Received: 8 October 2018 | Revised: 18 March 2019 | Accepted: 19 March 2019
DOI: 10.1002/wat2.1347

FOCUS ARTICLE

WIREs WATER WILEY

Reviewing benefits and costs of hydropower development evidence from the Lower Mekong River Basin

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Funding information
IDS program, Grant/Award Number: 80NSSC17K0259; NASA's LCLUC program, Grant/Award Number: 80NSSC18K1134

In this paper, we examine the benefits and costs of hydropower development in the Mekong River Basin. We compare four major reports—the Mekong River Commission's (MRC's) Basin Development Plan Programme, Phase 2 (BDP2), the Strategic Environmental Assessment of Hydropower on the Mekong Mainstream (SEA), the Study on the Impacts of Mainstream Hydropower on the Mekong River (MDS), and the MRC's recent council study (CS)—in order to provide the basis for a comparative analysis of the major impact evaluation literature on mainstream dam construction in the Mekong River Basin for the period of 2010–2018. The primary objective of the review is to identify points of agreement, disagreement, inconsistency, and knowledge gaps. Both Mekong River Commission reports (BDP2 and CS) suggest extensive economic benefits for proposed hydropower development, whereas the SEA and MDS indicate that the net impact would be negative. The projected impacts of hydropower development on fisheries, sediment flows, and ecosystems vary widely both in economic and biophysical terms. However, all four reports point to decreased food security and loss of local livelihoods for millions of people as major concerns related to dam development. While considerable resources have been devoted to producing these important studies, the lack of standardization across reports, especially assumptions and methodologies for economic impacts, frustrates efforts at meaningful comparison of their findings and precludes the prospect of clear analytical outcomes or policy impacts.

This article is categorized under:
Engineering Water > Planning Water
Human Water > Value of Water
Engineering Water > Methods

KEYWORDS
cumulative impact assessment, economic impacts of hydropower, hydropower, (Lower) Mekong River Basin, transboundary water management

1 | INTRODUCTION

Originating on the Tibetan Plateau and flowing over 4,900 km through China, Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam, the Mekong River supports more than 60 million people who live within 15 km of its banks, as well as critical ecosystems and countless species, making it one of the most economically and ecologically important rivers in the world. The Mekong is ranked 10th in the world in terms of length and 12th in volume, with a mean annual discharge of 470 km^3 covering a catchment area of 795,000 km^2. With high interseasonal flow variation, the Mekong's flood pulse characteristics underlie the region's rich biodiversity and biological productivity, especially for the river-floodplain ecosystems of Cambodia and Vietnam. The Mekong is the second most biodiverse river in the world in terms of fish species after the Amazon River, with an estimated 800 species, an abundance explained in part by its remote and tropical location (Van Zalinge et al., 2004). The river supports an inland capture fishery valued at US$ 11 billion/year (Nam et al., 2015).

While the characteristic cycle of flooding and drought in the basin has given rise to immense biological productivity, it has also created difficult conditions for human populations. Today, a majority of people living near the Mekong live below national and international poverty lines, pursuing subsistence lifestyles with relatively little economic diversity compared to other regions in the world.

The governments of the Lower Mekong Basin (LMB) countries are facing several complex challenges pertaining to the water resource development and management of interdependent and often conflicting outcomes of dam construction and operation (see Figure 1). Population growth, poverty and inequality, imperatives of economic development, agricultural investment and expansion, flood and drought mitigation, increasing river navigation, and increasing urbanization add additional dimensions to optimize the decision making challenges (Lu & Siew, 2006; Magee, 2006; Pech & Sunada, 2008).

Modernization of the LMB has been a decades-long dream. In 1947, the United Nations created a Mekong regional commission. In the early 1950s, the Bureau of Flood Control of the United Nations Economic Commission for Asia and the Far East (UNECAFE) suggested river development to ensure greater flood control, hydropower generation, and irrigated agricultural production. The Bureau also suggested greater cooperation and management between the four riparian countries (Jacobs, 2002). Due to decades of conflict and political instability, cooperation on development of the Mekong was not ratified until 1995, when LMB countries initiated the Basin Development Plan (BDP) to identify and prioritize the sustainable development of the Mekong River Basin (Commission, 2013).

To some LMB countries, hydropower development (Figure 1) represented a development strategy geared to national objectives of economic growth and poverty reduction, increase foreign direct investment and revenue from electricity generation, expand irrigated areas, improve navigation, and reduce flooding and drought. Lao PDR, for example, has stated aspirations to become the “Battery of Asia” with revenue from electricity exports used for social and economic development (Middleton, Garcia, & Foran, 2009). However, the proposed hydropower projects would also likely create food insecurity, environmental and social problems, concerns for all LMB countries. For instance, many studies show that the cascade of planned hydropower development will cause major changes to river hydrology, thus depleting capture fisheries, sediment, and nutrient flows, potentially undermining local livelihoods and well-being (Geheb & Pukinskis, 2012; Hall & Bouapao, 2010a; Kummu & Sarkkula, 2008; Orr, Pittock, Chapagain, & Dumaresq, 2012; Pittock, Dumaresq, & Bassi, 2016; Stone, 2011; Winemiller et al., 2016).

2 | METHODOLOGY

Recent reports (Costanza et al., 2011; Intralawan, Wood, Frankel, Costanza, & Kubiszewski, 2018) have evaluated basin-wide hydropower development in the LMB using benefit-cost analysis. These reports originate from the MRC framework for transboundary environmental impact assessment in an effort to strengthen the MRC's role in the production of knowledge and provide a foundation for regional cooperation (Grumbine, Dore, & Xu, 2012). For this study, we used cross-comparison of results from four major reports that comprehensively investigate hydropower development at the basin level: (1) Strategic Environmental Assessment of Hydropower on the Mekong Mainstream (SEA) published by ICEM in 2010, (2) Basin Development Plan Programme, Phase 2. Assessment of Basin-wide Development Scenarios (BDP2) published by MRC in 2011, (3) Study on the Impact of Mainstream Hydropower on the Mekong River (MDS) published by Vietnam's Ministry of Natural Resources and Environment in 2015, and (4) The council study (CS) published by MRC in 2018. Because economic benefits are often the primary justification for hydropower development, our analysis focused on projected economic benefits and costs of hydropower development, estimated as the combination of estimated gains or losses and unit price. We also noted the significant social and environmental impacts that in many cases are not assigned an economic value in the selected reports as knowledge gaps in the economic valuation. Furthermore, where data allow, we have standardized the reporting of forecast outcomes in annualized dollars (Table 1). However, direct comparison of forecast outcomes in the four reports is not possible due to the use of different assumptions and methods for NPV calculations.

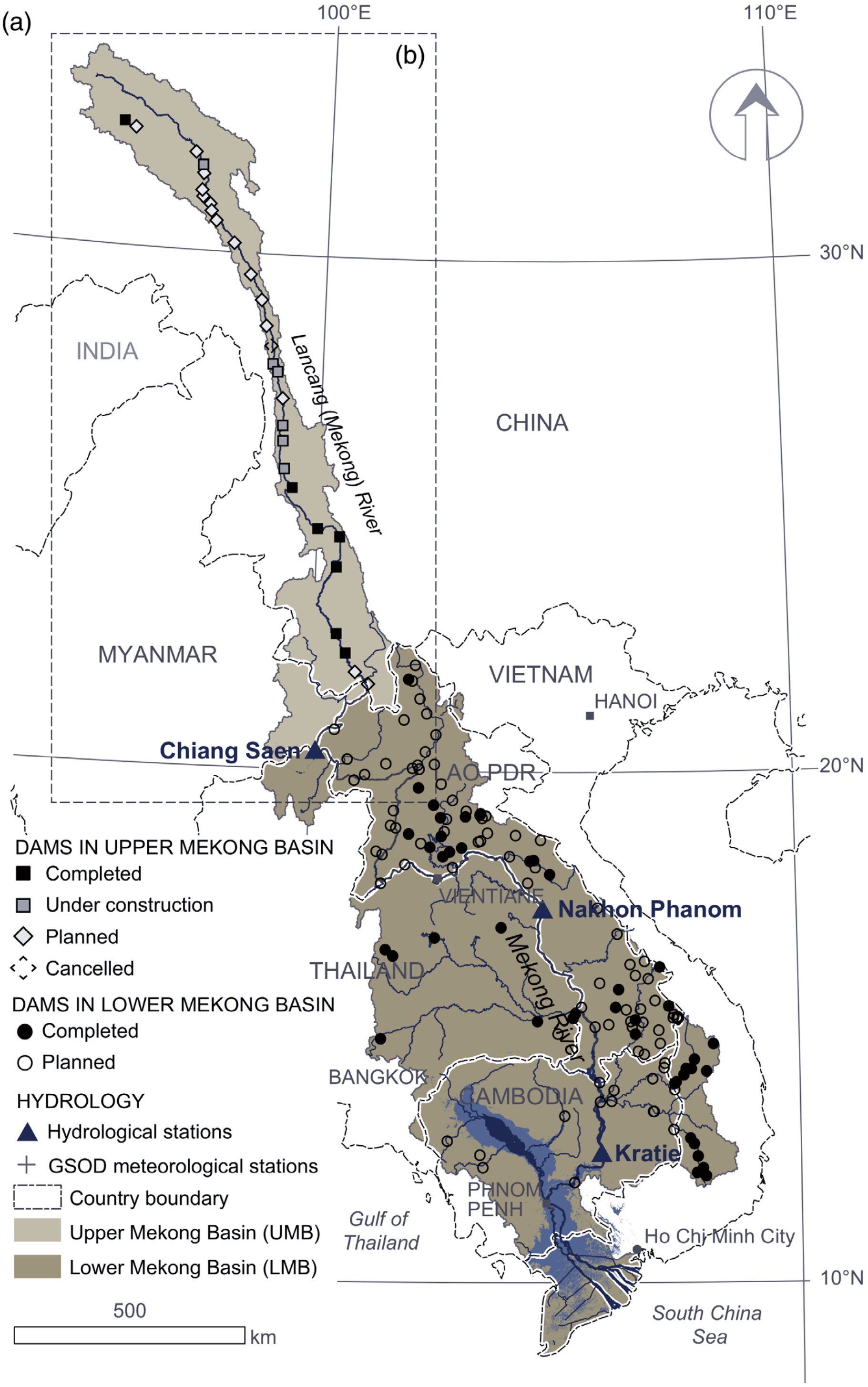

FIGURE 1 Planned mainstream hydropower development. (Source: (a) (Räsänen et al., 2017) (b) (Mekong River Commission, 2018a))

3 | REPORT SUMMARIES

3.1 | Strategic environmental assessment of hydropower on the Mekong mainstream—final report

In May of 2009, the MRC engaged an independent consulting group called the International Centre for Environmental Management to conduct a Strategic Environmental Assessment "to provide an understanding of the implications of mainstream hydropower development and recommendations on whether and how the proposed projects should best be pursued." In contrast to a project-based environmental impact assessment, the SEA covers a region in which multiple projects are anticipated over an extended time horizon. The intention was for the SEA to inform the Procedures for Notification, Prior Consultation

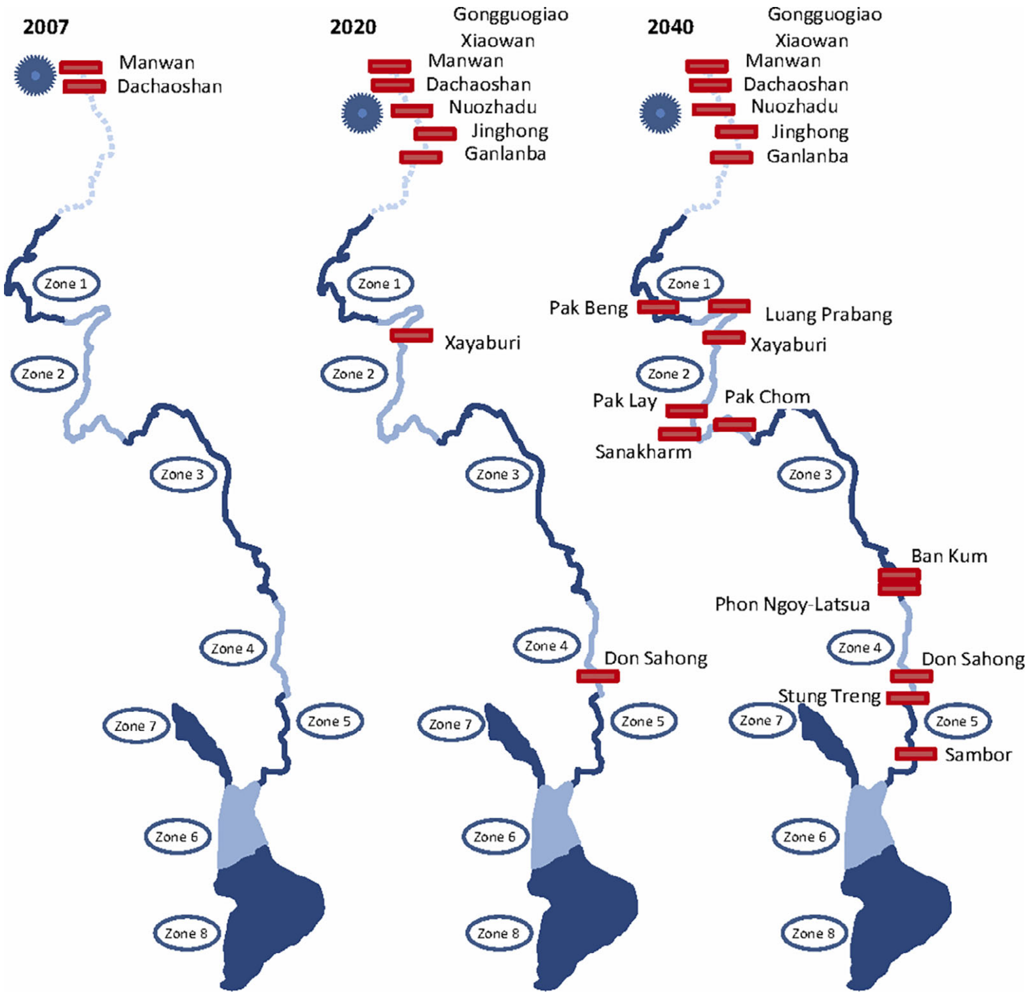

FIGURE 1 Continued

and Agreement process and the Basin Development Plan and ultimately to support national decisions concerning the mainstream hydroelectric project proposals. The final report was submitted to MRC in September of 2010, the year before the BDP2 was completed (ICEM, 2010).

The SEA examines both opportunities and risks of proposed hydropower development projects on the mainstream of the Lower Mekong River with special attention to issues of economic development, social equity and environmental protection. The document results from a program of intensive consultation with stakeholders throughout the region and expert analysis. The report references a "background methodological paper" containing information on the calculation of economic benefits and costs, but that information could not be located for the present review.

The analysis includes the examination of three development scenarios stipulated by the BDP:

1. A "definite future scenario" that considered only hydropower development projects that were complete, under construction, or had secured agreement for development before 2015, including six of the mainstream projects in China and 41 hydropower projects on the tributaries of the LMB (i.e., 47 projects in all).
2. A "20 years without mainstream dams" scenario that included additional tributary hydropower and irrigation projects identified by the LMB countries within their development plans for 2030 including some 71 tributary projects and six Chinese dams (i.e., 77 projects in all) and water abstraction of 4.6 billion cubic meters to supply 6 million ha of irrigated land.
3. A "20 years with mainstream dams" scenario that included the additional 12 LMB (Thakho—a diversion planned dam near Khone Fall in Lao PDR is included) mainstream hydropower projects which were being considered.

Given the similarity to the other reports' scenarios summarized here, the positive and negative impacts of the third scenario—all 12 mainstream dams as well as 71 tributary dams—were considered by sector, with the following estimated quantitatively: capital investments; revenue generation; fisheries; agriculture and forestry; and wetlands.

TABLE 1 Annual benefit and cost (millions of US$/year)

Theme	CS (M3CC—M1 the effect of development scenario)	MDS (scenario 2)	MRC—BDP2 (20 year plan incl. all dams + climate change)	SEA (scenario 3)
Publication year	2018	2015	2011	2010
Scope	Eleven mainstream and 103 tributary dams with climate change	Eleven mainstream and 72 tributary dams with no climate change	Eleven mainstream dams and 30 tributary dams, plus climate change	Twelve mainstream and 72 tributary dams with no climate change
Spatial extent	Lower Mekong River Basin within 15 km corridor	Downstream floodplains of Cambodia and Vietnam. 106,350 km^2	Lower Mekong River Basin within 15 km corridor	Lower Mekong River Basin
Temporal extent	To 2040	To 2030	To 2030	To 2030
1. Hydropower,	$ 9,396.1	NA (dry year: −54.44% in water volume; −1.12 m in water level for 10 day interval at Kratie, Cambodia. Dry year: −36.07% in water volume and −0.12 m in water level for 10 day interval at Tan Chua, Vietnam).	$ 5,344.05	$ 3–4,000
2. Irrigated agriculture	Total agriculture: $ 6,410.8 irrigation: $ 1,228.3	Rice production: −552,500 tons (Vietnam) and −203,300 tons (Cambodia) per year for 10 years Maize production: −21,700 tons (Vietnam) and 41,000 tons (Cambodia) per year for 10 years. No effect estimated on crop area and crop calendar −$ 426 (Cambodia) −$ 250 million (Vietnam) in fisheries and farming sectors	$ 270.30	Riverbank production: −$ 21 Paddy production: −$ 4 nutrient replacement: $ 24 new irrigated production: $ 15.54
3. Reservoir fisheries	Included in 5	NA	$ 32.59	$ 14
4. Aquaculture	NA	Little to no impact	$ 211.81	NA
5. Capture fisheries	−$ 658.2	Whitefish: −80−100% capture fisheries: −50% Total fish production: −614,000 tons OAA: −45,000 tons (of total) economically valuable: −315,000 tons (of total) Inland fisheries: −$ 580 (Vietnam) coastal fisheries: −50,000 tons or −$ 150	−$ 1,220.0	−$ 476
6. Wetlands (natural capital)	−$ 7,314.1 (uncertainty range: min: −4,761.8 max: −9,865.9) includes Themes 6, 7 & 9	Little to no change in extent	$ 16.29	−$ 4 to 13.8
7. Social/cultural impact	Included in 6	Major and concentrated. Fish consumption: −26 kg/person/year (Cambodia) −120 kg/fisher/year (Cambodia) 100 highly affected communes in an Giang and Dong Thap with greater than 10% loss of net income (Vietnam)	4.3 million livelihoods threatened	

TABLE 1 (Continued)

Theme	CS (M3CC—M1 the effect of development scenario)	MDS (scenario 2)	MRC—BDP2 (20 year plan incl. all dams + climate change)	SEA (scenario 3)
8. Sediment & Nutrients	Included in 13	Silt and clay transport: −59–66% at Kratie Sediment transport and accretion at river mouths: −4–12 m/year P transport: −49 to 56% N transport: −58 to 62% at Kratie	Reduced sediment flow with adverse effects on wetlands, agriculture productivity, coastal fisheries	Sediment transport: −75% from 160–165 to 42 million tons/year at Kratie nutrient replacement: $ 24
9. Biodiversity & Forest reduction	Included in 6	Fish: −10% of species large population declines of surviving migratory fish. Extinction of Irrawaddy dolphin reduction in distribution and population of mussels and reduction in drift of invertebrates little to no impact of open water and floodplain wetlands extent of dependent species. Moderate impacts on biodiversity due to changes in primary productivity, riverine habitat, and loss of coastal wetlands.	−$ 67.62 (hotspot loss) − $ 60.61 (forest loss)	NA
10. Recession rice	Include in irrigated area	NA	$ 45.29	River bank gardens: −54% or −$ 21
11. Flood & Drought protection	Floods: $ 125.5 droughts: included in 2	NA	−$ 44.48	NA
12. Salinity mitigation	NA	Salinity intrusion: +7,550 km2 (scenario 1), 0 km2 (scenario 2), and 11,200 km2 (scenario 3) +1.6 million people affected (Vietnam)	−$ 0.33	NA
13. Bank erosion losses	$ 347.7	5 m of "deep scour" downstream of Kraite bed degradation moves downstream at 1.5–2 km/year	Reduced wet season flow may reduce bank erosion, but "river regime change" will increase bank erosion"	NA
14. Navigation	$ 5,003.3	Little to no economic loss. No impacts on mainstream from Kampong Kor to downstream of Phnom Penh and Vietnamese Delta region.	$ 10.43	NA

3.1.1 | Socio-economic effects

The economic benefits of the proposed construction include the substantial capital investments, which were estimated at $25 billion or $1.5 billion per year on average. It is acknowledged that much of this investment would not be made locally but would rather accrue to foreign design and engineering firms. The report estimates the benefits of electricity exports at $3.8 billion per year, with 70% accruing to Lao PDR and the remaining 30% to Cambodia.

Paddy rice production was projected to see a gain of $15.54 million per year through improved irrigation, diminished by losses of $4.1 million per year through permanent inundation of paddy fields. Meanwhile, losses in riverbank production were estimated at $21 million per year, and the cost of fertilizers to replace phosphates captured in reservoirs was estimated at $24 million per year.

3.1.2 | Environmental effects

The assessment projects net losses in inland capture fisheries of $476 million per year, only partially offset by gains of $14 million per year in new reservoir fisheries. While the impacts on delta and coastal fisheries are expected to be substantial, lack of information preclude reliable analysis. Instead, the report focuses on the costs of lost nutrients to the marine fishery from sediment capture behind dams, estimated at $40 million per year, and on the negative impacts on the regional fishing equipment, supply, and processing industries, which were calculated at $2–4 billion.

The report concludes that most of the "instream" wetlands in the central part of the LMB would be heavily impacted, and estimates the loss of ecosystem services at between $4 million and $13.8 million per year.

The main message of the report is a recommendation that all contemplated mainstream should be deferred for a period of 10 years in order to enable more complete accounting of the overall costs.

3.1.3 | MRC—Basin Development Plan Programme, Phase 2 assessment

In April 2011, MRC published an extensive report titled "Assessment of Basin-Wide Development Scenarios" as part of its Basin Development Plan Programme, Phase 2 (BDP2). BDP2 was produced in consultation with all MRC member countries in order to evaluate the effects of water-related development on socio-economic and environmental outcomes, as well as their tradeoffs (Mekong River Commission, 2011).

The report presents and assesses a range of dam development scenarios for comparison, ranging from a "baseline situation" (BS) to "long-term future scenarios" that attempt to peer 50 years into the future (2060). This summary focuses on BDP2's assessment of the effects up to 2030 of a 20-year plan that includes all 11 proposed mainstream LMB dams, 30 proposed tributary dams (56 total tributary dams), and the effects of climate change. The scenario's impacts are compared to the BS's hydrological (1985–2000), economic (2008–09), environmental and social conditions. The report does not make recommendations or position itself as a decision-making tool for specific development projects. Rather, it is intended to be used as a tool for big picture discussions among MRC member countries around the LMB development scenarios.

Drawing on the MRC's draft "Assessment Methodology" (2009), the BDP2's assessment aggregates 74 parameters to evaluate 42 different criteria. It responds to 12 development objectives "established under the IWRM-based BDP assessment framework for economic, environmental, social and equitable development as being most pertinent for examining the relative performance of each scenario" [Ibid, 16]. For the purposes of comparison, the assessment assigns an economic net present value (NPV) to various effects (e.g., hydropower generation, decline of capture fisheries) and examines the incremental impacts relative to the BS. However, not all effects—most notably the significant social effects (e.g., over 4.3 million threatened livelihoods)—are assigned a net present value.

3.1.4 | Socio-economic effects

The anticipated economic benefits of the 20 years plan that includes all 11 mainstream dams are significant, with a positive projected economic value of NPV $33.404 billion. Nearly all of those economic benefits (NPV $32.823 billion) are attributable to the anticipated 26.424 MW of hydropower generated. Hydropower development also accounts for roughly 81% of the 20 years plan's total investment cost of $63.7 billion [Ibid, 76]. Within this scenario, Lao PDR—home to most of the new and proposed dams—is expected to be both the largest investor ($30.872 billion) and the main economic beneficiary (NPV $22.604 billion) [Ibid, 77–78]. Other significant economic benefits anticipated within this scenario include expanded irrigated agriculture (NPV $1.659 billion) and aquaculture (NPV $1.261 billion), though the benefits of expanded aquaculture are more than offset by the dramatic decline in capture fisheries (NPV $-1.936 billion). Vietnam and Cambodia stand to experience the fewest economic benefits—NPV $3.727 billion and $2.628 billion, respectively [Ibid, 78]—and the greatest social and environmental harms in this scenario (see below).

Many of the 20 years plan's anticipated "severely negative" social impacts stem from these environmental impacts, most notably altered flow regimes and the depletion of capture fisheries. For example, the massive decline in capture fisheries, especially in Cambodia (40–57%) and Vietnam (36–43%) [Ibid, 58], means a critical reduction of an abundant and widely accessible source of protein and income. The growth of aquaculture is unlikely to fully offset the loss of production from capture fisheries. Cambodia will experience the largest deficit, though both Thailand and Laos will also experience deficits. However, even in Vietnam, where aquaculture is expected to offset the decline in capture fisheries in terms of overall production, distributional considerations arise, as those who depend on capture fisheries for their livelihoods and food security are unlikely to be the primary beneficiaries of aquaculture expansion.

While the construction and operation of the 11 mainstream dams and additional 30 tributary dams—along with associated developments in aquaculture, reservoir fisheries, and irrigated agriculture—in the 20 years plan are expected to generate roughly 1.4 million job-years [Ibid, 72], they will also threaten the livelihoods of over 4.3 million people [Ibid, 90]. When comparing the numbers of exposed vulnerable resource users (i.e. those who depend on the river and/or wetlands for their livelihoods and food security, as well as those who stand to be displaced by the dams) with the numbers of jobs created under the 20 years plan, it becomes clear that the number of exposed vulnerable resource users far exceeds the number of jobs created in all countries through at least 2030, with by far the greatest disparities in Cambodia and Vietnam. Furthermore, as the report notes, even in cases where jobs are created, “the nature of the jobs created may not be appropriate for those whose livelihoods are threatened. Thus the current infrastructural investments embodied within the various scenarios may, and most probably do not, offer an immediate solution to the impacts they create on rural livelihoods” [Ibid, 73].

3.1.5 | Environmental impacts

The report predicts that the 11 mainstream dams and 30 additional tributary dams in the 20 years plan would have “a small incremental effect on the basin-scale hydrology,” but potentially “large significant impacts locally and near contiguously along most of the LMB mainstream between Kratie and Chiang Saen, raising water levels in upstream pondage areas and, depending upon their operation, downstream as well” [Ibid, 89]. The mainstream dams, being run-of-river, will not likely change wet season flows significantly, though they are expected to moderately increase dry season flows. Compared to the baseline, the mainstream dams are expected to reduce saline intrusion affected areas by over 300,000 ha, though most of the associated agricultural gains stemming from reduced saltwater intrusion in the delta will be offset by losses due to rising sea levels over the next 20 years [Ibid, 43]. As for the effects of the 11 mainstream dams and tributary dams on the Tonle Sap, the report predicts that “flow reversal remains at about a 13% reduction of volume entering Tonle Sap with a slight increase in the delay of flow reversal occurring to 8 days on average” [Ibid, 89].

The report anticipates that the dams will cause “severely negative” environmental impacts [Ibid, 54] due to a combination of increased pondage and backwater effects, reduced sediment flows, altered river channels, riverbank erosion, loss of habitat (e.g., wetlands, deep pools, and rapids), increased agro-chemical residues (due to agricultural intensification), and near total barriers to fish migrations, among other factors. In addition to causing an estimated 25% basin-wide decline in capture fisheries, the dams will negatively affect at least 23 biodiversity hotspots (14 will be “highly impacted” and 9 will be “moderately impacted”) and will likely cause the extinction of two “flagship” species (the giant catfish and the Irrawaddy dolphin), among others [Ibid, 89]. To be sure, not all anticipated environmental impacts will be negative. For example, the report anticipates that “the 11 LMB mainstream dams would have the potential to reduce the greenhouse gas emissions of the regional power sector by about 50 million tons CO2/year by 2030” (Ibid, xi].

3.2 | Study on the impact of mainstream hydropower on the Mekong River

The report “Study on the Impact of Mainstream Hydropower on the Mekong River”, also known as the “Mekong Delta Study” (MDS), was commissioned by the Ministry of Natural Resources and Environment of the government of Vietnam and prepared by the consulting firms HDR of the United States and DHI of Denmark. The intellectual contribution of the MDS, as compared to other impact assessments, was to focus on the unique human and biophysical conditions characterizing the downstream floodplains of Cambodia and the Mekong Delta of Vietnam. The impact assessment area (IAA), approximately 106,000 km^2, includes 13 and 14 provinces of Vietnam and Cambodia, respectively (DHI & HDR, 2015).

The MDS had the following three main objectives:

1. Develop a comprehensive database on the hydrological, ecological, biophysical, and socio-economic conditions in the LMB that would enable the assessment of the impacts of hydropower projects on the floodplains and Delta region of Cambodia and Vietnam.
2. Assess the various impacts of hydropower projects on downstream human and natural systems.
3. Contribute to achieving a consensus on the impacts of hydropower projects on the Mekong Delta and to determine various avoidance, mitigation, and enhancement measures in partnership with stakeholders.

Finalized in December of 2015 after a 30-month work period and based on internationally accepted assessment standards, the MDS includes analyses of three primary scenarios and four dam development alternatives. Scenario 1 estimates the downstream human and environmental effects of 11 proposed hydropower dams on the mainstream of the Mekong River. Scenario 2 includes the effects of 72 tributary dams planned through 2030 to those effects analyzed in scenario 1, while scenario 3 adds the effects of mainstream water withdrawals. Because the other reports under review here include the effects of tributaries, we will focus on scenario 2 for purposes of comparison. The MDS also models four alternatives in dam development (i.e., development alternatives), varying which and how many of the 11 mainstream dams were built. Each of the modeling iterations above was then compared to two baseline conditions; (1) normal hydrological conditions (year 2007) and (2) dry hydrological conditions including reservoir drawdown to maximize electricity production (year 1998). Unlike some of the other reports reviewed here, the cumulative effects of climate change (but also sea level rise and deforestation) were not considered in the MDS. Furthermore, the report did not assess upstream from the IAA including the likely benefits of flood control, hydropower, and irrigation and their ancillary socio-economic benefits.

The impacts of these scenarios and development alternatives on river flow and flood patterns, sediment and nutrient loading, salinity intrusion, and barrier effects (i.e., impact drivers according to the MDS) were modeled and then assessed for their effects on fisheries, biodiversity, navigation, agriculture, livelihoods, and economics (i.e., resource areas according to the MDS). The primary analytical models used were the (1) Soil and Water Assessment Tool (SWAT), (2) a suite of MIKE models, commercial software developed by DHI, (3) ECOLab (nutrient transport), and (4) the MDS Agri Model (crop yield).

3.3 | Main results of the MDS, scenario 2

3.3.1 | Socio-economic effects

Both the lost productivity in agriculture and particularly in fisheries would negatively affect food security, livelihoods, and social and financial well-being of populations in the floodplains. The losses in the farming and fishing sectors were estimated to be $426 and $250 million USD in Cambodia and Vietnam, respectively, and these losses would be concentrated in specific communes in each country. For example, in the communes of An Giang and Dong Thap of Vietnam, farm incomes were estimated to decline by 28%. In rural households of Cambodia, fishers' incomes were expected to decline by as much as 47%. Due to the substantial losses in productivity in the fisheries sector, the MDS estimates a reduction of 42% in fish consumption to 21 kg/person. Fishers were estimated to reduce their fish catch by 120 kg per person annually.

Losses to agriculture were estimated due to reductions in sedimentation, water quantity and quality, and nutrient loading as well as changes in salinity. Losses in rice and maize production in Vietnam and Cambodia were estimated at 755,000 tons and 63,000 tons, respectively. Qualitatively, the MDS judges these to be relatively low impact results. No impacts were projected for crop area and crop calendar.

3.3.2 | Environmental effects

The MDS results indicate that water flows and levels are affected only modestly in normal hydrological years but greatly during dry season drawdowns. Fluctuations in flows during the dry season are up to 16,000 m^3/s and in water levels up to 2 m within 31 km downstream of the last of the 11 dams. Dry season drawdowns and filling of the reservoirs greatly affect water levels and flow rates in the floodplain and Delta regions. Ten days after drawdown, the MDS estimates a 54 and 36% decrease in water volume at Kratie in Cambodia and Tan Chau in Vietnam, respectively. Dam operations for hydropower could lead to water level fluctuations of 2.31 m at Kratie with dissipating effects downstream to Vietnam.

Sediment deposition would decrease by up to 66% under scenario 2 in the Cambodian and Vietnamese floodplains, adversely affecting biological and agricultural production, increasing stream bank erosion, and decreasing sediment buildup in riparian and coastal areas. Phosphorus and nitrogen loss under Scenario 2 were estimated to be roughly 51% and 58%, respectively. The reduction in sediment deposition was estimated to reduce accretion at river mouths from 4 to 12 m per year, leading to an increase in salinity intrusion, affecting an additional 7,550 km^2 and 1.6 million people in Vietnam under scenario 1 when compared to baseline results. Under scenario 2, however, the MDS estimates a decrease in salinity intrusion due to the effects of water transfer from wet to dry seasons as a result of tributary dams.

The mainstream dams would block the migratory routes of many freshwater fish leading to the near extirpation of whitefish which accounts for 74% of the top 10 commercial fish caught in the region, the extinction of up to 10% of all fish species, and severe declines in remaining fish populations. Capture fisheries would also be affected by nutrient and sediment loss as well as the detrimental effects on spawning and nursery habitats due to reservoir filling. The MDS estimates 614,000 tons of annual loss of all fish (middle of estimated range), 45,000 tons of annual loss of other aquatic organisms (OAA), and 315,000 tons of annual loss of economically important fish in Vietnam and Cambodia under scenario 2. In dollar terms, the loss in inland fisheries in Vietnam was estimated at $580 million USD. Overall, under scenario 2, the MDS report estimates a 50% loss in capture fisheries. Losses in aquaculture were estimated to be minor, because water level and nutrients were not reliant on mainstream flows but rather pumps.

Due to blocked migratory routes, decreases in primary productivity, and loss of riverine habit and coastal wetlands due to a reduction of sediment transport and river bank erosion, an estimated 10% of freshwater fish will be extirpated along with the iconic Irrawaddy dolphin. The report estimates that the distribution and abundance of freshwater mussels would also decrease. Because there was little change in the estimated extent of open-water and floodplain wetlands, there would be negligible loss of dependent wetland species, although coastal wetlands, including mangroves, would be lost in the Mekong Delta. As over one-third of migratory fish species in the region are carnivorous, some changes in fish, mollusk, crustacean, and other aquatic organisms' populations are likely due to changes in top-down control.

3.4 | MRC council study

In November 2011, Prime Ministers of Cambodia, Lao PDR, Thailand and Vietnam met at the third Mekong-Japan Summit in Bali to formulate a sustainable development strategy that enhances benefits and minimizes negative transboundary impacts to all member countries. One month later, the MRC council meeting approved the commission of a comprehensive study to identify the positive and negative impacts of different Mekong River development scenarios for the entire LMB. The CS, published in 2018, took six years to complete and was broader in scope than BDP2. The CS was intended to address BDP2 shortcomings (e.g., the modeling of hydropower impacts on fish, food security, sediment and ecosystems)—the previous development space that defined narrowly around hydropower development and methodological shortcomings in assessing environmental changes. The CS study had the following main objectives (Mekong River Commission, 2018b):

1. To study the positive and negative impacts of water resource developments in the LMB;
2. To integrate the results into the MRC knowledge base and enhance the Basin Development Planning process; and
3. To promote capacity building and to ensure technology transfer to Member Countries.

The main development scenarios of the report (M1, M2, and M3) identifies different combinations of investments in multiple sectors, including hydropower, agriculture and irrigation, flood protection, and navigation.

The baseline scenario, M1, was identified as the year 2007. The Definite Future Scenario, M2, includes all existing, under-construction, and firmly committed development in the six thematic sectors expected to be in place by 2020. The planned 2040 Development Scenario, M3, included 11 mainstream dams (6 in upper Lao PDR including Xayaburi, Pak Beng and Pak Lay, 3 in lower Lao PDR including Don Sahong, and 2 in Cambodia and 129 tributary dams (98 in Lao PDR, 14 in Vietnam, 11 in Cambodia and 6 in Thailand), while the M3CC scenario, similar to M3, additionally forecasts the impacts of climate change. Thirteen subscenarios were defined to assess sector-specific variations. Consulting with regional working groups, national organizations, and regional stakeholder forums, thematic teams of technical experts were formed to study and report on the following impacts: hydropower, flood protection, domestic and Industrial water use, agricultural land use, irrigation and navigation. Multidisciplinary teams were formed to review and report on hydrology, bio-resources, socio-economics, macroeconomics and climate change. In addition, the results of the thematic reports and multidiscipline reports were combined into a cumulative impact assessment (CIA) and Key Findings report. The macroeconomic assessment covers impacts on the entire LMB, while other sector assessments limit their scope to a 15 km corridor on both sides of the Mekong mainstream, the Tonle Sap in Cambodia and the Mekong Delta in Vietnam. This review will only look at the effect of the full development scenario with climate change consideration (M3CC-M1).

The macroeconomic assessment was structured into three tiers. First, NPV was calculated at the sector level focusing on agriculture, hydropower, fisheries, and navigation. Second, the sector effects were combined to assess impacts on Gross Domestic Product (GDP) for LMB countries. A third tier included the wider socio-ecological systems to assess the long-term natural resource viability and integrity of development strategies.

3.5 | M3CC scenario thematic reports

3.5.1 | Socio-economic effects

The report indicates a NPV of $154.1 billion (annual benefit of $ 9,396.1 million) in the hydropower sector when compared to the baseline M1 scenario. All LMB countries would benefit from hydropower development (Lao PDR NPV—$36.7 billion, Cambodia NPV—$11.9 billion, and Vietnam NPV—$25 billion) with Thailand being the main beneficiary (NPV—$80.5 billion). The total NPV of the existing plus the planned dams is estimated at $163.1 billion. In other words, if none of the hydropower dams including existing, under construction, and planned dams were developed and no alternate electricity generation implemented, the energy sector income would drop by 21.5% in Lao PDR, 26.3% in Thailand. 32.8% in Cambodia, and 48.8% in Vietnam.

Flood control infrastructure is not included in the main scenario. According to the subscenario, however, the economic benefits of flood control infrastructure, mainly in Thailand and Cambodia, are positive, with an additional NPV of $1.3 billion across the LMB for M3CC scenario. The benefit estimated for Cambodia and Vietnam were more than for Lao PDR and Thailand. These benefits are mainly linked to the expected increase in assets of a growing population combined with increasing flood exposure for the M3CC scenario.

Rapid industrial growth and urbanization will increase water demand and increase pollution of rivers and water bodies. Industrial parks in the Vietnam delta are estimated to be the source of 76.6% of M3 industrial wastewater, estimated to increase across the LMB by 170% in the M3 scenario compared to the M1 baseline. The estimated M3 levels of total nitrogen and phosphorous are estimated to exceed the MRC safe water guidelines for the protection of human health.

Under M3CC, the NPV of the agriculture sector is predicted to increase by $103.5 billion when compared to M1 with an estimated annual benefit of $ 6,410 million. The gains would occur mostly in Thailand (NPV of $158.9 billion), Cambodia (NPV of $129.5 billion), Vietnam (NPV of $125.0 billion), and Lao PDR (NPV of $48.2 billion). It is noted that the total benefits to the agriculture sector far outweigh those in hydropower (NPV of $163.1 billion), fisheries (NPV of $68.8 billion), and navigation (NPV of $68.9 billion). However, agricultural expansion would involve substantial deforestation in Lao PDR and Cambodia and be constrained by higher labor demands.

Irrigation expansion is expected to increase mainly in Lao PDR, Cambodia and to a lesser extent Thailand, to 10,854,849 ha under 2040 planned development scenario (M3 cc) compared to 7,241,829 ha under the M1 baseline. This will improve food production substantially but will require considerable infrastructure investment, mechanization and entail higher labor demand. Despite high investment costs, the total NPV of irrigation expansion is likely to be $19.8 billion (Irrigation thematic report page 102), increasing by $9.6 billion in Thailand, $7.5 billion in Cambodia, and $5.9 billion in Lao PDR (Irrigation thematic report table 20 page 102) while decreasing by $3.1 billion in Vietnam, indicating higher expected costs than benefits. Due to an expected increase in water depth allowing the passage of larger ships, the report forecasts a total benefit of $68.9 billion NPV to the region with the largest gain of $ 55.5 billion in Vietnam. In contrast, Cambodia would see a gain of only $8.5 billion NPV.

3.6 | M3CC scenario disciplinary reports

3.6.1 | Socio-economic effects

Social data at district/provincial levels were analyzed within the 15 km corridor to forecast development with and without hydropower. Undernourishment (measured as nutritional food security and child stunting) in the M3 scenario was estimated to increase, especially in Lao PDR and Cambodia, primarily a result of reduced fish catch. Additional labor associated with population growth was assigned to secondary and tertiary sector employment under M1. The shift from secondary and tertiary sector employment to lower paying agriculture to meet agricultural expansion labor demands resulted in poverty levels (percentage of population below national poverty lines) in Lao PDR and Cambodia estimated to increase by 15–20% under the M3 scenario compared to M1 poverty levels.

3.6.2 | Environmental effects

Dry season flow would increase (opportunity for irrigation expansion) and wet season flow would decrease (due to reduced flood damage). Long stretches of the Mekong River from Chiang Saen to Kratie are expected to become lake-like habitats, which are unsuitable for many current fish species.

The combination of reservoirs and dams (blocking fish migration) would cause a 30–40% decrease in Mekong fisheries or 1 million tons/year) under the M3 scenario and a decline of $21.7 billion NPV in the fishery sector. Estimates of fish production is higher when compared to prior studies because the modeling of fish stocks under the CS predicts a substantial expansion of generalists species including non-native species, as migratory fish species disappear and reservoirs create more habitat for generalists. While this ecological shift compensates for losses in fish biomass affecting food security, there are substantial losses in fish biodiversity. However, under the baseline, the combined fishery sector in Mekong basin could generate up to $70.6 billion without any dam in place.

With climate change, the hydrological cycle is expected to undergo significant change. This will result in the wet season river flow increasing slightly due to increased precipitation.

The CS arrives at several main conclusions. Under the M3CC scenarios, there are likely declines in the resilience, vulnerability and sustainability of communities in the LMB. Whitefish, for example, will be lost in most of the Mekong River which will negatively impact food and nutritional security and poverty for riparian communities. Further affecting food security, surplus production (i.e., the economic value of production after food security needs have been met for 100% of the regional population) of rice, fish and livestock under scenario M3 declined by US 4.1 billion. Half of the forecast economic growth is from hydropower but this causes greater negative impacts on other sectors, negatively affecting future growth potential. For example, sediment and nutrient loads are expected to be reduced by 97% for M3CC scenario. This will result in reduced soil fertility, rice production and fish yields especially in the Cambodia floodplains, Tonle Sap and the Mekong delta. Moreover, the economic benefits from hydropower are not distributed equitably between or within member countries and much profit will accrue to foreign companies and banks. Total household incomes are expected to decline by $589 million across the corridor zones compared to the baseline. Environmentally, the decrease in NPV of natural resources is predicted to be $110 billion largely due to deforestation although reforestation plans, particularly in Cambodia, could reverse the declining trends in natural resources. Extensive bank and river bed erosion is expected, especially along the Mekong River from Vientiane to Stung Treng and in Vietnam's Mekong Delta.

The CS suggests that a possible solution to minimize the trade-off between hydropower and fisheries is to impose a 19% levy on annual profit of mainstream dams and 9% levy on tributary dams to fishery households. The levies represent the proportion of hydropower profits required to compensate downstream fish related losses and degraded riparian ecosystem services estimated using a bespoke ecosystem valuation tool (Mekong Region Futures Institute, 2015).

The CS also notes that sustainable water resource development in the LMB (the main objective of the MRC 1995 Agreement) will not be achieved with unilateral investment decisions of Member Countries.

4 | DISCUSSION

While hydropower revenue estimates are simply the amount of projected electricity sales multiplied by the expected price, our summary found a wide range of estimated annual benefits from $3 billion (SEA) to $9.4 billion (CS). The variation in estimated benefits is likely the result of different assumptions regarding power gate prices, export prices, capital costs, adjustment factors to account for hydropower efficiency, resettlement costs, environmental mitigation costs, power revenues and trading models and tariffs negotiated by different power purchasing agreement, installed capacity, electricity exported, peak hour output, amount of exported power, annual operation and maintenance costs and taxes, and royalties. Similarly, the estimated impacts of hydropower development on navigation showed wide variation as negligible (MDS—Cambodian and Vietnamese floodplains), $10 million (BDP2), and $5 billion (CS).

The impacts of hydropower development on social systems (i.e., resettlement, livelihoods, and food security) are major concerns in all reports, although gaps in knowledge remain, especially in the framing of these types of trade-offs in economic terms. Setting aside the critical question of whether it is possible to assign a monetary value to such things as home, community, culture, identity, attachment to land, local knowledge, and food and livelihood security, among others, when such values are left out of economic impact assessments, the result is a highly skewed picture of both the net impacts of dam development and the distribution of benefits and burdens. There is some agreement, however, that reductions in sediments (59–66% under MDS and 75% under SEA) and nutrients (P loss of 51% and N loss of 50% under MDS) pose profound problems for downstream agriculture and fisheries. In the agricultural sector, the value of new irrigated agriculture is estimated at $15.5 (SEA), $270 (BDP2), and $1,228.3 (CS) million, respectively. The MDS, however, reports productivity losses of rice and maize in downstream floodplains. Moreover, SEA estimates the cost of nutrient replacement of $24 million annually.

In capture fisheries in particular, all reports estimate dramatic declines in productivity but with considerable variation (−$476 million under SEA to −$3 billion under BDP2), which can be explained in part by different assumptions regarding fish prices (e.g., BDP2 $0.80/kg, SEA $0.68/kg), impacts to capture fisheries (−25% for BDP2, −50% in MDS, −40–80% in CS), efficiency of fish passage, and adaptation of fish species to new environments. To some extent, the net economic losses in capture fisheries may be compensated for by gains in aquaculture. BDP2 estimates annual gains of $212 million in aquaculture while the MDS estimates no effects on aquaculture in the Cambodian and Vietnamese floodplains. However, the economic benefits and protein produced from increased aquaculture will likely not accrue to those most negatively affected by declines in capture fisheries—in other words, those vulnerable resource users who depend on capture fisheries for their livelihoods and food security. Productivity effects in agriculture and fisheries can affect food security. For instance, the MDS estimates a loss in fish consumption in Cambodia of 21 kg/person/year and in fish catch of 120 kg/fisher/year although previous estimates suggest annual per capita fish consumption for Tonle Sap fishers at 61 to 87 kg/fisher/year (Hall & Bouapao, 2010b; Hortle KGaB, 2015).

Collectively, the reports identify methodological and knowledge gaps in the valuation of natural resources, ecological processes and functions, and ecosystem services, commonly contested, ever evolving, and rarely representative of the local context. BDP2, for example, assumed the value of wetland loss at $2,000 per hectare for seasonal flooded forest and $1,000 per hectare for marshes, lakes and ponds. While global estimates of the value of wetland ecosystem services from $3,300 to $25,680/ha/year (De Groot, Stuip, Finlayson, & Davidson, 2006), in Southeast Asia, a meta-analysis of wetlands and mangrove ecosystem services estimated this value at $4,185/ha/year (Brander et al., 2012). Other estimates from Southeast Asia range between $9,613 and $15,646/ha/year (Mekong Region Futures Institute, 2015). The reports summarized here provide a range of estimates for the impacts on wetlands and other natural capital from a loss of $7.3 billion to a benefit of $16 million (BDP2). The MDS notes large knowledge gaps in understanding the effects of hydropower development on ecosystems and recommends improvement in biological and ecological inventories as well as our understanding of habitat use, seasonal movements and migratory behaviors, the effects of aquaculture on wild species, genetic studies on population structure and therefore vulnerability, the effects of sediment and nutrient loading changes, and the effects of a loss or reduction in aquatic species on ecosystem productivity and composition. Only the SEA and CS reports provide an economic estimate of changes to biodiversity. None of the reports estimate changes in carbon storage or sequestration, water purification and groundwater recharge, waste assimilation, timber, nontimber forest products as well as ecosystem services related to recreational, cultural, spiritual, and aesthetic values of natural resource loss.

5 | CONCLUSION

In this paper, we provide a summary of four major impact assessments of hydropower development in the LMB. The four reports were published between the years 2010 and 2018 with each providing a partial rationale and limited reference to previous reports to justify subsequent analysis. Three of the reports (BDP2, SEA, CS) were initiated by the MRC. The findings and recommendations of SEA were not endorsed by all MRC member countries and not taken into account in BDP2. The CS, seemingly recognizing the possibility of duplicative efforts, notes the prior efforts of SEA and MDS but does not distinguish those from its own. If anything, the authors concede their similarity (i.e., understanding the social and environmental impacts of ongoing and planned hydropower development on the mainstream of the Lower Mekong River). Published earliest of the four reports, the SEA notes that it "supports the wider Basin Development Planning (BDP) process by complementing the MRC BDP assessment of basin-wide development scenarios with more in-depth analysis of power related [sic] and cross-sector development opportunities and risks of the proposed mainstream projects in the lower Basin." Further details of what is meant by "more in-depth analysis" is absent from the report. Perhaps the clearest explanation for distinctiveness among the reports was given by the MDS, arguing that the efforts under BDP2 and SEA were not appropriate to understand the specific context (i.e., local water infrastructure, marine and coastal conditions, dense and more urban populations, extensive agriculture) of the Cambodian floodplains and Vietnamese Delta regions. The MDS and CS are further distinguished by being the only two of the four to report social and environmental impacts largely in noneconomic terms. It is noteworthy that while the general analytical scope of these four reports is similar, their more technical and methodological choices, often opaque, make them largely incommensurable.

All four reports address the substantial economic and environmental trade-offs associated with hydropower development though the magnitude and absolute values of such tradeoffs vary. Social trade-offs are acknowledged, though not quantified to the same degree. Ecological, economic and social trade-offs associated with the expansion of irrigated agriculture are emphasized in the CS, the MDS, and to a lesser extent the BDP2 and SEA.

One might assume that the lack of standardization in temporal and spatial scales, scenario choice, model parameters and assumptions, and units of reported outcomes are explained by the need to address existing uncertainties, improve upon current methodologies, respond to newer or better data, or elaborate on prior analyses. Undoubtedly, there is some truth to this. However, these distinctions are not specified in detail and in no case are outcomes compared or explained in terms of those of prior efforts as might be expected in other scholarly work. In other words, the assessments are not in conversation with each other. Evaluating the soundness of these reports' analyses or whether they met their respective objectives is beyond the scope of this paper. However, it seems clear that there were missed opportunities in generating knowledge through the consolidation and comparison of insights and results of each subsequent assessment. As such, critical questions arise: What motivates the generation of each report? And, of what real use to policymakers and decision-makers is this collection of similarly framed, methodologically diverse, partially detailed, and often conflicting analyses?

Some understanding of the political and economic changes in the region offers a few suggestions. The MRC facilitates the joint management of water resources and sustainable development of the Mekong River for the countries of Cambodia, Lao PDR, Thailand, and Vietnam, each varying geographically and hydrologically within the LMB, with competing interests, different politics and economic objectives, and thus facing different futures with the development of the LMB. The MRC is one example of an increasingly more polycentric approach to governance of the Mekong. Compared to when the Mekong Committee was first established in 1957, the geopolitics of the region is less state-centric and increasingly includes the private sector, NGOs, IGOs, regional powers, and diverse representation from other parts of civil society including rural, urban, ethnic minority, and ethnic majority groups. The compendium of assessments, therefore, may represent the unique and diverse concerns of a broadening stakeholder group. Second, while the influence of the U.S. has waned in the region, China's influence has strengthened. In comparison with the Mekong Committee, the Greater Mekong Subregion (GMS), established by the Asian Development Bank in 1992, included Myanmar and China and emphasized the construction of large infrastructure to support trade and economic integration rather than broad sustainable development goals (Hirsch, 2016). China's Belt and Road Initiative is but one recent example of the historical role of regional banks in financing infrastructure being supplanted by national banks, private entities, and private/public partnerships. While the MRC's Procedure for Notification, Prior Consultation and Agreement (PNPCA) requires prior consultation with member countries for any proposed water use with transboundary effects (Grumbine et al., 2012), greater autonomy in financing infrastructure could lead to a more incremental, less consultative approach to infrastructure development and therefore assessment that is strategically motivated by the interests of particular stakeholders. Third, economic disparities between MRC member states have grown in the past several decades since cooperation on the development of the LMB first began. Whereas growth in GDP, electricity consumption, and energy use in Thailand and Vietnam has far outstripped that in Cambodia and Laos, agriculture, as a proportion of GDP, while declining in all four countries, is greater in Cambodia and Laos. With such differences, it is perhaps no surprise that objectives for hydropower development might vary among the four LMB countries along with their evaluation of basin-wide projects. Subsequently, absent from all reports are clearly specified development objectives (e.g., Sustainable Development Goals [SDGs]) as well as a determination of how the modeled scenarios might contribute to meeting those objectives. In summary, while the upstream/downstream dynamics provide ongoing challenges to cooperation among the four member countries of the MRC, a shared understanding of mutual interest and common futures is further complicated by the multiplicity of contesting stakeholders, greater opportunities for financing large infrastructure, increasing disparities among member countries, and a lack of consensus on basin-wide development objectives and strategies.

Our summary of four impact assessments of mainstream hydropower development on the LMB points out the need for clearer international standards in developing more inclusive, participatory processes for establishing development objectives, corresponding articulation of scenario assumptions, methodology, reporting, and impact assessment. While large, intergovernmental institutions like the World Bank and regional banks have made progress in standardizing their own internal procedures and in improving transparency, there are few widely accepted, internationally recognized standards. The problem is likely to become more acute as development objectives and local realities within and between MRC countries diverge, and as nontraditional lenders exert increasing influence in the region's push for large infrastructure developments.

Synoptic representations of costs and benefits of large-scale development agendas can be valuable tools for planners and decision-makers, as they can bring certain aspects of a complex constellation of interacting factors into relief. However, cumulative impact assessments such as those discussed in this paper simply cannot account for the diversity and unevenness of local experiences with dam development or the host of interacting social and environmental effects that do not easily lend themselves to quantification. For example, while the BDP2 estimates that 4.3 million livelihoods will be directly threatened under the 20-year plan, such an estimate tells us little about whether and how those whose livelihoods are threatened will also experience threats to their homes, health, household and community wellbeing, culturally-significant practices and relationships to place, etc. While there is some acknowledgment in the reports that benefits and burdens will be distributed unevenly, the nature and extent of such disparities remain largely unexamined and feature minimally in the aggregate accounting of costs and benefits. Furthermore, cumulative impact assessments fail to account for the effects of cross-sectoral interactions of large infrastructure and natural resource management projects, such as those between dam development and the large-scale industrial tree plantations in Laos and Cambodia, which can significantly affect the vulnerability and responses of local populations (Baird & Barney, 2017). Collectively, these limitations of cumulative impact assessments suggest the need to fundamentally reexamine their utility as currently conceived as well as their methods of knowledge procurement, assessment, and reporting to make them more meaningful to policy makers and representative of the concerns of the broad constituency of people affected by hydropower development.

ACKNOWLEDGMENTS

This work was supported by grants to Michigan State University from NASA's LCLUC program (Award # 80NSSC18K1134) and IDS program (Award # 80NSSC17K0259). This study contributes to the Global Land Programme (glp.earth) and Future Earth (http://www.futureearth.org/).

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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How to cite this article: Intralawan A, Smajgl A, McConnell W, Ahlquist DB, Ward J, Kramer DB. Reviewing benefits and costs of hydropower development evidence from the Lower Mekong River Basin. *WIREs Water*. 2019;6:e1347. https://doi.org/10.1002/wat2.1347