demands for textile processing (e.g., bleaching, washing, dyeing).

The cumulative threats associated with hydropower, sand mining, and climate change may create a perfect storm for industries operating across the LMB by increasing both their exposure and vulnerability to climate and water-related risks such as extreme flooding and drought. This may lead to consequences such as regular flood damages and water shortages for vital factory operations, as well as increased competition for water resources between sectors (e.g., between rice production and textiles). This poses not only physical and financial risks to these supply chains, but also regulatory and reputational risks as competition for resources increases.

Cumulative threats from hydropower may, in the long-term, also impact food security across the basin (e.g., requiring food imports from elsewhere), impacting the cost of living and reducing the purchasing power of consumers to buy electronics and textiles, which may not be seen as a necessity during hard times. Shifts towards non-primary sources of employment (e.g., pull towards urban areas and factory work, away from agricultural employment) may also increase energy demands (and therefore increase dependency on hydropower).

These threats may contribute to risks facing the textile and electronics supply chains in Viet Nam and Cambodia. Degraded water quality due to saline intrusion may lead to freshwater shortages for materials processing. Along with increased vulnerability to flood risks, this may disrupt factory operations and cause financial risk for companies as they adapt to changing conditions. This could also be exacerbated if factories must source water from elsewhere to meet demand (e.g., through groundwater pumping, which may be expensive), with knock-on effects across the supply chain, increasing product prices for consumers, creating uncertain market risks if domestic consumers then decide to source products elsewhere.

If businesses depend on hydropower for their energy supply, they may face additional financial risks during periods of drought, when electricity shortages are more likely (e.g., as seen in Cambodia and Viet Nam recently). Loss of power may reduce productivity significantly in factories, leading to unexpected costs. This may also have a knock-on effect on those employed at

factories, who may find their jobs at risk if their labour is not needed, or the company can no longer afford to pay them. Textile industries operating in affected areas of the LMB also face regulatory risks if governments decide to implement policies to combat hydropower-related threats such as groundwater over-extraction, inter-sectoral water competition, and wastewater treatment.

Table 7. Summary of threats, risk, and consequences for textiles and electronics sectors associated with hydropower development in the Lower Mekong Basin

Changes induced by hydropower development:

WATER SHORTAGES FOR FACTORY OPERATIONS IN THE DELTA

THREATS	AFFECTED STAKEHOLDERS	RISK TYPE	CONSEQUENCES	FURTHER POTENTIAL IMPLICATIONS
Reduced freshwater availability (adequate quantity and quality) due to increased saline intrusion, reduced water flows from upstream, water scarcity during dry periods, and increased flood risk	Consumers	Financial risk	• Product costs increase to recuperate rising operation costs	• Broader impacts on the economy if operational costs rise due to unemployment and rising product prices • Reduced competitiveness of Vietnamese / Cambodian brands on international markets
	Business owners	Market risk Financial risk Regulatory risk	• Consumers may source products elsewhere due to rising costs • Reduced competitiveness on global markets • Increasing operational costs at factories due to water shortages (e.g., needing to source water elsewhere, such as from groundwater or additional water treatment steps) • If operations depend on hydropower, additional costs due to electricity shortages during dry periods • More stringent regulations on water use and wastewater treatment may lead to fines or orders of compliance • Stranded assets • Disruption of logistics	
	Factory workers	Financial risk	• Rising operational costs may mean some workers are laid off	
	Brand/retailer	Reputational risk	• Loss of social license to operate in affected areas, loss of reputation if non-compliant with any new regulations	
	Growers (e.g., silk, cotton)	Physical risk Financial risk	• Lack of freshwater availability (and other associated issues re: loss of fertile land) reduces crop yields and productivity, and may lead to economic losses	

IMPLICATIONS FOR FOREIGN INVESTMENT IN MEKONG HYDROPOWER

Hydropower represents vast foreign direct investment opportunities and potential for economic growth for the Lower Mekong Basin countries, involving a wide range of private investors such as multi-national companies through private-public partnerships, and foreign development banks like the World Bank. China alone finances half of the world's total hydropower projects and has invested more than US$ 6 billion in Cambodia and Lao PDR. The potential reputational and regulatory risks surrounding hydropower projects do not stop at their construction. Governments further down the electricity supply chain importing hydroelectricity similarly face such risks, and while importing hydroelectricity from other countries is increasingly attractive for many (e.g., Viet Nam), the environmental and social externalities associated with such trade agreements need to be considered fully, as well as the implications for supply chains.

REPUTATIONAL AND REGULATORY RISKS OF CONTINUED INVESTMENT

There have been numerous public disputes around large-scale hydropower projects in the Lower Mekong, particularly between upstream and downstream countries due to the disproportionate impacts felt by the latter. While all LMB countries are members of the regional intergovernmental platform, the Mekong River Commission (MRC), the body does not have any legal authority to prohibit hydropower dam construction, nor has it had significant engagement with other economic sectors. Nevertheless, governments and private investors face considerable reputational risks, particularly in highly publicised cases such as the 1,285MW Xayaburi Hydropower project in Lao PDR (a joint investment between a Thai construction company, six Thai commercial banks, a state-owned bank, and the Lao government). Despite recommendations from the MRC to delay construction until adequate environmental and social impact assessments could be conducted, and public protests in Thailand, Cambodia and Viet Nam, the Lao government made the decision to proceed. This decision caused reputational damage and legal repercussions to investors and developers involved.

Both government and companies thus face reputational and regulatory risks around controversial hydropower sites, particularly as public awareness of the potential social and environmental impacts grows. There is a rising public expectation that electricity systems address sustainability objectives, including how potential benefits and losses are distributed across society, and whether this distribution and the approval process is perceived to be fair (Middleton & Ketelsen, 2022). Public understanding of the potential negative ecological and social consequences of hydropower dams also continues to detract from its attractiveness as a 'green' energy solution. Many companies across sectors do not seem to fully understand how their business may be impacted as a result of the cumulative changes to the Mekong River caused by the operation of hydropower projects. Such considerations should be at the forefront of decision-making processes of foreign investors.

International trade in hydroelectricity is an important consideration when assessing countries' hydropower-related risks, due to the potential environmental and social

externalities posed. For example, while Thailand has a policy to not build any further hydropower projects domestically, which has reduced its reputational risk, it remains the main market for bilateral electricity trade from Lao PDR, and as such essentially externalises the environmental and social consequences of hydropower development. Other countries seeking to import hydroelectricity from the LMB may thus be seen to do the same, including Singapore.

CASE STUDY: ENVIRONMENTAL EXTERNALITIES OF MEKONG HYDROPOWER POSE REPUTATIONAL RISKS FOR SINGAPORE

The Singaporean government recently commenced its plans to import hydroelectricity from the LMB region through the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project, and moved forward with the agreement to import 1GW capacity from variable power sources, including hydropower from Cambodia, as part of its target of achieving net-zero carbon emissions by 2050. This would mean it is the only country outside the LMB with significant hydropower imports from the basin and this has been met by public concerns around the true sustainability of hydropower from the Mekong.[14] Not only does this plan present considerable reputational risks, but also physical and financial risks to Singapore's food security due to the country's reliance on rice imports from the Lower Mekong region, as well as other key supply chains. In this section, Singapore's economy and supply chains (fisheries, rice, sand and construction, and energy) are briefly discussed, followed by the implications in terms of hydropower-related risks in its trade relationship with the Lower Mekong region.

Singapore is an open economy heavily dependent on trade and international commerce to meet its basic needs for food, energy, and water due to limited natural resources, which may in the long term increase the vulnerability, and therefore financial and market risks, of its supply chains that are dependent on natural resources in the Lower Mekong. The country's dependence on imports is particularly pronounced in the case of food, as less than 1 per cent of Singapore's land area is used for agriculture. Singapore imports more than 90 per cent of its food, including staples such as fruits and vegetables, meat, and rice. In 2020, almost 65 per cent of Singapore's rice was imported from the Lower Mekong Region, with most coming from Viet Nam and Thailand (Yong, 2022).[15] Meanwhile, Singapore also imports significant quantities of fish from Cambodia, Thailand, and Viet Nam. The country is also dependent on sand imports for construction and land reclamation projects, though it has reduced imports significantly in recent years due to criticism for importing from countries with environmental and human rights issues. Singapore has thus implemented strict measures and regulations to ensure the sustainable sourcing of sand.[16]

Given the serious negative impacts of hydropower development on rice production in the LMB, this has implications for Singapore's import market. While it is likely that Singapore can replace any lost production from other sources, this may come at a financial cost. The country's fish imports from the LMB may also face **market risks** if fish stocks decline, though the country's low dependence on imports for fish reduces its vulnerability.

Under the Singaporean government's plans to increase renewable energy sources (partly due to its current reliance on natural gas for 95 per cent of its electricity supply), the country will begin a trial of importing hydroelectricity (which it perceives as a green source of energy) from Lao PDR via Thailand and Malaysia as part of the Lao PDR-Thailand-Malaysia-Singapore Power

14. This excludes the PRC which has a number of large dams in the Upper-Mekong Basin.
15. See Observatory of Economic Complexity: https://oec.world/en/profile/bilateral-product/rice/reporter/sgp#:~:text=Singapore%20imports%20Rice%20primarily%20from,and%20India%20(%247.35M)
16. In 2008, the Singapore government established a Working Group on Sustainable Development of the Built Environment, which included representatives from the government, industry, and civil society. In addition, in 2015, the Singaporean government introduced a certification scheme for imported sand, called the Sand and Granite Quarries Certification Scheme, which requires importers to obtain certification from the government to ensure that the sand they import meets environmental and social standards. The scheme is designed to prevent illegal sand smuggling.


© Elizabeth Kemf / WWF

Integration Project (LTMS-PIP), from 2022 to 2024. Through this scheme, electricity company Electricite Du Lao PDR (EDL) will export up to 100 MW of hydropower (approximately 1.5 per cent peak electricity demand) to Keppel Electric via Thailand and Malaysia using existing interconnectors.[17] However, the impacts of hydropower on ecosystems and the natural resource base of livelihoods and economies of the Mekong mean that low carbon hydropower is not a sustainable choice.

Despite the Singaporean government's hopes of tapping a low-carbon energy source to support its fulfilment of the Singapore Green Plan 2030 and to improve the country's energy security and stability, such an investment comes with **reputational and financial risks**. First, **reputational risks** may increase in the coming decades as public awareness of the negative environmental and social impacts of hydropower increases, as well as the problems associated with externalising such negative impacts (e.g., by addressing over-reliance on greenhouse gas-emitting power sources such as natural gas by importing electricity supply that has other negative environmental impacts elsewhere). Given hydropower's high vulnerability to drought, there are also **financial risks** associated with increasing reliance on hydroelectricity, which may result in Singapore needing to find alternative electricity sources.

Singapore has a strong reputation as a leader in sustainability in the ASEAN region, with its commitment to ambitious national targets in relation to international goals and initiatives (e.g., CITES, Kunming-Montreal Global Biodiversity Framework and Paris Agreement). Its continued investments in hydroelectricity from the LMB region need to be considered from that perspective.

17. See https://www.straitstimes.com/singapore/environment/singapore-to-trial-import-of-renewable-hydropower-from-laos-in-cross-border

ENERGY ALTERNATIVES

AND REGIONAL OUTLOOK

Hydropower is often presented by advocates as a relatively benign, clean and 'green' source of energy. However, a better understanding of the systematic risks posed by hydropower casts doubt on its role as a viable alternative source of low-carbon energy and climate change mitigation tool. There is simultaneously a developing awareness of alternative strategies for electricity provision in the region, which do not pose such high risks, offering other pathways forward for the region.

Hydropower development in the Lower Mekong Basin in recent decades has been largely driven by developers in an ad hoc manner without strategic planning. Little attention has been paid to the systemic and cumulative risks posed by hydropower. However, not all hydropower projects are the same; some pose higher risks than others. For example, those on the Mekong mainstream or areas with critical ecological functions or endangered habitats pose higher risks than small run-of-river plants, or those constructed on already highly regulated rivers or at the bottom of hydropower cascades.

Hydropower development in the basin has been sub-optimal, and a coordinated approach to hydropower planning in the basin could greatly reduce hydropower impacts while realising a similar amount of energy. This was demonstrated by a recent study in the 3S basin, which found that 68 per cent of the basin's hydropower potential could have been developed with only a 21 per cent decline in sand reaching the delta, whereas current development realised only 54per cent of potential hydropower capacity while capturing 91 per cent of the sand (Schmitt et al., 2018).

Alternative renewables technologies such as solar PV and wind have seen dramatic reductions in cost over the last decade. On-shore wind costs declined by 56 per cent and utility scale solar PV by 85 per cent between 2010 and 2020 (Schmitt et al., 2019). As a result, these technologies have been much more widely deployed globally, with installed renewables capacity growing by 130 per cent over the last decade (ibid.). These technologies have also been more widely adopted in the Mekong region. There is thus significant potential for the wider development of solar PV, as well as on- and off-shore wind in the region. Care needs to be taken in citing developments to avoid social and environmental impacts, with solar often placed on unused land, covering parking lots, buildings, and floating installations in reservoirs. Power generation by solar and wind-based technologies is dependent upon the time of day and weather

conditions; given that power supply needs to be matched with availability in real time this presents a challenge. Advances in the cost and availability of battery technology will help address some variability issues facing these renewables (IRENA, 2018). At the same time, a recent study found significant potential for pumped storage hydropower in the Lower Mekong Basin, which could enable further variable renewables penetration (ANU, 2022). Pumped storage systems pump water up to a reservoir when spare electricity is being generated and then release it to power turbines to generate electricity at times of higher demand.

Existing hydropower could also be managed to support the deployment of variable renewables (FME CenCES, 2017). The flexibility offered by hydropower – including being managed to balance system loads – could serve to address issues of variability of supply stemming from renewables generation. This would mean the development of revised power purchase agreements for hydropower generators that make provision for this use case. Greater renewables deployment would also likely strengthen the case for greater integration in the regional power systems, moving from what are currently national grid systems with some limited interconnections to a more integrated regional system.

Only a decade ago, alternatives to the development of hydropower in the region were limited. However, over the last 10 years, dramatic cost declines in renewables technologies and ancillary technologies, and improvements in the understanding of how renewables can be integrated into electricity grid systems mean that these technologies now present a viable and attractive alternative to hydropower development in the basin - with far less negative social and environmental impacts.

Worldwide, hydropower development has slowed down since the 1990s and ageing hydropower dams are starting to be removed in some regions, with signs of ecosystem recovery already evident in many areas. The LMB is, however, lagging behind this shift. Given hydropower's significant environmental threats and externalities across social, environmental and economic spaces, it is therefore time for hydropower to be seen not as a complete substitute for fossil fuels, but as a supplementary energy source for other renewables as the region transitions to a net-zero carbon energy system.

CONCLUDING

REMARKS AND RECOMMENDATIONS

As the threats posed to the Mekong's unique river system by continued hydropower development become more prominent, it is vital that Lower Mekong governments, foreign investors, and businesses alike expand their understanding of hydropower-related risks and how they are distributed geographically and temporally.

In this section, we lay out ten strategic recommendations for key stakeholders involved in either hydropower development planning, hydroelectricity imports, or supply chain operations in high-exposure areas so they can address their levels of risk. Recommendations for further research and engagement are also provided.

01 Lower Mekong governments should better consider the trade-offs of further hydropower development, and assess alternative renewable technologies, such as wind and solar energy, for meeting the growing energy demands of the region as well as climate change mitigation and adaptation, and biodiversity conservation goals. This includes reconsidering regional hydroelectricity investment plans, such as the recent Lao-Thai-Malaysia-Singapore (LTMS) regional hydropower trade agreement, and consider alternative pathways for achieving climate change targets, while ensuring that cross-border electricity trade is both carbon-neutral and sustainable.

02 Foreign investors (including governments with plans to import hydroelectricity from the LMB, such as Singapore) should assess the true costs, including social and environmental externalities, of hydropower – as well as their impact on climate change adaptation measures (e.g., through nature-based solutions) – and weigh these against decarbonisation goals for climate change mitigation. Cost-effective, greener renewable energy alternatives are available so that hydropower is not the primary energy source but rather complements other technologies. Investors should take advantage of the dramatic cost declines of renewable and ancillary technologies in recent years, together with the abundance of renewable resources in the Mekong and consider these technologies as alternatives to hydroelectricity.

03 Businesses sourcing their energy from LMB hydropower should consider shifting towards alternative renewable technologies to achieve their own sustainability and corporate social responsibility goals, as public awareness of the risks associated with hydropower increase.

04 NGOs supporting ESG in the private sector to provide educational tools to businesses operating in the LMB so they understand the broader, systemic implications of hydropower on supply chain operations beyond water shortages and start to consider the potential consequences of reduced sediment and nutrient flow, saline intrusion, land subsidence, and riverine habitat fragmentation.

05 Businesses operating in high-exposure areas (e.g., the Mekong Delta) should conduct risk assessments for hydropower-related threats beyond short-term and localised threats, and how they might reduce their vulnerability to these threats and act as leaders in responsible business practices in the LMB. This could be done through local business platforms such as the Mekong Delta resilient business network,[18] using tools and materials already established.[19]

06 Business leaders should work together to advance collective action on water issues using established frameworks, so that the scale of action matches the scale of the risks to be addressed.

07 LMB governments should provide the enabling conditions for attracting responsible businesses through stricter environmental regulations and encouraging private sector engagement (e.g., wastewater treatment requirements, water saving practices, and good regulatory frameworks to ensure compliance).

08 Non-water related ministries in LMB governments should increase awareness of hydropower-related risks across their sectors (e.g., ministries related to commerce and industry).

09 Governments and academia to conduct further studies on hydropower-related risks facing specific business supply chains in the LMB, particularly those with opaque business operations or complex chains of causality, such as those in the electronics, textiles, fisheries and rice sectors.

10 Hydropower will be a part of a sustainable energy transition, but not in the role the technology has historically played in terms of electricity supply. Governments should manage and progress the hydropower sector fully cognizant of the damaging impact hydropower has on natural and economic systems of the region. Planning of new projects should carefully consider siting and use of hydropower as a supplementary energy source for the transition to other renewable energy sources, not a complete substitute for fossil fuels.

While these recommendations are ambitious, it is important for all relevant stakeholders – from national governments to businesses and foreign investors – to take urgent action in not only improving awareness of the substantial financial, market, physical, reputational, and regulatory risks facing supply chains in the Lower Mekong in the coming decades, but also in establishing themselves as responsible leaders in sustainable business operations and a regional energy mix that does not undermine the Mekong's unique natural system.

18. See more about the Mekong Delta resilient business network at https://tuoitrenews.vn/news/business/20220506/mekong-delta-resilient-business-network-debuts-in-Viet Nam/66993.html
19. See, for example, the science driven targets developed by WWF: https://wwf.panda.org/discover/our_focus/freshwater_practice/water_management/science_targets_water/

REFERENCES

ANU. (2022). Policy Brief: Pumped Storage Hydropower for the Mekong Region. Australian National University.

Arias, M. E., Cochrane, T. A., Kummu, M., Lauri, H., Holtgrieve, G. W., Koponen, J., & Piman, T. (2014). Impacts of hydropower and climate change on drivers of ecological productivity of Southeast Asia's most important wetland. Ecological Modelling, 272, 252–263. https://doi.org/10.1016/j.ecolmodel.2013.10.015

Arias, M. E., Piman, T., Lauri, H., Cochrane, T. A., & Kummu, M. (2014). Dams on Mekong tributaries as significant contributors of hydrological alterations to the Tonle Sap Floodplain in Cambodia. Hydrology and Earth System Sciences, 18(12), 5303–5315. https://doi.org/10.5194/hess-18-5303-2014

ASEAN Center for Energy. (2020). ASEAN Plan of action for energy cooperation (APAEC) 2016-2025. Phase II: 2021-2025. ASEAN Center for Energy. https://aseanenergy.org/asean-plan-of-action-for-energy-cooperation-apaec-phase-ii-2021-2025/

Binh, D. V., Kantoush, S. A., Sumi, T., Mai, N. P., Ngoc, T. A., Trung, L. V., & An, T. D. (2021). Effects of riverbed incision on the hydrology of the Vietnamese Mekong Delta. Hydrological Processes, 35(2), e14030. https://doi.org/10.1002/hyp.14030

Binh, D. V., Kantoush, S., & Sumi, T. (2020). Changes to long-term discharge and sediment loads in the Vietnamese Mekong Delta caused by upstream dams. Geomorphology, 353, 107011. https://doi.org/10.1016/j.geomorph.2019.107011

Bond, N. (2015). Examining Adaptations to Changing Fish Populations of Tonle Sap Lake in Cambodia: A Case Study of Pursat Province, Cambodia. University of Guelph.

Bravard, J. P., Goichot, M., & Gaillot, S. (2013). Geography of sand and gravel mining in the Lower Mekong River. EchoGeo, 26. https://doi.org/10.4000/echogeo.13659

Do, T. N., & Burke, P. J. (2023). Is ASEAN ready to move to multilateral cross-border electricity trade? Asia Pacific Viewpoint, 64(1), 110–125. https://doi.org/10.1111/apv.12343

Eslami, S., Hoekstra, P., Nguyen Trung, N., Ahmed Kantoush, S., Van Binh, D., Duc Dung, D., Tran Quang, T., & Van Der Vegt, M. (2019). Tidal amplification and salt intrusion in the Mekong Delta driven by anthropogenic sediment starvation. Scientific Reports, 9(1), 18746. https://doi.org/10.1038/s41598-019-55018-9

Golden D., Shapero A, Vaitla B, Smith M. R., Myers S., Stebbins Eh, Gephart J. A. (2019) Impacts of Mainstream Hydropower Development on Fisheries and Human Nutrition in the Lower Mekong. Frontiers in Sustainable Food Systems (3), DOI=10.3389/fsufs.2019.00093

Gruel, C.-R., Park, E., Switzer, A. D., Kumar, S., Loc Ho, H., Kantoush, S., Van Binh, D., & Feng, L. (2022). New systematically measured sand mining budget for the Mekong Delta reveals rising trends and significant volume underestimations. International Journal of Applied Earth Observation and Geoinformation, 108, 102736. https://doi.org/10.1016/j.jag.2022.102736

Hackney, C. R., Darby, S. E., Parsons, D. R., Leyland, J., Best, J. L., Aalto, R., Nicholas, A. P., & Houseago, R. C. (2020). River bank instability from unsustainable sand mining in the lower Mekong River. Nature Sustainability, 3(3), 217–225. https://doi.org/10.1038/s41893-019-0455-3

Hackney, C. R., Vasilopoulos, G., Heng, S., Darbari, V., Walker, S., & Parsons, D. R. (2021). Sand mining far outpaces natural supply in a large alluvial river. Earth Surface Dynamics, 9(5), 1323–1334. https://doi.org/10.5194/esurf-9-1323-2021

Hoang, H., Tuan, L. A., & Heijnert, K. (2022). Upscaling of Flood-Based Agriculture in Mekong Delta in Viet Nam.

Hortle, K. G. (2007). Consumption and yield of fish and other aquaticanimals from the Lower Mekong Basin. (MRC Technical Paper No. 16, p. 87). Mekong River Commission.

ICEM. (2010). Strategic Environmental Assessment on Hydropower on the Mekong Mainstream—Summary of final report. ICEM.

IEA. (2021). Thailand Power System Flexibility Study. International Energy Agency. https://iea.blob.core.windows.net/assets/19f9554b-f40c-46ff-b7f5-78f1456057a9/ThailandPowerSystemFlexibilityStudy.pdf

Intralawan, A., Smajgl, A., McConnell, W., Ahlquist, D. B., Ward, J., & Kramer, D. B. (2019). Reviewing benefits and costs of hydropower development evidence from the Lower Mekong River Basin. WIREs Water, 6(4). https://doi.org/10.1002/wat2.1347

Intralawan, A., Wood, D., Frankel, R., Costanza, R., & Kubiszewski, I. (2018). Tradeoff analysis between electricity generation and ecosystem services in the Lower Mekong Basin. Ecosystem Services, 30, 27–35. https://doi.org/10.1016/j.ecoser.2018.01.007

IRENA. (2018). Electricity Storage and Renewables: Costs and Markets to 2030. International Renewable Energy Agency.

Jha, P. (2023, January 9). New Laos-Cambodia line set to expand power trade, ties. Khmer Times. https://www.khmertimeskh.com/501216024/new-laos-cambodia-line-set-to-expand-power-trade-ties/

Jordan, C., Tiede, J., Lojek, O., Visscher, J., Apel, H., Nguyen, H. Q., Quang, C. N. X., & Schlurmann, T. (2019). Sand mining in the Mekong Delta revisited—Current scales of local sediment deficits. Scientific Reports, 9(1), 17823. https://doi.org/10.1038/s41598-019-53804-z

Khôi, M. (2023, March 28). Ensure sufficient sources of materials for road foundation according to the progress of highway projects (Bảo đảm đủ nguồn vật liệu đắp nền đường theo tiến độ các dự án cao tốc). Báo Điện tử Chính phủ. https://baochinhphu.vn/bao-dam-du-nguon-vat-lieu-dap-nen-duong-theo-tien-do-cac-du-an-cao-toc-102230praiw314211649762.htm

Kondolf, G. M., Rubin, Z. K., & Minear, J. T. (2014). Dams on the Mekong: Cumulative sediment starvation. Water Resources Research, 50(6), 5158–5169. https://doi.org/10.1002/2013WR014651

Luong, B. (2023, February 12). Vietnam to import 3,000MW electricity from Laos. Vietnamnet. https://vietnamnet.vn/en/vietnam-to-import-3-000mw-electricity-from-laos-2109110.html

Middleton, C., & Ketelsen, T. (2022). Pathways to a Sustainable and Just Transformation of the Mekong Region's Electricity Sector. Center for Social Development Studies, Faculty of Political Science, Chulalongkorn University, and the Australia- – Mekong Partnership for Environmental Resources and Energy Systems.

Middleton, C., & Un, B. (2017). Living with the flood: A political ecology of fishing, farming, and migration around Tonle Sap Lake, Cambodia. In C. Middleton, R. Elmhirst, & S. Chantavaninch (Eds.), Living with Floods in a Mobile Southeast Asia (1st ed., p. 20). Routledge, Taylor & Francis Group.

Ministry of Natural Resources and Environment, G. of V. (2015). Study on the Impacts of Mainstream Hydropower on the Mekong: Final Report. (p. 112).

MRC. (2017). The Council Study: Biological Resource Assessment—Technical Report Series. Volume 4: Assessment of planned development scenarios. Mekong River Commission.

MRC. (2018a). Modelling the impacts of climate change and development infrastructure on Mekong flow, sediment regimes, and water quality (The Council Study). Mekong River Commission Secretariat.

MRC. (2018b). State of the Basin Report. Mekong River Commission.

MRC. (2022a). Mekong low flow and drought conditions in 2019-2021. Hydrological Conditions in the Lower Mekong. https://www.mrcmekong.org/assets/Publications/Mekong-low-flow-and-drought-conditions-2019-2021df.pdf

MRC. (2022b). Sustainable Hydropower Development Strategy: A basin-wide strategy for a changing Mekong River Basin. MRC Secretariat.

Ng, H. S. (2022). Singapore begins importing renewable energy from Laos through Thailand and Malaysia. CNA. https://www.channelnewsasia.com/singapore/singapore-import-hydropower-renewable-energy-laos-through-thailand-malaysia-2766251#:~:text=SINGAPORE%3A%20Singapore%20started%20importing%20renewable,Electricite%20du%20Laos%20(EDL).

Orr, S., Pittock, J., Chapagain, A., & Dumaresq, D. (2012). Dams on the Mekong River: Lost fish protein and the implications for land and water resources. Global Environmental Change, 22(4), 925–932. https://doi.org/10.1016/j.gloenvcha.2012.06.002

Praiwan, Y. (2021, August 9). Egat to import more electricity from Laos. https://www.bangkokpost.com/business/2162227/egat-to-import-more-electricity-from-laos)

Schneider, P., & Asch, F. (2020). Rice production and food security in Asian Mega deltas—A review on characteristics, vulnerabilities and agricultural adaptation options to cope with climate change. Journal of Agronomy and Crop Science, 206(4), 491–503. https://doi.org/10.1111/jac.12415

T N, H., & THU, H. (2022, November 13). Mekong Delta: Worry... Lack of sand (Đồng bằng sông Cửu Long: Nỗi lo... thiếu cát). Hau Giang Online. https://www.baohaugiang.com.vn/kinh-te/dong-bang-song-cuu-long-noi-lo-thieu-cat-115786.html

Tu, H. (2023, March 15). Priority should be given to sand for highway projects in the Mekong Delta. Bao Dau Tu. https://baodautu.vn/can-uu-tien-cat-cho-cac-du-an-cao-toc-vung-dong-bang-song-cuu-long-d185535.html

UN. (2023). UN Comtrade Database [dataset]. https://comtradeplus.un.org/

Vanderbyl, T., & Pham, N. L. (2021). WWF Water Risks and the Textiles Sector in Cambodia (p. 55) [Internal report]. MCG Management Consulting.

Vasilopoulos, G., Quan, Q. L., Parsons, D. R., Darby, S. E., Tri, V. P. D., Hung, N. N., Haigh, I. D., Voepel, H. E., Nicholas, A. P., & Aalto, R. (2021). Establishing sustainable sediment budgets is critical for climate-resilient mega-deltas. Environmental Research Letters, 16(6), 064089. https://doi.org/10.1088/1748-9326/ac06fc

Woillez, M.-N., & Espagne, E. (Eds.). (2022). The Mekong Delta Emergency, Climate and Environmental Adaptation Strategies to 2050. Final Report GEMMES Viet Nam project. Agence Française de Développement.

Yoshida, Y., Lee, H. S., Trung, B. H., Tran, H.-D., Lall, M. K., Kakar, K., & Xuan, T. D. (2020). Impacts of Mainstream Hydropower Dams on Fisheries and Agriculture in Lower Mekong Basin. Sustainability, 12(6), 2408. https://doi.org/10.3390/su12062408

WWF

Working to sustain the natural world for the benefit of people and wildlife.

together possible™