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Tradeoff analysis between electricity generation and ecosystem services in the Lower Mekong Basin

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ABSTRACT

The Mekong River is the largest freshwater fishery and the third most bio-diverse river system in the world. Two of 11 planned mainstream hydropower projects, Xayaburi and Don Sahong, are nearly completed and a third project proposal, Pak Beng, has been submitted by the Lao PDR government for consideration. This paper builds on previous studies and examines the tradeoffs (between water use, food security supply and energy production) for the proposed mainstream hydropower projects in the Lower Mekong Basin (LMB).

The paper concludes that the forecast loss of capture fisheries, sediment/nutrients and social mitigation costs measured as Net Present Value (NPV at 10% discount rate) are greater than the benefits from electricity generation, improved irrigation and flood control. The paper also forecasts huge negative economic impacts for Cambodia and Vietnam in contrast to previous Mekong River Commission's (MRC) conclusions that all countries will benefit from hydropower development.

The paper recommends reassessing the economic impacts of hydropower development using full environmental cost accounting. It also recommends that a new LMB energy strategy be developed taking into account less hydropower income than previously anticipated, updated forecasts for LMB power demand and anticipated technology developments for improved energy efficiency & renewable energy (especially solar which is now competitive with hydropower).

1. Introduction

The Mekong River is the largest freshwater fishery in the world (Ziv et al., 2012). The estimated fish catch is approximately 2.0–2.6 million tons/year (Van Zalinge et al., 2004; Baran, 2010a,b; Mekong River Commission, 2010a; Mekong River Commission, 2011; An, 2015; Hortle, 2015; Nam, 2015; Lynch et al., 2016). It is the third most bio-diverse river system with nearly 800 fish species after the Amazon and Congo rivers (Dudgeon et al., 2006; Mekong River Commission 2010b; Winemiller et al., 2016). The estimated fish catch does not include another 0.5–0.7 million/tons of Vietnam coastal fishery, about 2 million ton/year of aquaculture and about 0.5 million tons/year of other aquatic animals which are all dependent on the intact ecosystem processes and functions (ICEM, 2010; Mekong River Commission, 2010a,b,c; Nam et al., 2015). The inter-seasonal variation on water level fluctuation and flooded area influenced by the southwest monsoon – about 1 meter in the dry season to roughly 10 m in the wet season – is the main driver of the productivity of the river (Kummu et al., 2014; Welcomme et al. 2016). The annual variation of the great lake and Tonle Sap area, for example, expand from 2200 in the dry months to 13,250 km^2 during the peak season. It is presently a home to about 70 million people – half of this population lives within a 15 km corridor and their livelihoods are closely linked to the Mekong River (Hall and Bouapao, 2010). Fish is the major source of protein for the local people accounting for 49–82% of animal protein consumed (Orr et al., 2012; Piesse, 2016; Pittock et al., 2016).

Like many other great rivers in the world, the Mekong River Basin is currently undergoing massive hydropower development. In the Upper Mekong-Lancang Jiang, six projects have been completed and have significantly altered the water flow at Chiang Saen, Thailand (Lu et al., 2014). For the Lower Mekong Basin, two of the 11 planned mainstream projects, Xayaburi and Don Sahong Dams are nearly completed. A proposal for a third dam, Pak Beng, has been submitted to Mekong River Commission (MRC) for

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consideration by the Lao PDR government and construction is expected to start later this year (2018).

Hydropower development would bring electricity generation, increased irrigated area and reduction of flood and drought which will considerably benefit the economies of LMB countries. However, the proposed hydropower projects would also cause major changes to the river hydrology, capture fisheries and sediment/nutrients dynamics which would adversely affect the productivity of Tonle Sap and the floodplains in Cambodia and the Vietnam Delta coastal zone (Kummu and Varis, 2007; Kummu and Sarkkula, 2008; Kondolf et al., 2014). Furthermore, the planned projects would alter aquatic ecosystems effecting the processes and functions of the ecosystem critical to sustainable human well-being. Under the foreseeable future situation with eleven mainstream dams plus 30 dams planned on the tributaries scenario, it is expected that the dry season flow will increase and the flood season flow will be reduced. This will result in severe impacts including lost biodiversity, environmental hotspots, and risk of extinction of Giant Catfish and Irrawaddy Dolphin. It is recognized that capture fisheries will decline substantially unless new developments in fish passage facilities are provided.

However, the best available fish passage technology which can handle the huge volume of tropical fish migration—up to 34 tons of fish per hour or about 3 million fish per hour at peak migration near Tonle Sap—has yet to be tested and remains a speculation (Dugan, 2008; Kang et al., 2009; Baran, 2010a,b; Baumann and Stevanella, 2012; Schmutz and Mielach, 2015).

2. Materials and methods

Development of the Mekong River Basin has been a decades-long dream. In early 1950s, the Bureau of Flood Control of the United Nations Economic Commission for Asia and the Far East (ECAFE) suggested development of the basin's great potential for hydropower generation and irrigated agricultural production. It also suggested development coordination among four riparian countries, Thailand, Lao PDR, Cambodia and Vietnam (Bakker, 1999; Jacobs, 1999). Due to the political instability in the region, it was not until 1995 that the new era of Mekong cooperation was revitalized. The LMB countries now agreed to '*cooperate in all fields of sustainable development, utilization, management and conservation of the water and related resources of the Mekong River Basin*...'. The Basin Development Plan (BDP) is seen as a tool '*to identify, categorize and prioritize the projects and programs to seek assistance for and to implement at the basin level*' (Mekong River Commission, 2013). BDP1 (2001–2006) laid the foundation for LMB coordination and brought country level institutions and staffs together to analyze and formulate development plans and projects put forward by individual LMB countries. BDP2 (2007–2011) took a comprehensive view of national and sub-basin water related developments. Different scenarios which provide a range of plausible future developments were constructed and assessed against economic, environmental, and social criteria totaling 12 development objectives and 42 criteria. The objectives derived from the individual country's concerns of each water resources development ranged from increases in irrigated agricultural production, hydropower production, improved navigation, decreased flood and drought damages, maintain productivity of fishery sector to maintain environmental protection, social development and social equity issues. According to the BDP2 evaluation of economic costs and benefits for all scenarios, "the analysis clearly demonstrates the overwhelming economic significance of hydropower within the different developments under consideration ... and Lao PDR (as the largest investor and power generator) gains the most economic benefits in all development scenarios". (Mekong River Commission, 2011).

Following the publication of Basin Development Plan Phase 2—Assessment of Basin-wide Development Scenarios (BDP2), Costanza et al., (2011) analyzed the BDP2 conclusions and argued that by changing some key assumptions such as fish prices, value of the wetlands, along with using a lower discount rate with an infinite time horizon for natural capital, the Net Present Value of hydropower development would become negative. More thorough assessment of the ecosystem services value and better treatment of distribution of cost and benefits among stakeholder groups and with the future generation were recommended (Kubiszewski et al., 2013). At present, MRC is conducting another study on Sustainable Management and Development of the Mekong River—the Council Study to fill the knowledge gap of major development in the LMB countries.

This study builds on previous assessments of basin-wide scenarios (Costanza et al., 2011; Kubiszewski et al., 2013; Intralawan et al., 2015). It also updated some inputs including electricity price, loss of capture fisheries, fish price, hydropower project data, values of wetlands, sediment loss and social and environmental mitigation costs. The study followed the international practice of economic evaluation method and MRC methodology on Initiative on Sustainable Hydropower Guidelines for the Evaluation of Hydropower and Multi-Purpose Project Portfolios (Mekong River Commission, 2015).

2.1. Scenario

A scenario is a plausible set of possible outcomes in the future which may be used as a frame of reference for project evaluations. BDP2 developed several scenarios for development of the Lower Mekong Basin based on plans put forward by each country. The scenarios formulated in BDP2 were based on individual country water related development plans and are summarized below:

1. Definite Future Situation (DFS) refers to the cumulative impact assessment of water-related developments occurred up to 2015 including dams on the Lancang and 26 tributary reservoir development in the LMB.
2. Foreseeable Future Situation (FFS) refers to the transboundary impact assessment of water resources development plans including 1.6 million hectare irrigation expansion and 30 planned tributary dam plus 11 planned mainstream dams up to 2030.
3. Long-term Future Situation (LFS) refer to the impact assessment of water resources development up to 2050.

This study focused on the second scenario (FFS which is comprised of 11 Lower Mekong mainstream dams (nine in Lao PDR and two in Cambodia) plus 30 dams planned on the tributaries) as FFS was considered to be a more realistic future scenario and the third scenario (LFS) was considered too speculative. The total capital investment for FFS is approximately US$ 50 billion in 2017 prices (Fig. 1). However, the actual investment cost could be higher due to higher standards and safeguards recognized as essential to achieve sustainable development. This study also focused on the FSS scenario in order to allow comparison with BDP2. Furthermore, this tradeoff exercise is intended to raise awareness, promote a dialogue platform for various stakeholders, and provide detailed analysis in order to achieve a more balanced development with the objectives of economic efficiency, social justice and ecological sustainability.

2.2. Economic analysis

The economic calculations in this study are similar to methods described in Sustainable Management and Development of the

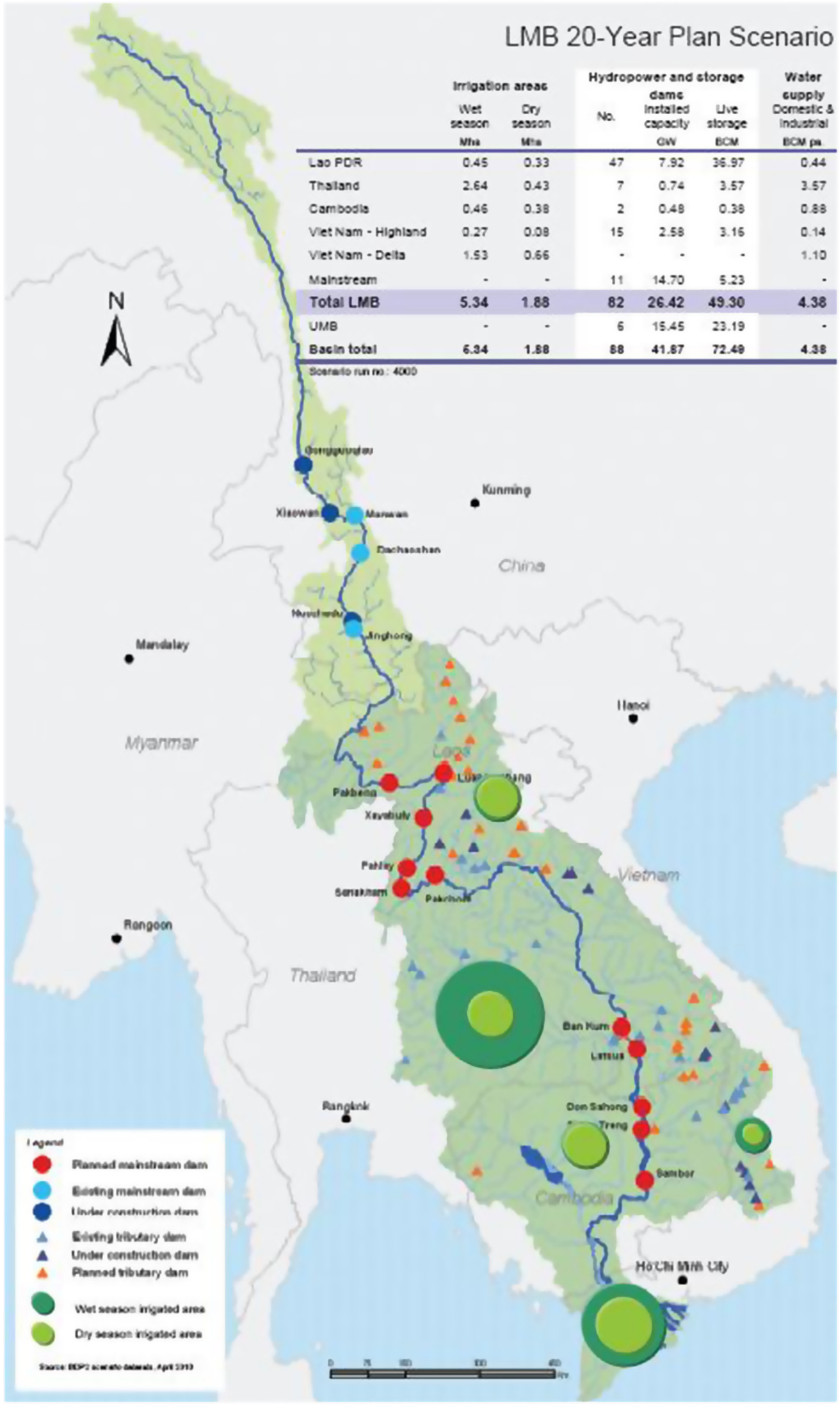


Fig. 1. Location of the 30 planned tributary dam plus 11 planned mainstream dams (from Mekong River Commission, 2011).

Mekong River—the Council Study and the hydropower economic evaluation manuals (International Renewable Energy Agency, 2012; International Finance Corporation, 2015; Mekong River Commission, 2015). Direct and indirect benefits and costs of hydropower development were identified, quantified, estimated and internalized to Net Present Values using the same discount rate of 10% and financial evaluation period of 50 years as BDP2 with economic inputs adjusted to 2016 prices using World Bank inflation data (The World Bank, 2015). Assumptions for economic evaluation are included in Table 2. It is recognized that the economic calculations in this study are based on many assumptions with varying degrees of uncertainty in the input data. However, this study used a best case scenario of conservative data to assess mainly three important factors in this evaluation – (hydropower generation benefits, capture fisheries loss and sediment/nutrients loss) which had the largest economic impacts. Sensitivity calculations were also carried out for these three factors. This study also estimated social mitigation costs which were excluded from the BDP2 economic assessment and revised the BPD2 environment mitigation cost which seemed to be underestimated.

2.3. Hydropower generation

As shown in Table 1, the total capacity of the 11 planned mainstream projects is approximately 13,000 MW capable of producing 65,000 GWh which would provide about 6–8% of forecast LMB power demand in the year 2030 (Intelligent Energy Systems Pty Ltd (IES) and Mekong Economics (MKE), 2016). About 90% of the electricity from these projects would be exported to Thailand and Vietnam which account for the bulk of LMB power demand (Piseth and Sophearin, 2014). The additional capacity of 30 planned tributary dams is about 10,100 MW which would produce an additional 44,000 GWh. The total capital investment for 11 mainstream dams plus tributary projects is projected to be $ 50 billion.

2.4. Project construction

A project construction time of six years is assumed for mainstream projects based on experience from major tributary projects and ongoing construction of the Xayaburi dam. It is assumed that the other mainstream projects would start by 2030 in line with the BDP2 scenario.

2.5. Electricity price

The price used in the NPV calculations is the electricity price available at the site of electricity generation. This price is paid by the electricity company (either domestic or foreign importer) and does not take into account any capital investment or operating costs for electricity transmission and distribution in the importing country. Electricity prices vary due to different electricity markets. To simplify this evaluation, an electricity price of $ 0.07/kwh for all mainstream dams and tributary dams (during the concession period) was used based on recent electricity sales agreements adjusted to 2016 prices. Following the concession period, an electricity price of $ 0.05/kwh was assumed. If all 11 planned mainstream projects were built, it is estimated that 9% of the total electricity generation would be supplied to Lao PDR, 57% to Thailand, 4% to Cambodia and 30% to Vietnam.

2.6. Operating & maintenance

This study assumed an annual operating and maintenance cost equivalent to 1.5% of capital investment based on recent experience with major current Mekong tributary hydropower projects. Based on personal communication with Mekong hydropower experts who prefer to remain anonymous, it is assumed that a capital injection of 10% initial capital investment will be required (to pay for major equipment overhaul following 25 years project operation) and annual operating and maintenance cost will increase to 2% capital investment following the concession period.

2.7. Allocation of benefits from hydropower operations

A benefit split of 30% for the host country (i.e., country where the dam will be built which receives an equity share of profit plus royalty plus tax) and 70% for the country funding the project and/or importing the electricity was assumed for the 25–30 year concession period. This is based on existing large scale hydropower projects where the project owner is 80% Thailand 20% Lao PDR and 90–95% of the electricity will be exported to Thailand. This assumption results in a hydropower benefit split of 23% Lao PDR, 47% Thailand, 5% Cambodia and 25% Vietnam for the 11 dams scenario.

2.8. Electricity import benefit

It is assumed that countries receiving hydropower electricity will benefit from using low cost hydropower instead of electricity generated from natural gas or coal. This cost saving benefit is estimated to be 10–15% of the value of total electricity generation from mainstream and tributary projects and a conservative figure of 10% was assumed in this study based on electricity generation, transmission and distribution data in Thailand (Ruangrong, 2012). The bulk of this benefit accrues to Thailand and Vietnam as they import most of the hydropower electricity.

2.9. Reservoir fisheries

The capacity and storage area of hydropower reservoirs along the Mekong River would increase considerably with more dams, resulting in an increase in reservoir fish catch. This study used the same increase in catch for reservoir fisheries as BDP2 (64,000 tons/year for the 11 dams scenario) and assumed a fish value of $ 2.50/kg based on the current market price.

Table 1
Information of mainstream hydropower in the LMB (adapted from (ICEM, 2010)).

	Capacity (MW)	Electricity generation (GWh)	Villagers to be resettled	Capital investment ($ million)	Electricity market
Pak Beng	912	4846	6700	2400	10% Lao; 90% Thailand
Luang Prabang	1410	7380	12,966	2800	10% Lao; 90% Vietnam
Xayaburi	1285	7500	2130	3700	5% Lao; 95% Thailand
Pak Lay	1320	5948	6129–18,000	2400	10% Lao; 90% Thailand
Sanakham	660	3700	4000	1530	10% Lao; 90% Thailand
Pak Chom	1080	5320	535	2700	10% Lao; 90% Thailand
Ban Khoum	1870	8430	953	4400	10% Lao; 90% Thailand
Lat Sua	650	3500	0	2100	10% Lao; 90% Thailand
Don Sahong	240	1760	66	720	100% Lao
Stung Treng	980	4870	10,000	2000	10% Cambodia; 90% Vietnam
Sambor	2600	11,740	19,000	4900	10% Thailand; 20% Cambodia; 70% Vietnam
Total Mainstream	12,950	64,994	68,350	29,650	
Tributary projects	10,100	44,000		20,600	
Grand Total	23,050	108,994		50,250	

Table 2
Key assumptions for economic evaluation of hydropower in the LMB.

	Calculation Method	Assumption
Hydropower benefit	NPV(10) – 50 year time period assumption for investment – 6 years construction for mainstream projects and 5 years construction for tributary projects. The hydropower benefit was estimated using an electricity price derived from market prices and existing power purchase agreements	Total capacity 12,950 MW $ 0.07/kwh (during concession) and $ 0.05/kwh (after concession) O&M 0.015% and 0.02% of Capital investment (during and after concession period) 10% capital injection after concession
Irrigated agricultural production	Using the same number as BDP2 and updated to 2016 price	Using the same number as BDP2 and updated to 2016 price
Reservoir fisheries	NPV(10) – 50 year time period with phased cost impact*	64,000 ton per year Fish price $ 2.5/kg
Aquaculture	NPV(10) – 50 year time period with phased cost impact*	10% replacement of capture fisheries loss Fish price $ 2.5/kg
Capture fisheries	NPV(10) – 50 year time period with phased cost impact*	2.3 million ton/year Fish price $ 3.5/kg 35% migratory fish; 90% migratory fish loss
Wetlands	NPV(10) – 50 year time period with phased cost impact*	1700/ha/year for forest wetlands, $ 1400/ha/year for marshes, and $ 1100/ha/year for grassland wetlands
Social and cultural cost	NPV(10) – 50 year time period with phased cost impact**	Impact cost is 5% of Capital investment
Sediment/nutrients	NPV(10) – 50 year time period with phased cost impact*	Impact cost $ 450 million/year
Recession rice	Using the same number as BDP2 and updated to 2016 price	Using the same number as BDP2 and updated to 2016 price
Flood damage mitigation	Using the same number as BDP2 and updated to 2016 price	Using the same number as BDP2 and updated to 2016 price
Mitigation of salinity affected areas	Using the same number as BDP2 and updated to 2016 price	Using the same number as BDP2 and updated to 2016 price
Losses in bank erosion areas	Using the same number as BDP2 and updated to 2016 price	Using the same number as BDP2 and updated to 2016 price
Navigation	Using the same number as BDP2 and updated to 2016 price	Using the same number as BDP2 and updated to 2016 price
Country split hydro benefit	23% Lao PDR, 47% Thailand, 5% Cambodia and 25% Vietnam (based on export and home energy market during and after concession period. Most of the energy produced goes to Thailand and Vietnam. During concession period, the host country will benefit from tax and royalties)	
Electricity trading benefit	10% of the value of total electricity generation benefit from using low cost hydropower instead of electricity generated from natural gas or coal (cost saving approach)	

* Cost impact phased over ten year period starting in Year 5 of project construction.
** Cost impact phased over ten years starting in Year 1 of construction.

2.10. Aquaculture

Aquaculture production has expanded enormously throughout the Mekong Basin and current fish production is estimated to be about 2.4 million tons/year mainly from Thailand and Vietnam (Hortle, 2015). Additional aquaculture production would mitigate some lost capture fisheries. This study assumes a 10% increase in aquaculture production (for the 11 dams scenario) which is equivalent to 72,500 tons/year (ICEM 2010). The fish value for aquaculture was assumed to be $ 2.50/kg.

2.11. Capture fisheries

It is difficult to estimate the annual Mekong River fish catch from the four LMB countries, as official fish catch data do not cover small scale fishers. However, various literature reviews were used to derive the fish catch estimates (Van Zalinge et al., 2001; Hortle, 2007; Halls, 2010; Mekong River Commission, 2010b; An, 2015; Cowx, 2015; Nam, 2015). It is also difficult to estimate the loss in capture fisheries if all the planned mainstream dams were built on the Mekong River due to many different fish species with different migration habits. A wide range of 35–70% has been reported for the percentage of Mekong fish species that are long-distance migrants (Dugan et al., 2010). The planned dams would alter fish habitats and affect fish breeding and life cycles (Geheb and Pukinskis, 2012). A modeling study commissioned by MRC on the flow modifications and barrier affects caused by 1 to 3 Mekong dams concluded that a high percentage of migratory fish are vulnerable (Halls and Kshatriya, 2010). This study assumes that 35% of Mekong fisheries are long- distance migratory fish and that 10% of these fish would adapt and take advantage of new niches under the FFS scenario which comprises of 11 Lower Mekong mainstream dams plus 30 dams planned on the tributaries. This results in 90% loss of migratory fish under the 11 dams scenario (Table 3). The forecast capture fisheries loss is 725,000 tons/year which is in line with recent estimates reported by MRC (Nam et al., 2015). The fish value for capture fisheries is estimated from literature data, a recent regional market survey and personal communications with fish experts for the current price of the Mekong wild fish caught in Thailand, Cambodia and Vietnam. A conservative average fish value of $ 3.50/kg was assumed in this study which is lower than $ 4.8/kg reported recently by MRC.

2.12. Wetlands

The Mekong River and its associated wetlands (forests, marshes, and grasslands which are flooded during the rainy season) provide a wide range of ecosystem services. These services are essential in sustaining the livelihood and well-being of the local people. The wetlands provide food, medicinal plants, honey, insects, etc. which benefit local people directly and also nourish a local sense of place and other cultural activities. Various studies indicate that local villagers depend greatly upon these services provided by this terrestrial-aquatic intermediary zone (Hortle and Suntornratana,

Table 3
Estimated Fish Catch and loss under 11 dam scenario.

	Current fish catch (tons/year)	Forecast fish catch loss (tons/year)
Lao PDR	240,000	65,000
Thailand	920,000	60,000
Cambodia	770,000	430,000
Vietnam	370,000	170,000
Total	2,300,000	725,000

2008; Molle et al., 2009; Hall, 2010). The economic benefits of the wetlands services must be taken into the equation to ensure a comprehensive and balanced basin development plan.

Global estimates of the economic value of ecosystem services provided by wetlands range from $ 3300 to 25,680/ha/year (De Groot et al., 2006). A meta-analysis of South East Asian wetlands and mangrove ecosystem services estimated that the mean value of ecosystem services was $ 4185/ha/year (Brander et al., 2012). World Wildlife Fund report estimated the average value of ecosystem services in the Lower Mekong Basin countries at $ 1639/ha/year for freshwater wetlands (Emerton, 2013). A survey of 780 local households in Bung Khong Long (the largest freshwater lake in Northeast Thailand) was carried out in February 2012 and three economic valuation methods (choice experiment, avoided damage cost, and market price valuation) were used to estimate the value of water regulation, food production, water quality improvement, biodiversity, culture services, carbon sequestration, water supply and raw material. The total economic value of wetland ecosystem services was US$ 2.7 million per annum or about $ 1248/ha/year at 2012 prices (Chaikumbung, 2013). The paper uses local survey estimation which results in values of $ 1700/ha/year for forest wetlands, $ 1400/ha/year for marshes, and $ 1100/ha/year for grassland wetlands. This figure is believed to be more realistic because these rural households have low income and low ability to pay for such services, but it is still a conservative estimate.

2.13. Social impact cost

The mitigation costs of social/cultural impacts were not taken into account in BDP2. Hydropower construction on the mainstream and tributaries of the Mekong River pose potential threats to the food security and livelihoods of all communities within the project footprint, and for many more affected by transboundary impacts. Construction of the project structures, the reservoir, and associated facilities (e.g., physical plant and transmission lines, work and camp areas, access roads, quarries) will necessitate the relocation and resettlement of thousands of households affecting their livelihoods, access to traditional food sources and social well-being (Mekong River Commission, 2010a). The extent to which hydropower project developers provide adequate funds to cover resettlement costs and continue to fund social development programs after resettlement is the basis for evaluating social/cultural costs. Previous research shows that social mitigation costs were about 3–6% of total project costs (Maunsell Limited and Lahmeyer GmbH, 2004; Laplante, 2005). Recent experience at major Mekong tributary projects suggests that actual social mitigation costs are even higher than 3–6% capital investment. However, this study conservatively assumed 5% of capital investment to mitigate the social impact and that 70% of total social mitigation costs will be spent during the 6 year construction period and the remaining 30% during the first three years of commercial operation.

2.14. Environmental impact cost

Negative impacts of planned Mekong hydropower projects on biodiversity have not been properly assessed or mitigated in the past. The cost of forest land and forest loss is much higher than estimates for compensation plans in Environmental Impact Assessments. Habitat is lost due to the inundation of land for reservoirs and because land is needed for project construction and resettlement. Based on recent hydropower projects in the Lower Mekong Basin, environmental costs have been reported to be 1.5–5% total capital investment (Ministry of Natural Resources and Environment; Government of Vietnam, 2015). This study assumes that environmental mitigation cost equivalent to 3% of capital investment would be included in the committed project cost. However, recent data from major Mekong tributary projects indicate that actual mitigation costs are much higher.

2.15. Sediment/nutrients loading

The recent Mekong Delta Study (MDS) reported that the planned mainstream dams would significantly reduce the suspended sediment load and associated nutrients (Ministry of Natural Resources and Environment; Government of Vietnam, 2015). MDS expects severe adverse impacts on fishing and farming in Cambodia and Vietnam as a result of a combination of mainstream dam barrier effects (sediment trapped behind the dams) and the reduction in associated nutrient loading (phosphates and nitrates). The Chinese mainstream dams have already reduced the sediment load and its nutrient value by some 50% down from 160 million tons/year to about 80 million tons/year by the Upper Mekong Basin cascade of dam projects in China (as measured at the gauging station at Chiang Saen, Thailand) (Kondolf et al. 2014). Construction of the planned mainstream dams in the Lower Mekong Basin and the Mekong tributary dams is expected to cause a further 50% reduction of sediment load. This will result in reduced rice production in Vietnam (minimum estimated loss of $ 220 million/year), reduced rice production in Cambodia (minimum estimated loss $ 80 million/year) and less Vietnam coastal fishing (estimated loss $ 150 million/year). These conservative estimates add up to a total economic impact due to lost sediment/nutrients of $ 450 million/year (Ministry of Natural Resources and Environment; Government of Vietnam, 2015). However, MDS comment that if the sediment reduction is extended for decades, the loss in rice production in the Vietnam Delta would be 2,400,000 tons/year (about 6% of current production) and the loss in Cambodia would be 430,000 tons/year. The combined reduction in rice production (Cambodia plus Vietnam) is 2,830,000 tons/year which would increase the economic impact to $ 1.1 billion/year with rice valued at $ 400/ton – this is equivalent to NPV of minus $ 11 billion which is more than the hydropower benefit from electricity sales.

2.16. Mekong River hydrology

The hydrology of the Mekong River is already undergoing major changes due to hydropower projects built on LMB tributaries and the Upper Mekong (Lancang) in China (ICEM, 2010). Construction of the 11 planned mainstream hydropower projects would have an additional effect on mainstream water flows, sediment transport and flooding. According to SEA, 55% of the Mekong mainstream between Chiang Saen and Kratie will effectively become a very large reservoir with slow water flow. This will reduce the efficiency of sediment/nutrients transport which will adversely impact fisheries and farming. The dry season flow is expected to increase slightly and flooding in Cambodia and Vietnam would also decrease slightly. A significant increase (50%) in irrigation is forecast by BDP2. However, the combined economic impact of increased irrigation plus decreased flooding damage is small compared to the large NPV numbers estimated for electricity generation, capture fisheries loss and sediment/nutrients loss.

3. Results

3.1. Economic evaluation – net present value

The hydropower benefit (NPV of $ 6650 million) reported in Table 4 is the sum of the NPVs calculated for each mainstream dam and the 30 tributary projects combined together. As shown in Table 4, the NPV (10) of the total economic impact is negative

Table 4
Summary of NPV calculations for 11 dams scenario.

	BDP2 estimate ($million)	This study ($million)
Hydropower	32,800	6650
Irrigated agricultural production*	1659	1832
Reservoir fisheries	200	822
Aquaculture production	1300	931
Capture fisheries	−1900	−13,030
Wetlands	100	238
Social/cultural impact	0	−1665
Sediment/nutrients	0	−2311
Reduction in eco-hotspot/ biodiversity*	−415	−458
Forest area reduction*	−372	−411
Recession rice*	278	307
Flood damage mitigation*	−273	−301
Mitigation of salinity affected areas *	−2	−2
Losses in bank erosion areas*	0	0
Navigation*	64	71
Total economic impact	33,400	−7329

* Using same number as BDP2 but updated to 2016 prices.

$ 7329 million. This is contrary to the MRC Basin Development Plan (BDP2) which reported a positive economic impact of $ 33.4 billion as shown in Table 4 – below).

The revised hydropower benefit is $ 6.65 billion comprised of $ 2.5 billion from hydropower operations and $ 4.1 billion from electricity import benefit. Fig. 2 shows that the NPV (10) of forecast capture fisheries loss is much larger than the hydropower generation benefit. The revised calculation also includes estimated costs for social, environmental and reduced sediment impacts which were not taken into account in BDP2.

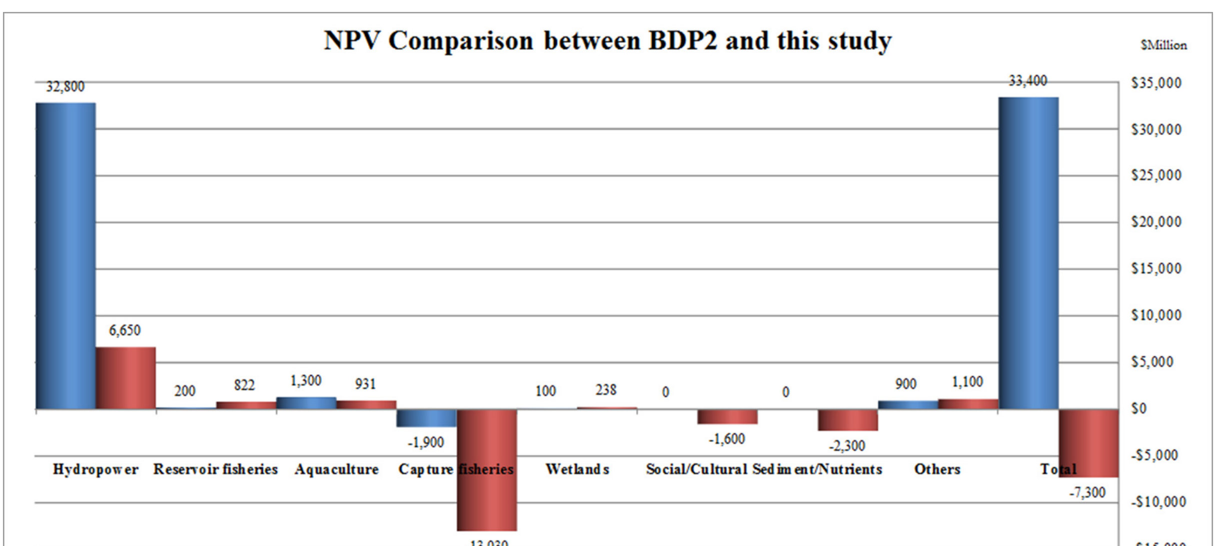
3.2. The distribution of costs and benefits between LMB countries

The distribution of costs and benefits between individual Lower Mekong Basin countries is difficult to estimate as other countries (e.g., China, France, Korea, Malaysia and Norway) are expected to participate in project funding and operations. This study assumed a benefit split of 30% for the host country and 70% for the country funding the project and/or importing the electricity, which resulted in hydropower benefit sharing of 23% Lao PDR, 47% Thailand, 5% Cambodia and 25% Vietnam. This differs significantly from BDP2 which concluded that Lao PDR would be the sole owner of hydropower projects located in Lao PDR and would receive the bulk of the forecast NPV benefit of $ 33 billion. This study finds that the Lao PDR benefit will be approximately $ 1.2 billion and this amount is mainly received after the concession period. Also, BDP2 concluded that all Lower Mekong countries would benefit from hydropower development. However, this study finds that Lao PDR and Thailand still benefit (but the benefit is much lower than estimated by BDP2) and that. Cambodia and Vietnam would suffer large negative economic impacts (Fig. 3)

3.3. Sensitivity analysis

The paper applies the sensitivity calculations for the total economic impact. Primary parameters were altered to determine their sensitivity included the discount rate on natural capital, electricity price, quantity of fish loss, fish price and social impact cost. This analysis showed that reasonable changes in the assumptions and parameter values create a broad range of Net Present Value (NPV), but all changes produce negative NPV to a greater extent than shown in BDP2 (Table 5).

As shown above, all the sensitivity calculations resulted in negative NPVs. Clearly, NPV numbers are very sensitive to the selected discount rate for natural resources. The lower the discount rate for natural resources the higher negative NPV for the planned projects. But even with the 10% discount rate, the NPV is still negative. Furthermore, the MDS estimate for extended loss of sediment/nutrients would increase the negative NPV by an additional $ 10 billion as mentioned in Section 2 above.



	Hydropower	Reservoir fisheries	Aquaculture	Capture fisheries	Wetlands	Social/Cultural	Sediment/Nutrients	Others	Total
BDP2	32,800	200	1,300	-1,900	100	0	0	900	33,400
This study	6,650	822	931	-13,030	238	-1,600	-2,300	1,100	-7,300

Fig. 2. NPV comparison between BDP2 and this study.

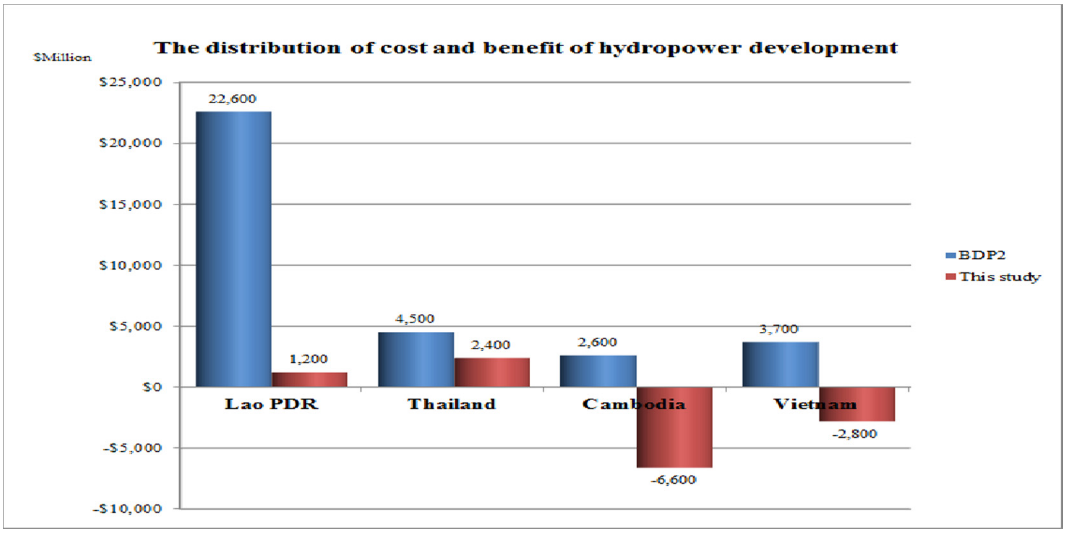


Fig. 3. Distribution of costs and benefits by country.

Table 5
Sensitivity calculations.

	11 dams scenario NPV ($ million)
Revised calculation (10% discount rate)	−7300
5% discount rate for natural resources	−27,800
3% discount rate for natural resources	−47,200
Electricity price increased by 10%	−2800
Electricity price decreased by 10%	−11,500
35% migratory Fish; 100% loss due to dams	−8700
35% migratory fish; 50% loss due to dams	−2000
Fish value increased to $ 3/kg for farmed and $ 4/kg for wild	−8800
Fish value decreased to $ 2/kg for farmed and $ 3/kg for wild	−5800
Increase in social impact cost to 8% capital investment	−8300
Decrease in social impact cost to 3% capital investment	−6700

4. Discussion and recommendation

This paper finds that a conservative estimate for the total external cost of 11 planned mainstream hydropower projects in the Lower Mekong Basin amounts to $ 18 billion. Some of these costs are not included or underestimated in previous analysis. It should be noted that this figure does not represent the full life cycle cost of hydropower projects in the LMB. The choice among hydropower development, biodiversity protection and sustainable livelihoods remains contested due to different societal values, priorities and interests of stakeholders involved or affected by the project development. Many other societal and ecological benefits and costs are more difficult to identify including the opportunity costs of increased resilience to climate change, other renewable energy development, decreased tourism, other intrinsic values of extinction of Mekong giant catfish and Irrawaddy dolphin. Furthermore, the potential carbon emissions reduction from these hydropower projects (which remains debatable) is not included.

The bottom line is that even with the most conservative assumptions about external costs, the NPV of these projects is still negative meaning that the project is not economically viable. Sensitivity analyses on these assumptions also show even more negative NPV.

This paper recommends a much more comprehensive economic evaluation of hydropower projects and alternative renewable energy possibilities in the LMB. Integration of all costs and benefits into the strategic energy planning as well as civil society participation is needed. Demand-side and supply-side assessment should be deserved and equal treatment with the objective of the investing in the least economic cost option. A comparative benefit -cost study and quantifying the nexus trade-offs of various technologies taking into account less hydropower income than previously anticipated, updated forecast for LMB power demand and technology developments for improved energy efficiency & renewable energy (especially solar which is now competitive with hydropower) should be considered to guide the energy development and inform decision makers on water related development policy in the region. An improved balance of the water food energy nexus, benefit sharing mechanism among countries and small scale renewable energy and food production should be promoted to support local economies and strengthen local food sovereignty. This could also reduce rural–urban inequality, resource utilization conflicts and eliminate many of the unnecessary, high external costs of large hydropower development.

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