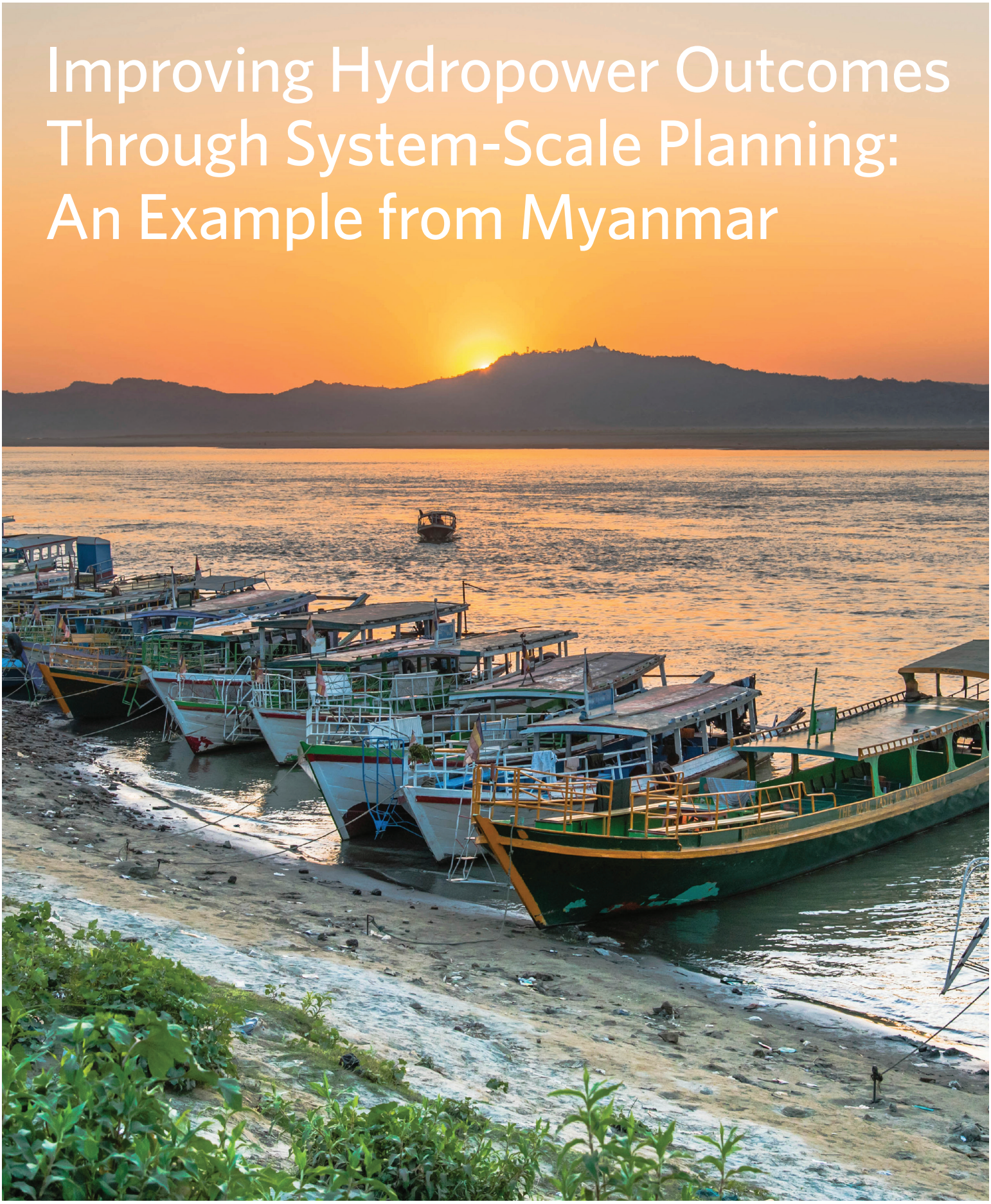
Improving Hydropower Outcomes Through System-Scale Planning: An Example from Myanmar



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Any strategy that focuses on one part of the water-food-energy nexus without considering its interconnections risks serious unintended consequences.

World Economic Forum: Global Risks Report (2011)

Myanmar has significant opportunities to develop hydropower, but currently lacks the data and decision support tools needed to understand the river basin-wide impacts of these developments and the trade-offs of alternative development options.

World Bank: Appraisal Report for the Ayeyarwady Integrated Basin Management Project (2014)

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Executive Summary

This report examines hydropower development in Myanmar to explore a fundamental challenge: how can governments make informed decisions about infrastructure development that will deliver the broadest range of benefits to their people over the long run? Hydropower provides a clear example of this challenge.

In summary, we propose that a systematic and comprehensive approach to hydropower planning can help countries deliver better development outcomes for their people.

For many countries, hydropower is a strategic resource that could increase energy supply at low costs and make important contributions to water resources management and development objectives (potential "co-benefits" of hydropower development and management). However, current approaches to hydropower development often fail to achieve this potential for broad benefits and incur high environmental and social costs. Decisions are often made at the scale of individual projects without a comprehensive understanding of how these projects fit within the larger context of both infrastructure systems and social and environmental resources. Short-term and project-focused decisions are not likely to produce hydropower systems that can fulfill their potential to achieve broad benefits and balanced development. This is because they will be systems in name only. In reality, they are groups of individual projects that are not well coordinated, miss opportunities for more optimal designs, and often cause high social and environmental costs—contributing to conflict and uncertainty for future investment. Most governments do not have a process in place to plan true systems and to strategically select projects that are in the best public interest.

We explore two broad hypotheses. First, hydropower planning at a system scale can help governments, developers and other stakeholders find better-balanced solutions with lower impacts and conflicts. Second, countries can adopt system-scale approaches in ways that avoid creating unacceptable burdens or delays. In summary, we propose that a systematic and comprehensive approach to hydropower planning and system design can help countries deliver better development outcomes for their people. We tested these hypotheses by developing an illustrative framework for hydropower planning and investment in Myanmar.

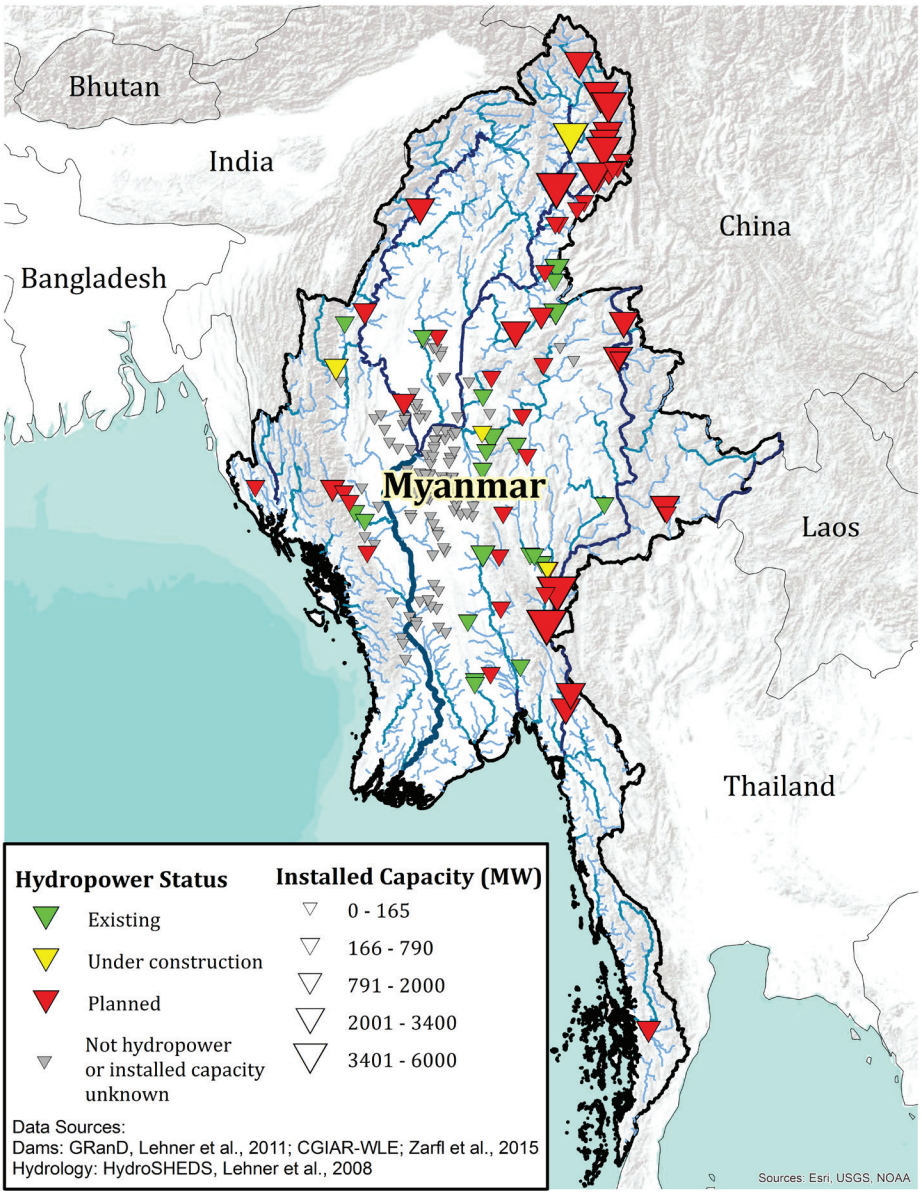
HYDROPOWER IN MYANMAR

Myanmar is a lower middle-income country with a large deficit in power supply. Only one-third of the population has access to electricity and lack of power constrains efforts to overcome poverty. At the same time, the country has a large undeveloped hydropower potential, estimated at 100 gigawatts (GW), some of which could be used to satisfy its own demand while some could be sold as energy exports to generate revenue for the country.

Myanmar's rivers provide a range of other benefits and resources. Rivers such as the Irrawaddy support productive fisheries, and Myanmar ranks fourth in the world in terms of inland fisheries capture. Nationally, freshwater fish harvests produce over 1.3 millions tons per year and employs approximately 1.5 million people. Irrigation, water supply, and navigation are other importhant uses of the water in the country's rivers. About 506 freshwater fish species have been recorded within Myanmar, 56 of which are endemic.

Potential sites for hydropower dams (Map 1) vary widely in terms of their technical feasibility, cost, potential for co-benefits, and impacts on social and environmental resources. Further, project sites could be developed with different designs (e.g., smaller or larger dams), and reservoirs could be managed with a range of different operating regimes (e.g., run-of-river operations, seasonal storage, or daily peaking) and these alternatives also affect the range of co-benefits and impacts from hydropower. For example, seasonal storage is often a prerequisite for co-benefits such as irrigation, water supply, navigation or flood control. Different types of operations can vary widely in terms of their impact on a river's flow regime and resources affected by flow, such as fisheries. Collectively, decisions about which dams to build and how they are designed and operated will determine whether hydropower in Myanmar is consistent with broad goals of sustainable development or if its impacts will cause social and environmental disruptions.

MAP 1. Map of hydropower projects in Myanmar



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The current delivery model for hydropower in Myanmar, as in most other countries, is not designed to manage these complexities. Recent hydropower development has generated a great deal of controversy due to environmental and social impacts. Much of the public perceives that power sector institutions and investors choose individual projects strictly on technical and financial criteria and give insufficient attention to cumulative impacts, trade-offs, and the potential for public co-benefits from reservoirs. The selection process is seen as a black box, with low levels of transparency and accountability. Given this context, it is not surprising that conflicts have led to suspensions for some major investments–such as the Myitsone project on the Irrawaddy River, and other projects have been contested and delayed, resulting in major costs to developers and to power consumers. These perceptions and conflicts, in Myanmar and elsewhere, erode public confidence in decision making and increase uncertainty for investors and funders.

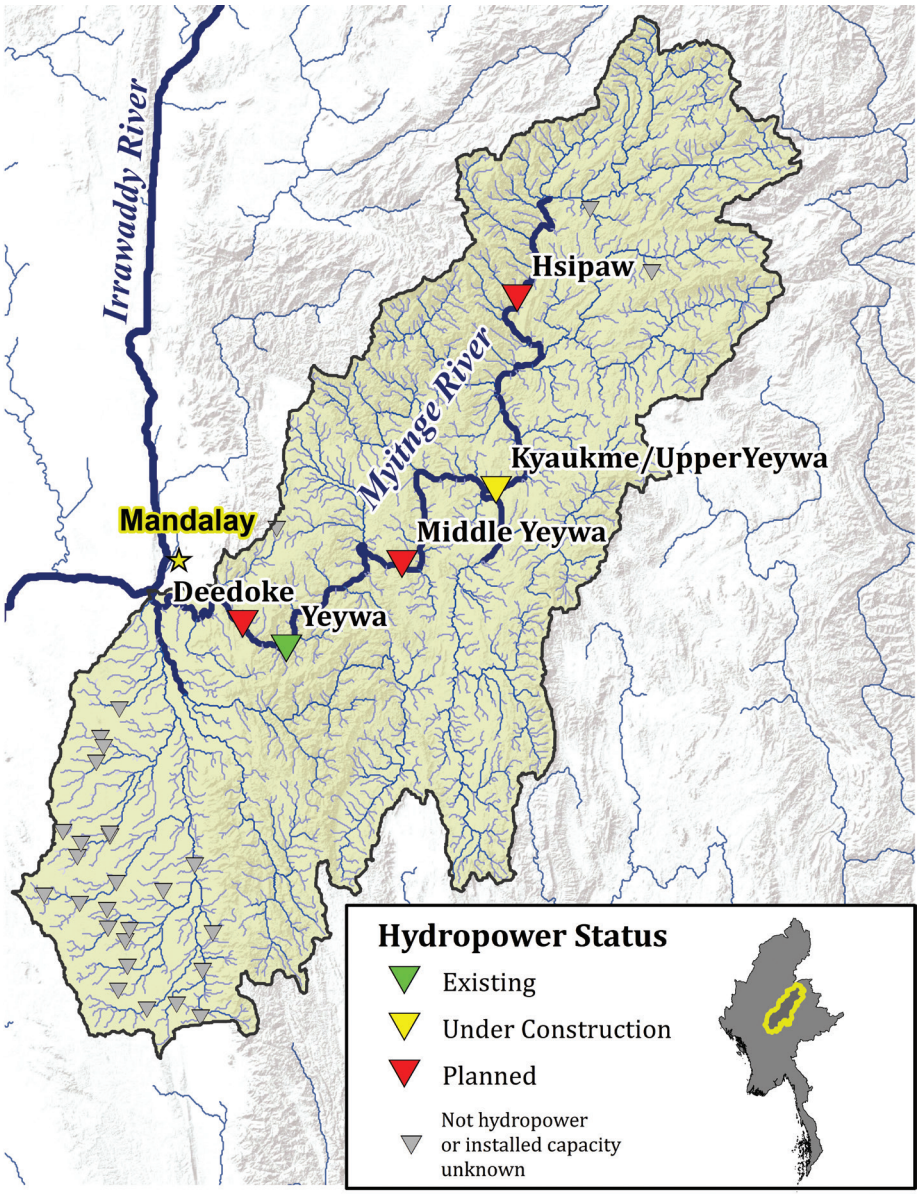
Myanmar's new democratic government now has to make important choices about hydropower management and development and it has indicated that it will emphasize sustainable energy. The objective of this study is to inform these choices. Rather than looking at the feasibility and sustainability of individual hydropower projects in a traditional case-by-case manner, we propose an approach for system-scale planning that compares different hydropower portfolios based on their quantitative performance across multiple criteria and visualizes this performance in a way that supports informed policy and investment decisions. Here we define a hydropower portfolio as a specific combination of existing and/or potential dams, with each dam having a defined location, design and operation. The planning approach does not presume additional dams because some portfolios will only include existing infrastructure, including alternative operating regimes. The criteria to measure portfolio performance should be defined by stakeholders to represent their interests or benefits from river management (e.g., energy, fisheries, navigation).

Our illustrative approach recognizes that all relevant stakeholder interests are legitimate and should be taken into account in a transparent manner and does not weight or otherwise pre-determine the different interests. The approach would allow decision-makers to balance trade-offs between different interests and to identify a combination of infrastructure and operations that will yield the fullest benefits to the country. It can lead to a better understanding of how to manage risks to the economy, communities, and ecosystems and point out actionable steps to achieve a broader range of benefits across economic, social and environmental values.

ILLUSTRATING THE BENEFITS OF A SYSTEM-SCALE APPROACH: ANALYSIS OF OPTIONS FOR THE MYITNGE RIVER

The timeframe and resources available for this study did not allow a comprehensive system-scale planning exercise at the scale of the country or a major river basin. Instead, we illustrate the potential benefits of system-scale planning by applying the framework to development options on the Myitnge River, a medium-sized tributary of the Irrawaddy River (Map 2). Development options within the Myitnge sub-basin are relatively simple, drawn from a potential hydropower cascade of up to five projects. Ten different stakeholder interests ('metrics') were defined: average and firm electricity generation; investment costs; flood control; navigation; displaced people; forest loss; fishery support; fish biodiversity; and sediment load. We examined multiple portfolios that represent different combinations of dams and operational rules. Each portfolio was quantified in terms of performance across all 10 metrics with outcomes simulated over 50 years. To illustrate that some metrics cannot be accurately measured at the scale of a sub-basin such as the Myitnge (e.g., the movement of migratory fish throughout a larger basin), some additional analyses were conducted at the scale of the entire Irrawaddy basin.

MAP 2. Current existing, under construction and planned dams in the Myitnge River basin

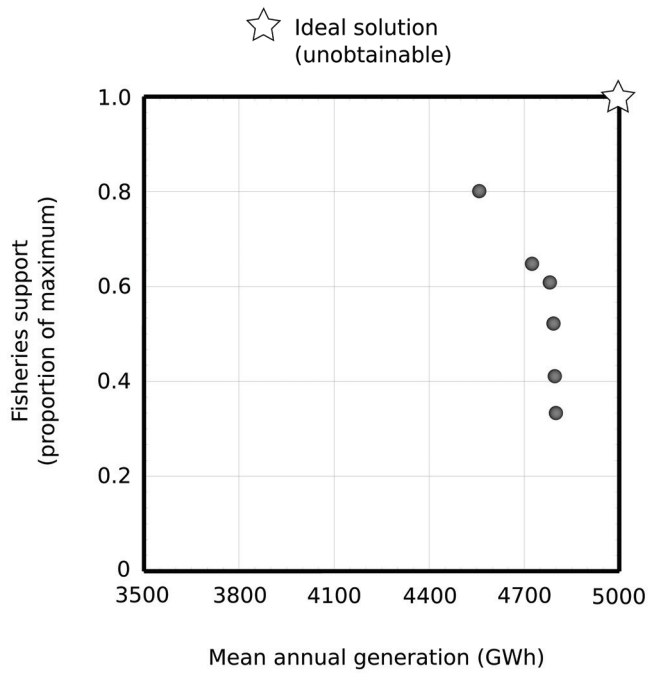


The results illustrated that some interests are compatible with each other but, for other interests, there are clear trade-offs. The results, and associated visualizations, can allow decision-makers and stakeholders to discuss and negotiate alternative development scenarios. The results and visualizations can also identify portfolios which will allow a better balance among a set of interests. For example, as generally expected, a larger number of dams in the Myitnge sub-basin causes increased fragmentation, sediment and nutrient trapping, and flow alteration, thus reducing the sub-basin's contribution to the overall fishery support in the Irrawaddy basin. However, there are several combinations of dams and operating rules that produce almost the same amount of energy, but with much lower impacts on fishery support (Figure 1).

Myanmar has the opportunity to carefully choose which investments it wants to prioritize in order to achieve portfolios that provide a more balanced or desirable range of benefits.

PHOTO: © Justin Blethrow

FIGURE 1. Trade-off between support for fisheries and mean annual hydropower generation



Trade-off between support for fisheries and mean annual hydropower generation. Each point shows the performance achieved by a combination of infrastructure investments and their operating rules.

This study was focused more on demonstrating the potential for a system-scale approach to improve decision making rather than trying to inform specific decisions for the Myitnge. The results from the Myitnge analysis do illustrate the benefits of a system-scale approach to planning hydropower. The analyses show that different development pathways will have large differences in performance across important interests and that some of these differences and opportunities can only be detected by looking at the system scale, rather than by evaluating projects one-by-one. The products of a system-scale approach can identify trade-offs to be discussed and negotiated in a rational and constructive process and point toward win-win solutions. Using a system-scale planning approach would allow Myanmar to carefully choose which investments it wants to prioritize in order to achieve portfolios that provide a more balanced or desirable range of benefits.

IMPLICATIONS FOR MYANMAR AND FOR OTHER COUNTRIES

During the period of this study, Myanmar was undergoing an unprecedented phase of political transition. The new political arrangements, including peace agreements, are still fragile, and a new economic system is emerging. The outgoing government intentionally left decisions on contentious hydropower projects to the future. The transition presented a number of challenges for this study: uncertainties over future government leaders and the direction they may envision for energy development and hesitancy of officials to make any commitments until the new leadership sends clear signals. However, the transition also provided a unique and timely opportunity to present some hydropower planning approaches and reform options.

The previous government's approach to hydropower development was to attract the maximum possible amount of hydropower investment. As a result, essentially all interested developers were encouraged to go forward with their proposed projects. However, after an initial wave of development interest earlier this century, relatively few projects have actually progressed because of security issues in ethnic minority regions, political uncertainty, and conflicts over environmental and social impacts leading to the suspension of some large-scale projects. Thus, even from a narrow commercial perspective, this non-selective, single-project approach seems to have had limited ability to meet economic needs, let alone to satisfy environmental and social stakeholders.

The Election Manifesto of the National League for Democracy (NLD) suggests that the new government will take a fresh look at the role that hydropower will play in future energy plans. Thus, the new government has the opportunity to evaluate the potential for the system-scale approach described in this report. Whatever decisions the government makes in terms of managing existing hydropower or developing new hydropower, those decisions can be informed by a system-scale approach that seeks to deliver broad development benefits.

The new government of Myanmar has two advantages. First, because very few projects have been built, a wide range of portfolios is still possible. Second, the government has a clear mandate to apply high standards to the hydropower sector.

The government has the opportunity to make decisions that can move Myanmar toward a hydropower system that delivers broad benefits while minimizing environmental and social conflicts. This report suggests that achieving positive development impacts through hydropower will most likely occur through a system-scale approach that can identify the best portfolios of projects. A new planning and licensing mechanism will need to be designed so that the country can select the best combination of projects and ensure that they are implemented and managed properly.

Building new planning and licensing mechanisms will not be simple, but the government of Myanmar has two advantages. First, because very few projects have been built–and none on the mainstems of the Irrawaddy and Salween–the government has many choices and a wide range of portfolios is still possible. Second, the new government has a clear mandate to apply high standards to the hydropower sector.

In the short term, the government could apply a relatively simple screening process and apply some risk-management "rules of thumb." This process would identify those projects likely to have the greatest conflicts and would allow the government to focus in the short term on projects that are likely to have relatively limited impacts, such as projects within existing cascades. In the medium term, over the next 12-18 months, the

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Strategic Environmental Assessment (SEA) for the hydropower sector in Myanmar, funded and contracted by the International Finance Corporation (IFC), will provide an opportunity to expand the discussion about system-scale issues. In parallel and in the longer term, government may want to consider building a comprehensive hydropower planning and selection mechanism, to prioritize projects that are clearly in the public interest. Bilateral or multilateral funders could support this process.

Several lessons have been learned from the study in Myanmar that are applicable in other countries, and to other infrastructure sectors. The approach presented in this study–integrated, quantitative, multi-criteria and multi-project planning, also called 'Hydropower by Design' by The Nature Conservancy–is still relatively new. It is part of an emerging trend and is recognized as the 'next frontier of hydropower sustainability.' Here we built on existing examples and combined spatial analysis with water resource management simulations to compare alternative portfolios of projects and development pathways. We believe that this approach has shown real potential value and that the technical analysis at its core could become an important contribution to the planning toolbox. Although it was relatively quick and inexpensive to apply, largely using publicly available data from global datasets, the approach was able to generate a plausible first approximation of development options for a basin.

Further, we improved understanding of the context in which such tools can be applied. A new planning and licensing mechanism, whether for Myanmar or any other country, depends not only on improved data. Absent improved decision processes, this would simply replace one 'black box' approach with a more complicated black box. A simulation model can identify a set of portfolios that are worth discussing, but it cannot replace political and investment decisions. Rather, we see system-scale planning as an opportunity to introduce a more accountable and transparent decision-making process that will lead to greater legitimacy and public acceptance of decisions. Stakeholder engagement is critical to developing useful models–for example by identifying and calibrating the metrics to track within the simulations–and stakeholder support will facilitate implementation of the promising portfolios identified by the planning approach. System-scale planning is as much a governance challenge as it is a technical challenge.

The project has been made possible by a financial contribution from the United Kingdom's Department for International Development (DFID) as well as in-kind contributions from The Nature Conservancy (TNC) and WWF; the organizations and individuals that were part of this collaborative effort are listed in Annexes 1 and 2.

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Chapter 1: Introduction

This study addresses a fundamental challenge: how can governments make informed decisions about infrastructure development that will deliver the broadest range of socio-economic benefits to their people over the long run? Further, given urgent needs for economic development, how can governments take this strategic and comprehensive approach in a way that does not result in unacceptable delays for planning? Hydropower provides a clear example of this challenge. While hydropower can increase energy supply and make other important contributions to development, decisions about individual projects are often made without considering the broader context of water management and river functions. These short-term and fragmented decisions can result in inefficient outcomes, create unnecessary conflicts, and constrain future options for systems that will deliver broader benefits. Yet most governments do not have decision processes or regulations in place to strategically select projects that are in the best public interest.

We explore two broad hypotheses. First, hydropower planning at a system scale will inform consensus-building and decision-making processes which are more transparent and accountable, helping governments, developers and other stakeholders find better-balanced solutions. Second, system-scale approaches can be adopted by countries in ways that avoid creating unacceptable burdens or delays. In summary, we propose that a systematic and comprehensive approach to hydropower planning and investment can help countries deliver better development outcomes for their people.

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HYDROPOWER DONE RIGHT COULD MAKE SIGNIFICANT CONTRIBUTIONS TO SUSTAINABLE DEVELOPMENT

The challenges of sustainable energy and water infrastructure development are well illustrated by Myanmar, a lower middle-income country with a large deficit in power supply. Only one-third of the population has access to electricity, and lack of power is holding back efforts to overcome poverty. At the same time, the country has a large undeveloped hydropower potential, estimated at 100 gigawatts (GW), some of which it could use to satisfy its own demand and some of which could be used to generate revenue through exports.

A lack of electricity–including an overall lack of supply and a lack of reliability of supply–undermines socio-economic development in various ways. Businesses (for example, farmers relying on electric irrigation pumps) invest less when they do not expect power to be available, and lose production due to short-term blackouts. They may have to spend more to provide their own alternative or back-up power generation (for example, diesel pumps and generators). Generally, studies show a high willingness of consumers to pay for reliable electricity supply, significantly higher than the costs of actually delivering power. Estimates of the cost of 'unserved power' vary widely between countries and between commercial, residential and other types of consumers (World Bank 2009). While there are no specific estimates of the cost of unserved power for Myanmar, it is safe to say that access to electricity is one of the main development bottlenecks.

Access to electricity is one of the main bottlenecks for development in Myanmar.

There is also broad agreement among energy planners that hydropower can be one of the cheapest and most flexible sources of electricity. While initial capital costs are high, operating costs are very low and well-run projects can deliver services for many decades. Different types of hydropower projects can deliver base load and peak load power, and provide a proven technology for storing power when grid demand is low. Thus, they are also a valuable part of a future low-carbon generation mix that includes intermittent renewable sources such as wind and solar. Almost all countries with a significant hydropower potential have moved to base their power systems on this source. Funding constraints can usually be overcome where there is a clear economic and commercial case for investing in hydropower. Water storage offered by hydropower reservoirs can also be used for other purposes, such as domestic water supply, irrigation, flood control, navigation, recreation and fisheries, and dams often are managed for several of these purposes. These co-benefits often do not generate significant direct revenues and would not be delivered without investments in hydropower.

BENEFITS AND DRAWBACKS ARE HIGHLY SITE SPECIFIC

In addition to the multiple benefits described above, hydropower can have several serious disadvantages. Inflows to the reservoir are naturally variable, between seasons and between years, and are likely to become more so with climate change. Creating more storage space to deal with this variability is costly, and not only in monetary terms. The costs include land lost to the reservoirs, access roads and transmission lines, with all its human uses and ecosystem values. They also include far-reaching changes to rivers downstream of reservoirs, again with negative impacts both on human users and on aquatic ecosystems. One example for a negative impact is related to the fragmentation of river systems. Each project–with its dam, reservoir and/or dewatered stretch below the

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dam–acts as a barrier, which is at best partially permeable to the downstream and upstream movement of fish. Fragmentation also affects other activities and processes such as navigation and sediment transport, with sediment and its associated nutrients being extremely valuable for downstream agricultural areas and for the stability of river channels, banks and deltas. Furthermore, while reservoirs can be used for multiple purposes, these are rarely fully compatible with each other (often even conflicting), and often lead to additional complexities in financing, design and operations.

The range of positive and negative impacts across individual projects is much larger for hydropower than for other sources of power. A gas-fired power plant can be bought 'off the shelf' and is fairly straightforward in its economic, environmental and social impacts, with only minor differences between locations. By comparison, no two hydropower projects are the same. They are individually designed and operated for each site, and show wide variations in their costs and benefits. Myanmar has sites available that are located between two existing dams, benefit from upstream storage and require no resettlement, with minimal downstream impacts. But the country also has sites available with major storage capacity, and major population displacement and fragmentation implications.

Finally, a significant development issue is the distribution of positive and negative impacts among population groups. While local communities may recognize larger benefits for the nation, few are willing to sacrifice and accept negative impacts, such as displacement by a reservoir, if they do not share in these larger benefits more directly. This could be through local access to power, a local share in the royalties, or significant community development initiatives. An unfair distribution of benefits and costs is likely to trigger or aggravate regional conflicts. Benefit sharing should be applied to all projects, and is not generally seen as a criterion for choosing between projects.

PROJECT SELECTION BY DEVELOPERS IS UNABLE TO DEAL WITH COMPLEXITIES

Given this wide variety of project options with variable costs and benefits, the selection process for individual projects becomes very important. Project selection generally starts with engineering surveys, which identify technically possible projects and provide first estimates of costs. Traditionally, these would then be reviewed and the most promising sites for meeting estimated power demand would be selected, through a government-led least-cost master planning process. Because this process generally rested in the hands of a single agency (e.g., the Ministry of Energy), these master plans typically focused on a narrow range of resources and values.

Most countries have now deregulated their generation sectors, and this master-planning approach has largely been superseded by developers identifying preferred projects. Typically, they then obtain an exclusive temporary right to prepare a site, through a Memorandum of Understanding (MoU) with government. As the last step in the selection process, they apply for an environmental license, which comes with a number of conditions for mitigation actions attached. Additional mitigation actions may be taken to satisfy safeguards formulated by financiers, or as part of voluntary corporate social responsibility commitments.

The range of positive and negative impacts across individual projects is much larger for hydropower than for other sources of power.

PHOTO: © Joerg Hartmann

Developers' preferences may be for the lowest costs per kilowatt hour (kWh), a certain installed project capacity, low risks or any other combination of project features. However, there are a number of key problems with having developers 'cherry pick' projects in this way:

1. In the absence of master plans that provide a comprehensive evaluation of all project options, developers draw on incomplete information and may not actually be able to identify an option that best conforms to their own search criteria.
2. Even if they are able to identify the 'cherries', their preferences are not necessarily the same as those of the host country. Developers want projects they can build while, ultimately, a government wants the best overall system of energy and water management. It is possible, for example, that a developer can only obtain finance for a small project at a given site, while the best development option for that site would actually be a larger project. Construction of the small project precludes the larger project and the better overall system that the larger option would make possible.
3. Developers often assume that mitigation solutions can be found for any site, and thus, environmental and social risks can be evaluated in a separate, later step. However, experience shows that site selection is the most important decision in terms of environmental and social impacts, and poor site selection can lead to impacts that cannot be effectively mitigated. Thus, even after mitigation, large performance differences remain between projects, and this exposes them to regulatory and public-acceptance risks. By the time environmental and social problems or negative impacts on other economic sectors become apparent, developers and politicians may have already made significant commitments, leaving no easy way out.
4. Related to the previous issues, a developer is generally only responsible for one site. However, in a region with multiple existing and planned projects, the economic, environmental and social implications can only be properly evaluated by looking at the cumulative impacts at the system scale. Treating all projects as if they were stand-alone almost certainly leads to sub-optimal (i.e., economically inefficient) outcomes.
5. While not developing a project is a reversible decision, developing a project is largely irreversible and can create path dependencies. A certain preferred configuration of projects is no longer possible once one project is built in the 'wrong' place (or, as described above, the wrong project is built at a site).
6. Developers generally have a shorter time horizon than governments should have, which can be related to their higher cost of capital or the limited duration of licenses and concessions. As the near future is more predictable than the distant future, developers may not aim to select and design projects that perform well under a range of uncertain future conditions.

There are a number of key problems with having developers 'cherry pick' projects.

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GOVERNMENTS ARE LOOKING FOR OPTIONS TO REFORM PROJECT SELECTION

Growing awareness of these problems is leading an increasing number of countries to re-consider their project selection mechanisms. In many countries, hydropower planning and ownership are dominated by the public sector. These public utilities or state-owned enterprises are expected to act in the public interest, although in practice, their experience and incentives are often oriented towards technical and financial criteria.

The following case studies from Brazil, Chile, Colombia, Norway and Iceland, illustrate examples of the different ways governments have tried to improve hydropower planning. There are positive elements from each case that ought to be considered, but also clear flaws that should be avoided.

Learning from Experience: Brazil – Public Project Selection Weakened by Insufficient Stakeholder Consultation

Brazil has kept the selection of projects in the public domain, and only invites developers to bid on projects once these have been identified through a systematic planning process. While this process does consider cumulative impacts and is conducted at the basin level, it is seen as quite technocratic with insufficient attention to a range of environmental and social issues, and has not led to full acceptance by stakeholders. Some Brazilian projects such as Belo Monte, have suffered multiple interruptions due to stakeholder protests and interventions by the courts; the costs of these interruptions are estimated at several million US dollars per day.

Learning from Experience: Chile – The Costs of a Failed Project

Planning reforms are sometimes triggered by major conflicts over projects. Such conflicts cause financial costs of delays and cancellations, but also opportunity costs of unserved power, administrative and political costs, and reduce the attractiveness of a country for investors. In Chile, developers have repeatedly failed to convince the public, the administration and the courts that their projects are in the public interest. They had already spent more than US$320 million on the largest project (HidroAysén with 2,750 megawatts [MW]) when the incoming government canceled it in 2014. By that time, different government agencies and stakeholders had already spent an unknown amount of resources on dealing with the project; the Environmental Licensing Agency's project website alone had more than 11,000 documents. HidroAysén had also become a political issue, and arguably was one of the reasons for the change in government.

As a consequence, risk perceptions for investments in the Chilean power sector have increased, power supply is failing to keep up with demand, and costs to consumers are rising. In an attempt to overcome past problems, the current government in Chile is now upgrading its sustainability standards and making relevant information easily accessible for all rivers. However, it remains to be seen how that will influence project selection.

Learning from Experience: Colombia – Thorough Project-Level Evaluation Could Be Improved by Multi-Project Assessment

In Colombia, the licensing process for hydropower provides some opportunity to consider multiple impacts, values, and alternatives during the early stages of project selection. Developers are required to submit several high-level design or siting alternatives for consideration by the Ministry of Environment, and the chosen alternative is then evaluated through a detailed feasibility study and environmental impact assessment (EIA). However, this process compares alternative options for a single project rather than comparing different projects with each other and prioritizing among them. In its annually updated generation expansion plan, the Ministry of Energy treats equally all technologies and all projects registered by developers.

Colombia also illustrates how improved information and mitigation policies can contribute to system-scale approaches. Within Colombia, The Nature Conservancy has developed a "conservation blueprint" for the Magdalena River that can guide system-scale decisions for hydropower, including siting of projects, priorities for conservation, and application of a new mitigation policy that includes compensation or "conservation offsets."

Learning from Experiences: Norway and Iceland – 'No-Go Areas'

A number of countries have improved stakeholder acceptance by setting aside no-go areas. Responding to emerging concerns, Norway conducted a country-wide master-planning exercise in the 1980s, applying two criteria (unit costs and conflict potential, with several sub-criteria) to several hundred potential sites. The plan was ratified by parliament and designated approximately half of the remaining hydropower potential as open for development, while the other half was declared protected from dam development to maintain other values.

There are a number of other countries which have identified no-go areas. Iceland regularly updates its master plan, and divides the remaining hydropower and geothermal potential into three categories (open for development, protected from development, and left for future consideration). Every four years, the new parliament appoints a stakeholder and expert committee, and at the end of the term, votes on the committee's proposal. Some countries, like the United States with its 'Wild and Scenic Rivers' legislation, have created their own protected areas category for no-go rivers. These approaches help to increase legitimacy and transparency in the selection process, assure stakeholders that not all rivers will be developed, and thus help to reduce tensions.

Convincing stakeholders that only the best projects will be selected appears to be especially important in countries that export a large share of their power, either directly or, like Iceland, in the form of power-intensive products like aluminum. In these cases, stakeholders are likely to insist that special care be taken to not impose unnecessary domestic impacts for the sake of hydropower developed primarily for export revenues and royalties rather than domestic supply.

WHAT SHOULD A MODERN APPROACH TO PLANNING INCLUDE?

The complexities of selecting hydropower projects that are in the best public interest should not be underestimated. An effective process will require data acquisition, analysis, dialogue and decision-making – all conducted within an institutional framework that can represent and balance various stakeholder interests.

We are proposing planning that follows an integrated, quantitative, multi-criteria and multi-project approach; also described as "Hydropower by Design" by The Nature Conservancy [TNC; Opperman et al. 2015):

BOX 1. Hydropower by Design

Hydropower by Design – An integrated, quantitative multi-criteria and multi-project planning approach

- Integrated because it considers all relevant criteria simultaneously, rather than sequentially; by comparison, most assessments, whether at the project level (EIA) or above the project level (cumulative and strategic environmental assessments), are implemented after technical-financial studies;
- Quantitative rather than qualitative, to increase the rigor of the analysis and the confidence in comparing multiple options;
- Multi-criteria because of the multi-faceted positive and negative impacts of hydropower; and
- Multi-project (or system scale) because cumulative positive and negative impacts of multiple projects are difficult to predict from a sequence of project-based assessments and a portfolio of hydropower investments that offer the broadest range of benefits can generally only be identified at a system scale, rather than project-by-project.

We are proposing an approach that strives to design an overall system of water and energy management, one composed of individual projects that work together and are designed to collectively produce a broader range of benefits to society than could be achieved by an approach characterized by uncoordinated decisions about individual projects. It is worth bearing in mind that the proposed approach differs significantly from traditional planning and assessment instruments, as shown in Table 1 below.

TABLE 1. The scope of existing planning and assessment instruments

	Single Project	Multiple Projects
Technical and Financial Criteria	• Pre-Feasibility Study • Feasibility Study • Financial Model • Designs and Tender Documents	• Master Plan
Environmental, Social and Economic Criteria	• Environmental and Social Impact Assessment • Cost-Benefit Analysis • HSAP Assessment • Environmental and Social Management Plans	• River Basin Management/ Development Plan • Strategic Environmental Assessment • Cumulative Impact Assessment • RSAT Assessment • High Conservation Value Assessment/ Conservation Blueprint

We are proposing an approach that strives to design an overall system of water and energy management, one composed of individual projects that work together and are designed to collectively produce a broader range of benefits to society than could be achieved by an approach characterized by uncoordinated decisions about individual projects.

PHOTO: © Joerg Hartmann

The preparation of individual projects through feasibility studies and subsequent EIAs does consider multiple criteria, but frequently misses opportunities to run these studies in parallel and iteratively improve siting, design and operational rules to identify overall best-fit solutions. An increasing number of countries and financiers also require assessments of cumulative impacts. However, again these are generally done after most important project decisions have been made. Because they are an approvals requirement, rather than a planning instrument, they typically focus on the incremental impact of the project under consideration against the background of other projects, instead of on the total impact of all projects in the region, and how it could be reduced. Further, these processes' emphasis on impacts–whether individual or cumulative–does not address the potential for planning well-balanced systems for water and energy management that maximize a broader range of benefits.

Traditional master planning for hydropower, as conducted in many countries up to the 1970s or 1980s, did look at multiple projects. However, it did so using a small subset of the criteria that would be considered necessary today; generally only technical feasibility, cost per kWh (levelized cost of energy) and cost per installed kW, and average and firm generation. Strategic environmental assessments are sometimes proposed to bring additional criteria to bear on hydropower master plans. They are often qualitative, or use relatively simple project-by-project metrics (such as, installed MW per km^2 of reservoir area, or number of displaced people). In some cases, as in Vietnam, these have been used to reconsider the ranking or sequencing of projects. In principle, SEAs could also apply water resource or energy modeling approaches to generate more comprehensive quantitative and cumulative insights.

Hydropower by Design aims to consider multiple criteria and multiple projects from the beginning, in an integrated way.

Using tools beyond those in the upper left cell of Table 1 will add more information and context, and will improve project quality. It would be significant progress if all countries regularly used a broad range of these available tools. However, Hydropower by Design goes one step further. To avoid a sequential process–in which environmental, social and economic criteria are introduced only after all important project or program decisions have already been taken–Hydropower by Design aims to consider multiple criteria and multiple projects from the beginning, in an integrated way.

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ACCOUNTABILITY LEADS TO PUBLIC ACCEPTANCE

The transparency and legitimacy of decision-making processes provides an important final distinction between traditional planning and assessment approaches and our proposed approach.

All these approaches (Table 1, page 17) can be, and often are, conducted by groups of experts in a closed process. Many countries involve stakeholders only in a formal and cursory manner, and do not make studies available to the public. Often these processes are largely managed by a single department, agency or ministry. At best, the process may allow some input from other government departments who, in theory, represent different stakeholder interests. The ultimate decision generally rests with a powerful government department such as the Ministry of Energy, generally with strong influence from developers. Very rarely are hydropower projects stopped through the environmental licensing process. Indeed, if agencies raise and sustain objections, their leaders may be more likely to resign or be removed. Sometimes authoritarian governments see no need to further explain decisions or to address the lack of participation; sometimes it is argued that the selection problem is technically too complex to allow substantial stakeholder involvement, or that it is more important to keep investment flowing into the sector. The 'black box' nature of this process generates stakeholder distrust and frustration, and with good reason: even where decision-makers try to optimize outcomes, for example through cost-benefit analysis, this involves many expert opinions and value judgments that are not shared with stakeholders. Rather than being at the center of attention, trade-offs can easily be hidden by assuming that if there is an overall benefit, losers will either be directly compensated by winners or will somehow gain from trickle down benefits.

The alternative is to organize the planning and decision-making process with the objective of developing a 'shared vision.' The guiding principles would be transparency, a willingness to consider multiple perspectives and the trade-offs between them, and an interest in finding balanced outcomes. Stakeholders would be involved in formulating the objectives, sharing data, building trust in the analytical tools and participating in the decisions. If a government is not yet prepared to open up decision processes to interest groups, it could at least organize an interagency process, perhaps chaired by a neutral institution such as a planning agency or a water resources commission.

BOX 2. Our Hypothesis

Integrated, quantitative multi-criteria and multi-project assessment and planning (Hydropower by Design) can identify portfolios of projects that collectively perform better than those produced by more limited approaches; but just as importantly, by being conducted in the open, it can help stakeholders find compromises and identify win-win solutions and generate a consensus in society.

PHOTO: © Jeff Opperman

Chapter 2: System-Scale Planning of Hydropower

This chapter provides a conceptual framework to guide system-scale planning before we apply the approach to Myanmar in the following chapters.

THE OVERALL OBJECTIVE OF SYSTEM-SCALE PLANNING IS SUSTAINABLE DEVELOPMENT

At the most general level, the objective of system-scale planning is to inform and catalyze a balanced and sustainable development trajectory for a region or country. Applied directly to rivers, this means that a region or country should maintain a system of rivers that can provide a broad range of socio-economic benefits to people. This can be accomplished by designating rivers, or sections of rivers, as "healthy" and "working". Healthy rivers deliver a range of ecosystem services, including productive fisheries that have high economic and cultural value, particularly in large, tropical rivers. Working (managed) rivers can contribute to development objectives for energy, navigation, flood-risk reduction, and water supply. Sometimes the same river reach can be considered both healthy and working; sometimes different parts of a river system get assigned different functions, with protected (healthy) and highly developed (working) reaches in different parts of the river system.

In their recent report about healthy rivers, Parker and Yates (2016) identify some key findings of relevance to hydropower planning (Table 2).

TABLE 2. Key concepts from "How do healthy rivers benefit society" working paper

How do healthy rivers benefit society
Rivers provide a wide range of benefits, yet are often exploited to deliver a relatively narrow range of objectives; the scope for attaining more benefits in many basins is large.
Economic benefits (e.g., commercial agriculture or hydropower) imply trade-offs amongst themselves, and with other benefits such as environmental goals. Understanding these trade-offs is a helpful step towards integrated water management.
Some benefits are more easily linked to economic outcomes, which should not preclude others.
Disservices such as flood risk also have to be managed.
The realization of benefits is often enhanced by human interventions (infrastructure, institutions, etc).
Groups and sectors typically benefit unequally from rivers, so tracking benefits incurred throughout the basin over space and time is an important part of arriving at water management interventions that achieve broad support.

Source: Parker and Yates, 2016

Construction and operation of reservoirs and hydropower infrastructure in a river basin will be an important determinant of river health and productivity. Dams and reservoirs–through their location, design and operation–change the physical processes of the river basin and affect the other economic and engineering functions within that basin. Collectively, a group of hydropower projects in a river basin will constitute a system, whether or not it was intentionally designed as a system or whether it evolved through a series of uncoordinated, project-level decisions. The impact of hydropower systems will vary widely depending on how projects were selected. This ranges from poor results, where benefits in one sector come at the high expense of other values, to high-performing, healthy and productive systems that can achieve balanced and equitable development for a country.

The overall goal of system-scale hydropower planning is to ensure that hydropower projects act together to advance economic, social, and environmental goals in their region. This central goal leads us to formulate three core questions about strategic hydropower system design:

- Has the overall hydropower system been designed such that it cost-effectively meets regional power demands, consistent with a sustainable approach to energy development for that country?
- Have trade-offs between hydropower production and other stakeholder-defined economic, environmental and social objectives been identified, quantified, deliberated and balanced?
- Does the planned portfolio of hydropower projects achieve robust and resilient performance under a wide range of plausible futures (i.e. considering both supply and demand uncertainty due to unknown future climate, economic, demographic and institutional changes)?

If the answer to each of these questions is yes, effective system-scale planning of hydropower has been achieved. The following sections of this chapter outline a proposed process and approach to arrive at affirmative answers to these questions.

HOW CAN A HYDROPOWER SYSTEM BE DESIGNED?

Effective system-scale planning begins with understanding the role hydropower could play in meeting national or regional energy demands. Once target levels of hydropower production have been set, different hydropower projects that alone or in combination could meet those targets are represented within a river basin model.

In some cases, that model can be relatively simple. For example, if the main interest is in balancing hydropower development and the connectivity of the river system, it may be sufficient to compare scenarios with different dam locations to understand trade-offs between energy and fragmentation. An ecological model could then predict how fish are affected by fragmentation. If the main interest is in balancing hydropower development and the loss of land, it may be sufficient to identify the areas inundated by reservoirs, and the values associated with them. These might be highly productive agricultural lands, indigenous communities' lands, or protected areas. Some examples for such analyses from Mexico, Colombia and Brazil are presented in TNC's 2015 *Power of Rivers* report.

PHOTO: © Günther Grill

Understanding how hydropower dam alternatives affect other users of water will require a river basin simulation model that can track flows and storage of water over time and predict the energy production of a particular hydropower system design as well as system performance across a range of other resources. These models can also be combined with the spatial analyses described above. The spatial analyses can either be an intermediate step towards calculating a particular performance metric; for example, fragmentation can be an input to a metric for fishery support. Or they can directly provide one of the performance metrics; for example, loss of forest land.

The river basin simulation model should be built in collaboration between a broad group of stakeholders so there is confidence that it is an accurate representation of the river basin and its resources and of its potential future infrastructure and management. Stakeholders should also lead or inform development of a comprehensive list of performance metrics that they agree quantify the relevant economic, social and environmental impacts of the river basin's management. The model is therefore able to predict performance across a diverse set of metrics for any possible system design. In addition to using current or historical conditions, design performance can be compared in terms of robustness and resilience under differing plausible futures. Finally, model output should be able to be displayed with clear visual graphics to facilitate dialogue and deliberation of trade-offs. Deliberation of trade-offs sets the scene for informed negotiation of designs by the major stakeholders in the final decision-making stage.

Understanding how hydropower alternatives affect other users of water will require a river basin simulation model.

The approach chosen for the analysis in Myanmar and described in Chapter 4 combined both spatial analysis and a river basin simulation model. The remaining sections of this chapter focus on the river basin simulation model, describing specific components of the modeling approach. To illustrate how the model works and how it can inform decision making, the chapter includes brief summaries of two previous applications of similar models.

Energy System Planning

In the proposed approach, we assume that an energy planning exercise has been conducted which identifies anticipated energy demands and sources, with a goal of meeting a country's realistic future demand in a way that can meet economic, social, and environmental objectives, including for greenhouse gas emissions. This high-level planning can identify a target for hydropower production levels for one or more time horizons that will be consistent with a sustainable plan for energy development.

Hydrological and Ecological Analysis

Accurate hydrological information on river flows will be an important part of any study, as planners will want to estimate production based on the best available hydrological data. If future hydrological uncertainty is to be considered (e.g., in relation to future climate change), a diverse set of hydrological inflows should be developed. In addition to hydrological time-series analysis, spatial work should be completed (e.g., to be able to measure hydrological connectivity and other hydro-ecological metrics). Products such as a conservation blueprint can improve understanding of the geographic distribution of important social and environmental resources.

PHOTO: © Justin Blethrow

River Basin Modeling

The performance of hydropower projects depends on factors such as river flows, water management rules, and upstream and downstream water use. The river basin simulation model (or simulator) acts as an impact model, which estimates various measures of performance for any given hydropower portfolio. Here we define a hydropower portfolio as a combination of existing and potential dams, each with a defined location, design and operation. An open and inclusive approach to managing the river basin simulator should be followed so that a broad range of stakeholders are co-owners of the model and support its credibility and accuracy.

Participatory Identification of Performance Metrics and Uncertainties

In addition to financial capital and operating costs, and engineered quantities like firm and total energy yield, the river basin model should track various metrics of system performance relevant to other sectors. Examples could include irrigated agricultural production, ecological indices (e.g., fisheries), navigation, sediment transport, number of people displaced by dams, loss of high conservation value areas and indigenous lands, etc. Stakeholders are likely to suggest metrics that directly measure the extent to which their interests are being met. Some metrics may make more sense to experts who understand causal relationships. For example, some basic knowledge of fluvial geomorphology is required to interpret the relevance of sediment transport, and some basic knowledge of fish biology is required to interpret the relevance of river fragmentation. Models can use intermediate metrics (e.g., fragmentation) or metrics that result from one or more intermediate metrics (e.g., fisheries productivity could be the result of various habitat metrics, such as fragmentation).

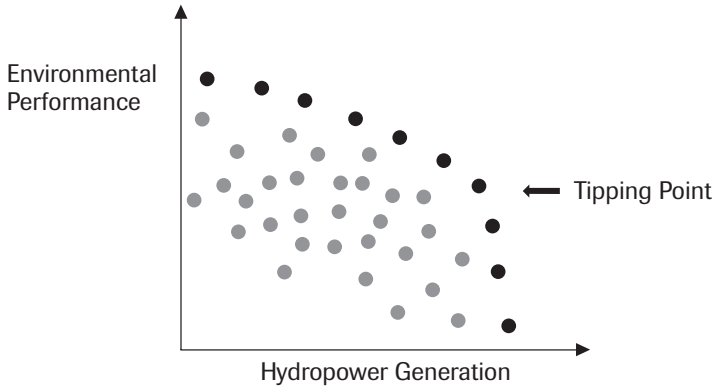
PHOTO: © Paola Bernazzani

Trade-Off Analysis

In this step, we filter through many plausible hydropower portfolios to identify the most efficient ones (i.e., those where subsequent improvement in one metric can only come at the expense of another metric). To filter through plausible portfolios, the simulator is linked to a search engine to perform computer-assisted filtering and produce results in the form of sets of high-performance portfolios, which can be visualized as trade-off curves or surfaces. Trade-off plots show the benefits achieved by the best performing alternatives (also called the Pareto-front or 'efficiency frontier' – see the black points in Figure 2). These are the alternatives that cannot be further improved in any dimension without losing some other benefit(s).

Trade-off plots show the benefits achieved by the best performing alternatives.

FIGURE 2. Performance of hydropower system portfolios



Plot showing how each system portfolio of different hydropower investments (each point) produces a different combination of environmental and hydropower benefits. The black points denote the non-dominated, highest performing asset combinations (Pareto-efficient), the grey points are the dominated portfolios (Pareto-inferior). The dark points trace a curve that will typically be of interest to system planners and decision-makers. Note the inflection or tipping point in this plot, beyond which more hydropower production comes with a greater relative decline in environmental performance.

Robustness Analysis

In this step, the search process seeks to evaluate hydropower system portfolios not just over historical data, but against a diverse ensemble of plausible future scenarios. One way to achieve this via a search process is to link the search to not a single simulation of historical conditions, but to a range of plausible scenarios. In such a way the robustness of a portfolio can be evaluated. Due to time and data constraints, this step was not taken for the exercise in Myanmar, but would be an important part of a fuller application of this approach.

Deliberation, Negotiation and Decision-Making

The output from the simulator should provide clear and visual results illustrating trade-offs, providing a solid foundation to inform the dialogue and decision processes of a multi-stakeholder group. Each group would be armed with the ability to compare portfolios and advocate for those which best meet their goals. This multi-stakeholder group should include direct representatives of groups that will be affected by decisions, representatives of government departments with responsibilities for different sectors and issues, representatives of different regions, or a combination of those.

PHOTO: © Justin Blethrow

WHAT VARIATIONS OF THIS APPROACH HAVE BEEN TESTED?

The key tools to implement a process as described above include hydrological and GIS spatial data analysis tools, a generalized river-basin management simulation model, a search technology, and visual analytics software to enable stakeholder understanding and negotiation.

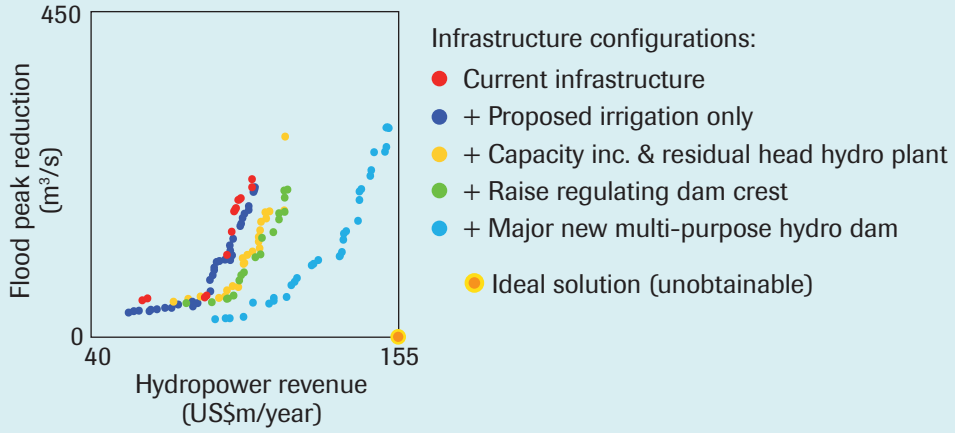
Different variations of the analyses above have been conducted in various countries. The case study boxes below summarize two examples for trade-off analyses from Nepal and Kenya.

Kenya – New Hydropower and Irrigation Investments on the Tana River

In Kenya's Tana basin there is competition for water between key economic sectors and the environment. The basin has 4.4 million inhabitants, 567 MW of installed hydropower capacity, 33,000 ha of irrigation, and ecologically important wetlands and forests. This study sought to identify and help decision-makers visualize reservoir management strategies that result in the best possible (Pareto-optimal) allocation of benefits between sectors. The study also seeks to show how trade-offs between achievable benefits shift with the introduction of new proposed rice, cotton and biofuel irrigation projects.

The management decisions investigated here are the volume-dependent reservoir release rules for the three major dams, and the extent of investment in new irrigation schemes. These decisions are made to maximize the provision of water supply and irrigation, energy generation, and maintenance of ecosystem services, which underpin tourism and local livelihoods. Ecosystem services depend on floods which inundate floodplains in the lower Tana basin. Trade-off plots help stakeholders assess multi-reservoir rule-sets and irrigation investment options by visualizing their impacts on different beneficiaries. Results quantify how economic gains from proposed irrigation schemes trade-off against disturbance of the ecosystems and local livelihoods. Full implementation of the proposed schemes is shown to come at a high environmental and social cost (Hurford and Harou, 2014).

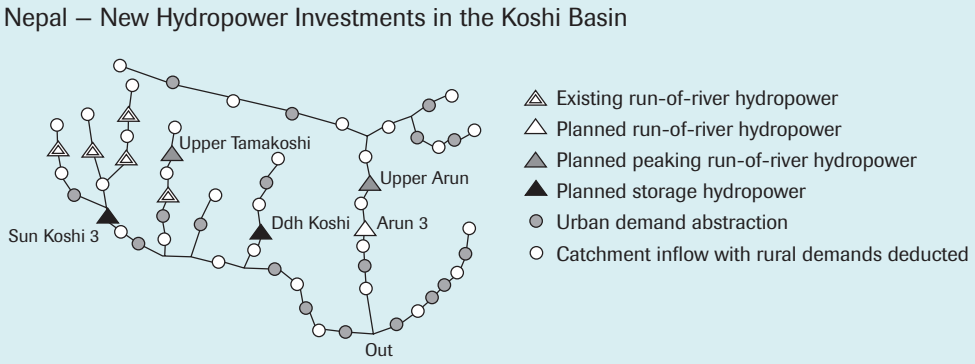
FIGURE 3. Infrastructure configurations and trade-offs



Trade-offs implied by different operating modes of key existing and planned infrastructure in Kenya's Tana basin.
Source: The University of Manchester, WISE-UP to Climate project

Nepal – New Hydropower Investments in the Koshi Basin

FIGURE 4. Planned hydropower projects in the Koshi basin study

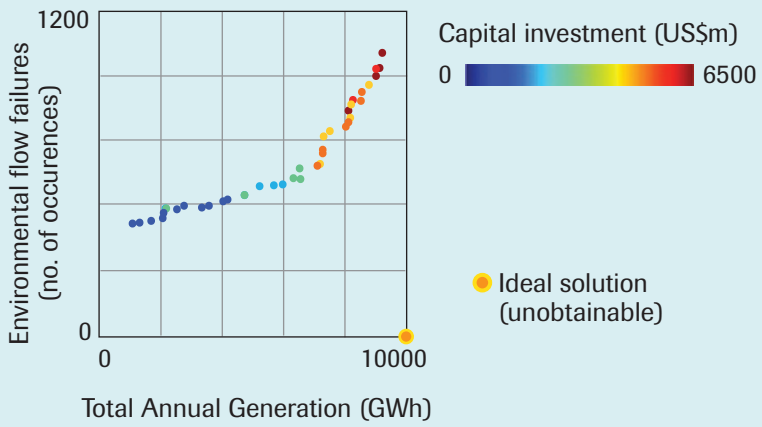


Source: World Bank, 2016

This study used a river basin impact model to simulate the Koshi basin hydropower system and its operation over a 30-year period. The system simulation includes various run-of-river and storage hydropower dams under consideration. Metrics considered included hydropower generation, the reliability and resilience of irrigation, water supply allocations, and environmental flows.

The system simulation model was linked to a multi-criteria search algorithm that filtered billions of possible combinations of investments and their operating modes to identify a small set of high-performing portfolios (the most efficient and robust combinations of options), given a range of uncertainties. This high-performing group of proposed projects and the trade-offs between their benefits was assessed visually (e.g. Figure 5 below, which shows the trade-off between the number of expected negative environmental events and hydropower generation).

FIGURE 5. Koshi basin study trade-off



Koshi basin study trade-off between the number of environmental flow failures over a 30-year period and the annual power generation with colour of points representing the capital costs of new hydropower projects. Source: World Bank, 2016

These case studies underscore how basin-scale assessments of hydropower systems are most useful when interdependencies exist between various parts of the environmental-economic system and/or when the various possible interventions are contested. In this case, system-scale trade-off analysis (Geressu and Harou, 2015) can help bring clarity about the performance of different bundles of proposed projects. System-scale assessment of hydropower investment is especially useful when the following apply:

- Various hydropower investments are being considered at multiple sites and they might impact each other, as well as existing uses and infrastructure projects.
- Diverse benefits are expected from the water system (e.g., hydroelectric generation, municipal and agriculture supply, flood control and others), development will cause negative impacts, and trade-offs between these interests and their stakeholder groups need to be managed to reduce conflict and achieve broadly shared development benefits.
- Decisions about new hydropower projects are sensitive to uncertainties such as climate change, future energy demands, energy prices, etc.

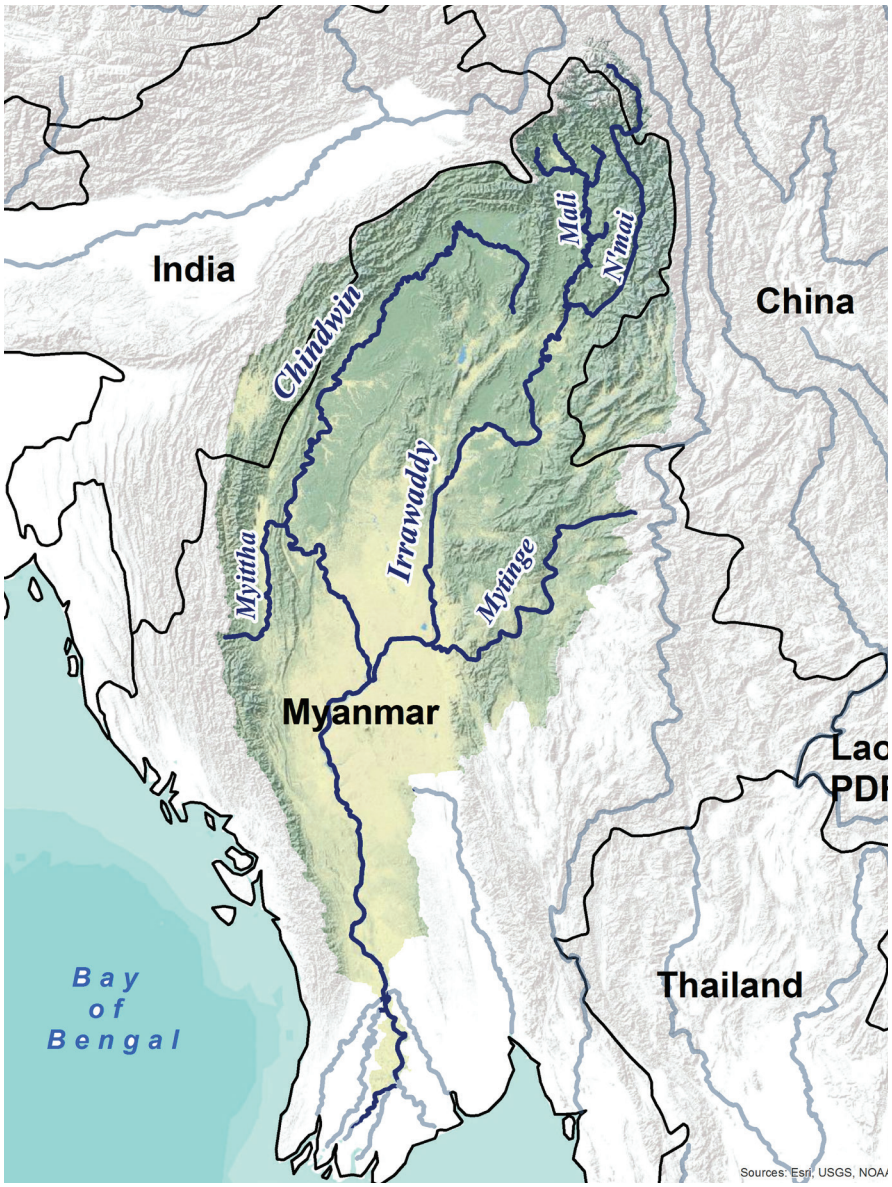
Because almost any part of a system can affect the performance of many or all other parts, system-scale analysis can reveal insights that are surprising and would not emerge from simpler, independent analyses of individual projects.

PHOTO: © Günther Grill

Chapter 3: Water Resources and Hydropower Development in Myanmar

This study adapted the generic approach described in the previous chapter to the specific situation in Myanmar and its Irrawaddy River basin, with primary focus in a selected sub-basin, that of the Myitnge River. This chapter provides background information that was used to build the model and that will help to interpret model results and the conclusions drawn in the final chapter. It should be kept in mind that there is very little publicly available information on planned hydropower projects, their water resource management implications, and environmental and social impacts. Myanmar has only recently introduced formal EIA requirements, and EIA documents and license conditions are not easily accessible.

MAP 3. Topographical Map of the Irrawaddy Basin



MYANMAR IS RICH IN WATER RESOURCES

Myanmar is a lower middle-income country with a population of 53 million and an income per capita (PPP) of US$4,706 per year. The country encompasses 676,590 square kilometers (about the size of France), and has abundant natural resources with 46 percent forest cover and 1,003 billion cubic meters per year of renewable internal freshwater resources. Per capita, this is more than twice as much water as the United States and more than 15 times as much as China. About 506 freshwater fish species have been recorded, 56 of which are endemic, and Myanmar is the world's fourth country in terms of inland fisheries captures.

Myanmar's two main rivers, the Irrawaddy and Salween, are part of a group of rivers–the others include the Brahmaputra, Mekong, Yangtze, and their tributaries–that arise in the eastern Himalayas and are fed by tropical monsoons. The Brahmaputra, Irrawaddy and Salween are also some of the world's largest and longest remaining free-flowing rivers, providing habitats to many freshwater species and important ecosystem services. Due to the monsoon climate, river runoff is highly variable between the seasons and also from year to year. There are about 13,000 square kilometers of permanent waterbodies in Myanmar, and 70,000 square kilometers of seasonal floodplains.

Myanmar's two main rivers, the Irrawaddy and Salween, are highly revered by its people. The Irrawaddy rises from the northern border regions with China, populated by Kachin people, and then flows through the heartland of the majority Bamar population. The Salween (also called the Thanlwin, and the Nu Jiang in China) forms in China and flows through a narrow valley for most of its course, forming the boundary between Thailand and Myanmar after it leaves China, and then becoming fully within Myanmar's borders. It is the main artery in the east of the country, populated by Shan and other minorities. Ethnic divisions and conflicts over natural resources, such as timber and minerals, have led to many conflicts in the region, some of which are unresolved.

The Irrawaddy (also called the Ayeyarwady) carries between 2,300 and 32,600 cubic meters per second and, especially during tropical cyclones, can cause major flood damage in the lowland floodplains and the delta (such as occurred in 2015). The fertile delta is 22,000 square kilometers large and is maintained by a large sediment load, estimated at 360-400 million tons per year. The delta coastline has remained largely stable since sufficiently precise records are available, suggesting equilibrium between sediment deposition and erosion. The freshwater ecology is poorly known, but generally assumed to be similar to the Mekong River. For example, small populations of the same species of freshwater dolphin survive in the mid-sections of both rivers. Within the Irrawaddy, 119 fish species have been recorded, though the basin likely supports a much higher number of species. There have been no surveys of freshwater sites of high conservation values that could be used to define 'no-go areas' or biodiversity offsets.

Myanmar's main rivers are also some of the world's largest and longest remaining free-flowing rivers, providing habitats to many freshwater species and important ecosystem services.

PHOTO: © Jeff Opperman

SEVERAL ECONOMIC SECTORS ARE SHARING THE IRRAWADDY

Key users of river resources in the basin include irrigated agriculturalists in the central dry zone of the country, communities that are dependent on water supply, the navigation sector, fishermen, and the hydropower sector.

Total water withdrawals in Myanmar are about 33 billion cubic meters per year, or 3 percent of renewable resources. Irrigated agriculture, most of it rice cultivation, is by far the largest water user, with 89 percent of all withdrawals and over 2 million ha or 18 percent of all agricultural land. By 2005, the Irrigation Department had constructed approximately 200 irrigation projects, and about 18 billion cubic meters (or half the annual withdrawal volume) can be stored in its reservoirs. Sedimentation of reservoirs is rapidly reducing their useful life. Reservoirs are stocked with fish, but fishing is not officially permitted. Irrigation reservoirs constructed in more recent years have often been multi-purpose reservoirs, providing other services such as flood management and small-scale hydropower generation. Domestic and industrial water supply is sometimes taken from reservoirs, but generally from smaller tributaries and groundwater, and abstractions are not a significant part of the total resource.

Navigation on the Irrawaddy at Mandalay just upstream from confluence with Myitnge.

PHOTO: © Joerg Hartmann

Navigation on the Irrawaddy–both by passenger and by cargo vessels–is an important part of the country's transport system. With economic growth, significant increases in freight transport are expected. Navigation is affected by increasing sedimentation, presumably because of land use change, and low depths in the dry season.

Myanmar in general, and the Irrawaddy in particular, have some of the most productive fisheries in the world. According to official data reported by the Food and Agriculture Organization of the United Nations (FAO), the inland capture fisheries yield increased rapidly from 290,000 tons in 2003 to 1.3 million tons in 2013; 78 percent of this came from open access, the rest from leasable fisheries. This is more than twice as much as the next productive South East Asian nations, Indonesia and Cambodia. Inland capture fisheries provided full-time employment for 490,000 people in 2013, and part-time employment for 1.1 million people. All these data are thought to be uncertain, and are possibly significant underestimates. Subsistence fisheries are an important contribution to livelihoods, especially for landless households. Myanmar also has very significant aquaculture and marine fisheries production. About 7 percent of the total catch is exported. Fish is a much more important component of the national diet than meat, and consumption per capita is estimated at roughly 40 kilograms per year.

THERE IS CONSIDERABLE INTEREST IN DEVELOPING MORE HYDROPOWER

Because of its abundant water resources and the significant elevation drops from its mountains, the country's total technical hydropower potential is estimated at 100 GW, of which only 3.1 GW have been developed to date. The Irrawaddy basin alone is estimated to account for 38 GW of potential capacity. There are no dams on any of the mainstreams; the first one would have been the Myitsone Dam on the upper Irrawaddy, which was suspended by government in 2011. Myanmar therefore has an exceptionally large range of choices still available regarding the siting of its future hydropower projects and how to achieve balance between hydropower and other values.

Inland capture fisheries provided full-time employment for 490,000 people in 2013, and part-time employment for 1.1 million people.

Electricity consumption per capita, at 153 kWh/year, is extremely low by international standards. The share of hydropower in total electricity generation is above 70 percent, and the last government's plans for increasing generation are largely based on hydropower. Based on a high demand growth scenario, the Ministry of Electric Power estimated that by 2030 hydropower would have to provide sufficient capacity to satisfy a domestic demand of 14.5 GW along with a 30 percent reserve margin, a 32 percent 'hydro effect' margin (to accommodate lower dry season flows), and a 23 percent margin for exports by Independent Power Producers (IPPs). These margins result in a projected need of installed capacity that is 185 percent of 14.5 GW, or 26.8 GW.

Electricity consumption per capita is extremely low by international standards, at 153 kWh/year.

A draft national power master plan, prepared with the support of Japan International Cooperation Agency (JICA), is being discussed, but does not go to the level of prioritizing individual hydropower projects. The incoming government will want to review the plans and may steer power development in a different direction. Reflecting the opinion of much of civil society, the National League for Democracy's Election Manifesto articulates strong support for sustainable energy sources and signaled that it would take a fresh look at the role of large hydropower in the country's energy system

PHOTO: © Jeff Opperman

(Box 1). However, some new hydropower will likely be part of the preferred supply mix. For example, WWF's energy vision for Myanmar includes 11.9 GW of hydropower by 2050 for a 'business-as-usual' scenario, and 8.2 GW in a 'sustainable' scenario.

BOX 3. National League for Democracy, 2015 Election Manifesto Excerpt

The freedom and security to prosper

Changing people's lives for the better requires having the freedom and security to prosper. For the sectors set out below, the NLD will take the following actions:

vii) Energy

2. The construction of the large dams required for the production of hydropower causes major environmental harm. For this reason, we will generate electricity from existing hydropower projects, and repair and maintain the existing dams to enable greater efficiency.

viii) Environment

The NLD will carry out the following activities in order to reduce the current levels of pollution and environmental harm, and to create a better environment:

5. Land and water:
   c. We will enact a law in order to protect against the destruction of the watershed area, groundwater, swamp and tidal zone ecosystems, and to protect the water flow.
9. Investment:
   a. We will enact legislation to assess and evaluate the risks of environmental harm resulting from domestic and international investment.
   b. We will encourage research and investment to reduce environmental damage and support environmental rehabilitation.

According to Myanmar's Ministry of Electric Power (recently renamed Ministry of Electricity and Energy), the following numbers of projects are in various stages of preparation (note that there are various lists in circulation, which are not entirely consistent with each other). If all of these were developed, the installed capacity would increase 14-fold, and the average size per project would increase five-fold:

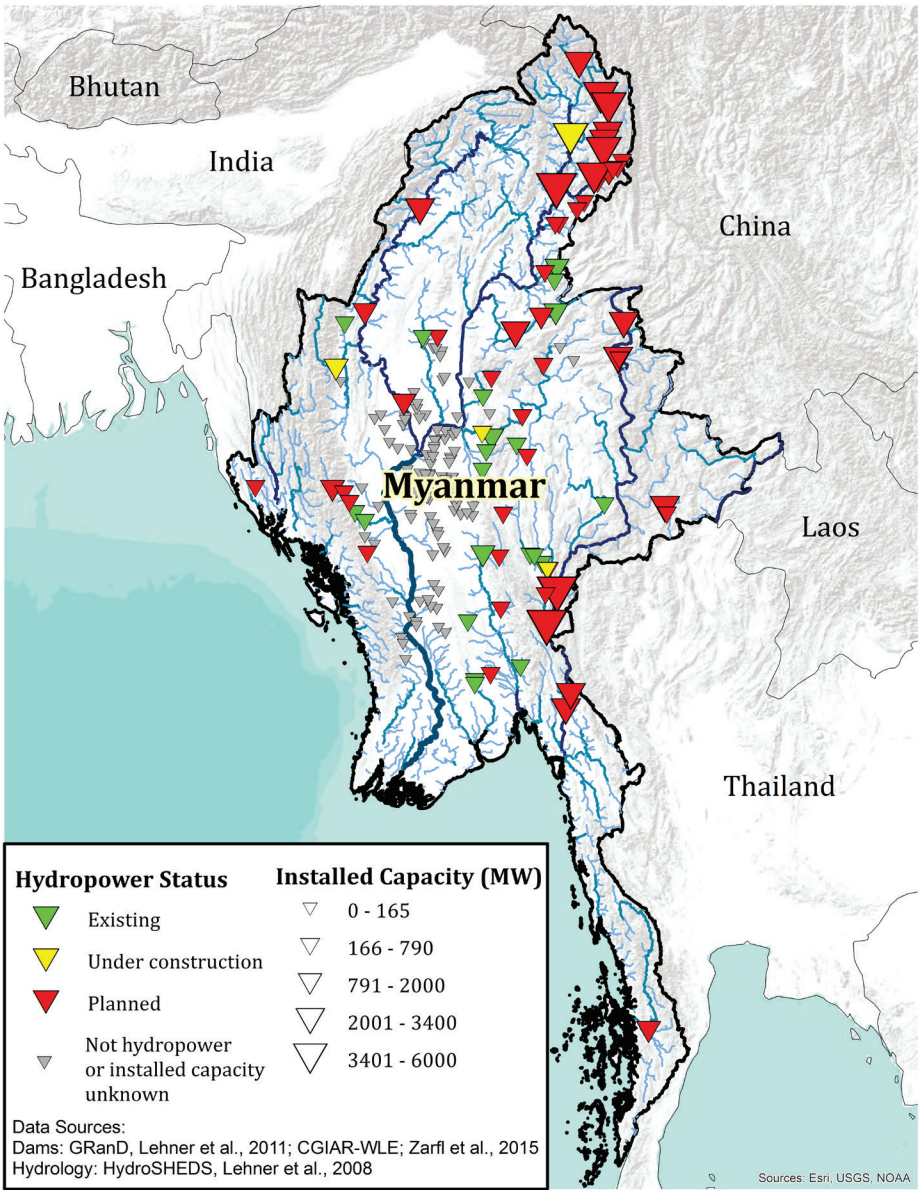
TABLE 3. Hydropower dams in Myanmar

Development Stage (from most advanced to least advanced)	No. of Projects	Installed Capacity (MW)	Average Installed Capacity per Project (MW)
In Operation	25	3,151	126
Under Construction	6	1,522	254
Environmental License, Joint Venture Agreement (JVA)	4	12,700	3,175
Feasibility Study, Memorandum of Agreement (MoA)	19	16,970	893
Memorandum of Understanding (MoU)	12	8,583	715
Planned/Proposed by Developer	4	783	196
Total	70	43,709	624

Source: Ministry of Electric Power, Myanmar

As can be seen on the map below, most of the hydropower potential is located in the north-eastern states, which are populated by ethnic minorities and under only partial control by the central government. According to an overview of hydropower potential by state, out of a total of 46.1 GW, 41 percent is in Kachin State, 27 percent is in the Shan States, and 15 percent is in Kayin State, including almost all of the projects larger than 1,000 MW. This has presented a dynamic and complex political situation for foreign investors and many projects have suffered setbacks.

MAP 4. Map of hydropower projects in Myanmar



Source: The Nature Conservancy.

The Myitnge River, a medium-sized left-bank tributary, enters the Irrawaddy just downstream of Mandalay.

PHOTO: © Emily Chapin

INSTITUTIONAL AND STAKEHOLDER INTERESTS IN WATER RESOURCES ARE NOT WELL ARTICULATED

All water-using sectors are under direct control by their respective ministries, which reflects a history of an authoritarian government with little room for private enterprise. In recent years, government became more willing to give licenses to local and foreign businesses; while this accelerated investment, government did not seem to have the capacity to carefully vet the investment proposals, creating opportunities for corruption.

The power secor can serve as an example for the issues facing government agencies. Before its recent merger with the Ministry of Energy, the Ministry of Electric Power comprised seven departments and companies, through which it owns practically all power assets in the country. The responsibilities of the departments and companies are not always clearly defined. The incoming government intends to streamline the administrative structure across all agencies. In the hydropower sector, important reforms would cover the planning and selection of projects as well as regulatory approaches with respect to review, licensing, impact mitigation, compensation and benefit sharing, and the terms of joint venture and concession contracts between investors and the government. The incoming government will need some time to redirect the bureaucracy away from previous policies, and may consider the rationalization of the sector structure, for example through the 'unbundling' of policymaking, planning, regulatory and corporate functions, as the most urgent priority.

Similar issues apply to the other water sector-related agencies, such as the Ministry of Environmental Conservation and Forestry (now called the Ministry of Natural Resources and Environmental Conservation); the Ministry of Transport (now called the Ministry of Transportation and Communications and includes the Directorate of Water Resources and Improvement of River Systems, as well as the Department of Meteorology and Hydrology); the Ministry of Livestock, Fisheries and Rural Development; and the Ministry of Agriculture and Irrigation (these have been combined into the Ministry of Agriculture, Livestock and Irrigation). In addition to internal structural and capacity challenges, the different departments also find it difficult to coordinate and cooperate. In recognition of this challenge, and to promote integrated water resources management, the National Water Resources Committee (NWRC) was established in 2013. It has not developed major influence so far, but will be strengthened through an ongoing program financed by the World Bank.

Non-government stakeholders include communities, businesses and business associations; regional and ethnic groups; civil society organizations, both domestic and international; the media; academia; and bilateral and multilateral development partners and organizations. The number of these stakeholders is growing, and after many years of authoritarian rule Myanmar needs to develop new approaches to accept stakeholder interests as legitimate, encourage pluralistic opinions, and involve them in policy development and on the decisions on specific investments. Through expert groups and other mechanisms, NWRC is making an effort to improve engagement with non-government stakeholders.

A SUB-BASIN CAN ILLUSTRATE THE ISSUES RELATED TO HYDROPOWER DEVELOPMENT

In order to demonstrate the proposed planning approach and its potential to improve the quality and legitimacy of decisions, this study elected to focus on the Myitnge River, a medium-sized left-bank tributary that enters the Irrawaddy just downstream of Mandalay–the second biggest city in Myanmar. The Myitnge comes from the Shan plateau and generally flows in a southwesterly direction. At the confluence with the Irrawaddy are the remains of the ancient Burmese capital Inwa, highlighting the historic strategic importance of these rivers.

According to a river reach classification exercise by WWF for the Greater Mekong Region, the mainstem of the Myitnge is considered a large river (long-term average discharge between 100 and 1,000 cubic meters per second), with medium variability (ratio between maximum and average long-term monthly discharge between 2 and 2.25); associated floodplains and a low gradient (< 0.25 percent) near the mouth, increasing to medium gradient and sections of high gradient (> 1.5 percent) further upstream; a small quantity of coarse sand and gravel; and largely flowing through a low elevation karst landscape (one of the more frequent river classes, with 10.4 percent of all streams in the Greater Mekong Region above 1 cubic meters per second).

While there is a lack of more detailed publicly available data about the Myitnge basin, this initial analysis is to illustrate the potential for a system-planning approach and we overcame the limited local data by using globally available data or plausible assumptions. We focused on 10 metrics that could be positively or negatively affected by hydropower development.

Four of the ten stakeholder interests are defined at the mouth of the Myitnge, and are related to its contributions to the overall Irrawaddy basin. These include:

- Flood control, considering that the highest floods have negative impacts on livelihoods and infrastructure in the Irrawaddy floodplain;
- Navigation support, considering that the lowest flows have negative impacts on river traffic;
- Fishery support, considering that while the most productive fisheries are downstream in the delta, the Irrawaddy is one interconnected ecological system and fish depend on the tributaries; and
- Sediment delivery, considering that erosion and sediment transport are natural processes and trapping of sediment in reservoirs not only reduces their storage capacity and value, but also in the long run, leads to undesirable geomorphological changes such as riverbank erosion and loss of land along the Irrawaddy.

Three other stakeholder interests are locally relevant, in the sub-basin itself. These include:

- People that may be displaced by hydropower projects;
- Forest cover that may be lost; and
- Local fish biodiversity that may be impacted.

Finally, there are three stakeholder interests that are relevant from the point of view of the country's power sector:

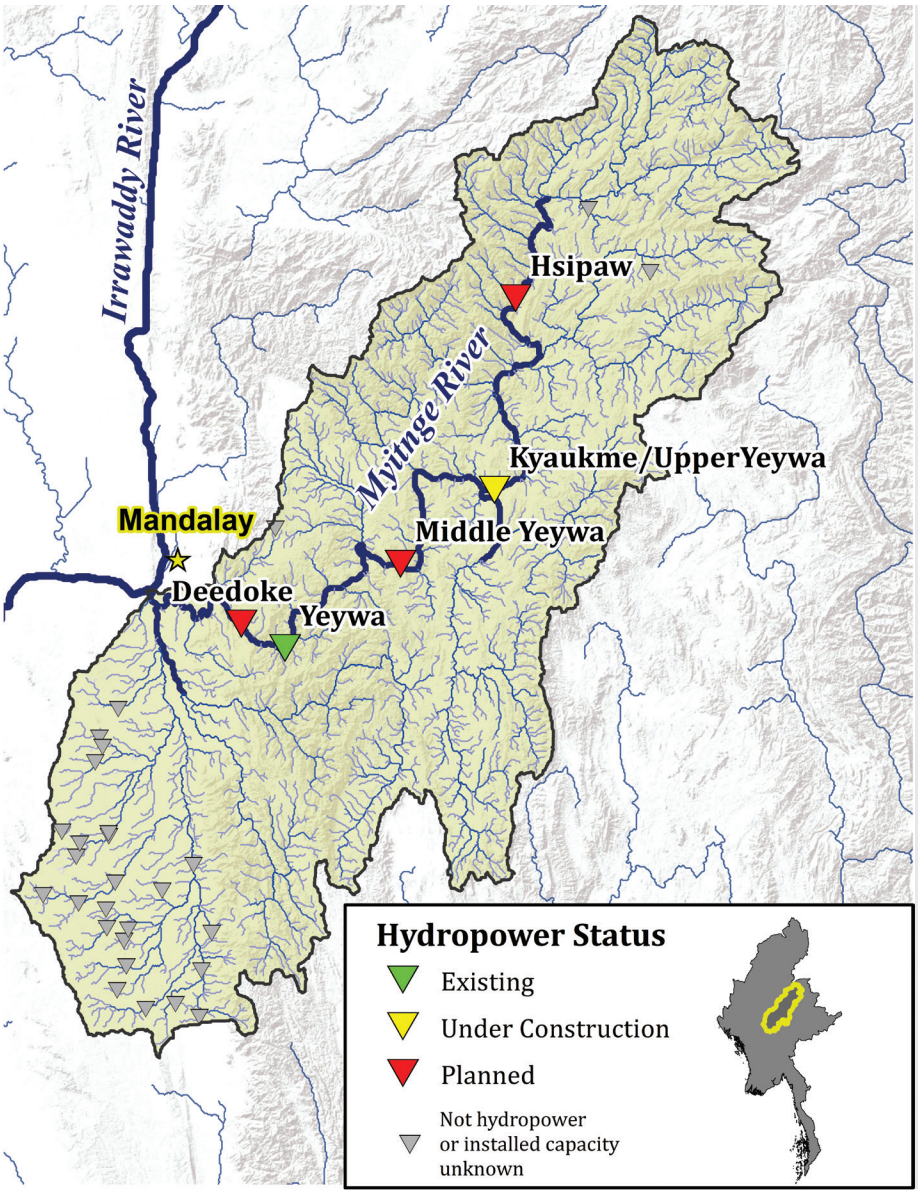
- The potential contribution of the sub-basin to total generation;
- Firm generation; and
- Investment costs associated with the different hydropower options.

PHOTO: © Joerg Hartmann

EVEN A SMALL CASCADE CAN REVEAL THE BENEFITS OF SYSTEM-SCALE PLANNING

The Myitnge already has one major operational project, the recently commissioned Yeywa (790 MW), located approximately 50 km east of Mandalay,. This is the largest power plant in Myanmar. Upstream, the government is building its second project in the cascade, Upper Yeywa (289 MW). Two additional projects along the mainstream of the Myitnge are under preparation by SN Power (Middle Yeywa) and by a consortium including K-Power and Andritz (Deedoke). Several variants of Middle Yeywa are being considered, and for simplicity, only a high dam and a low dam variant are included in the analysis. Deedoke would be a low-head dam with very little additional storage at the bottom of the cascade. Another project called Hsipaw has been identified that would complete the cascade, with a total head over the five dams of about 400 m, from 470 m.a.sl. to 70 m.a.s.l (meters above sea level). There are a number of smaller irrigation and multi-purpose dams in the basin, either existing or planned, and most of them in the southern part of the Myitnge basin, which belongs to the country's dry zone. An inter-basin transfer to provide additional irrigation water to the Meikthila Plains also presents interesting water resource implications; but to simplify the analysis, only the five-dam cascade was considered.

MAP 5. Current existing, under construction and planned dams on the Myitnge River basin



Source: The Nature Conservancy.

Chapter 4: Assessing Hydropower Trade-Offs in the Myitnge River Basin

This chapter describes an application of the approach to system-scale planning of hydropower summarized in Chapter 2. The Myitnge River basin was used to aid a demonstration of the approach because the river has a manageable number of development options, more easily considered than would be the case with the whole of the Irrawaddy Basin, for example. For some metrics that are most relevant at the scale of a larger basin, we also conducted some initial spatial analyses at the level of the whole Irrawaddy basin, which is presented at the end of this chapter. Through this relatively simple case, we aim to show how a system-scale approach helps identify high value combinations of hydropower investments that would likely not have been identified via a project-by-project approach.

In order to investigate the impacts of different infrastructure investment and operation options on the performance of the Myitgne basin, a river basin simulation model was built to represent the main channel of the river basin and the existing and proposed dams along it. The simulation model outputs 10 metrics of system performance which correspond to a variety of stakeholder interests. These metrics evaluate the performance of the system resulting from different interventions. Note that due to time constraints, and because this is an initial rapid implementation, the metrics were selected by the project team to represent sectors and resources we know to be important in this region. A more advanced application of this should include extensive stakeholder engagement to define and refine metrics.

The model provides "trade-off curves" (in two dimensions) or trade-off surfaces (in multiple dimensions), which allow decision-makers to better visualize their options, and balance performance across many factors.

The simulation model was coupled to a search algorithm to filter a large number of possible hydropower development interventions to identify those which maximize the efficiency of water use and illustrate to decision-makers the highest performing alternatives for balancing the costs and benefits accruing to different stakeholders.

HOW WAS THE MODEL BUILT?

A detailed technical description of how the Myitnge River simulation model was built is provided in Annex 3. This section will only provide a cursory introduction, to give the reader a sense of which data and assumptions would typically go into such a model.

The key elements are the following:

- Inflows to the river basin model were generated by combining long-term mean monthly river discharge data for each dam location on the Myitnge, derived from a global model, with 11 years of observed monthly flow data for Sagaing gauging station on the Irrawaddy River.

PHOTO: © Emily Chapin

- The model represents the impacts of decisions from adding infrastructure and a range of operations of existing or future dams. The Myitgne River basin has one existing dam, one dam under construction, and three proposed dams. The Upper Yeywa is currently under construction, and this decision cannot be reversed, so is treated here as an existing dam. The proposed dams include Deedoke, Middle Yeywa and Hsipaw. Middle Yeywa was considered to have two mutually exclusive design options, "high" dam height and "low" dam height.
- In terms of investment decisions, there are 12 possible combinations of the proposed dams, but there are many more possible combinations when one considers the different ways the dams could be operated. In the model, each dam's releases were controlled by a storage-dependent release rule curve which dictates how much water should be released at each model time step. The model was run at a monthly time step, as higher resolution flow data were not available during this study. Releases from the dams went first to hydropower turbines then to support downstream flows.
- Ten performance metrics were developed to represent a diverse range of stakeholder interests in the performance of the basin (Table 4). Some of these metrics represent positive impacts that should be maximized, others negative impacts that should be minimized. We tried to define metrics to quantify issues that stakeholders care about directly, rather than abstract notions that they would find difficult to interpret. However, some metrics may require further improvement. Stakeholders may not immediately recognize that sediment trapping in reservoirs has long-term consequences for loss of land in the delta, for example.
- The definition of the metrics involves multiple assumptions that are largely based on plausibility, rather than dedicated research. For example, there is no ecological model available that would link the building of dams in the Myitnge basin to changes in fish biomass in the Irrawaddy river system. In the absence of such a model, we assumed that primary fishery support depends equally on three factors: connectivity, nutrients and natural flow variations. We did not consider mitigation actions, such as fish ladders and sediment flushing, to keep the model simple and because in practice such mitigation actions are often costly and do not work particularly well. As better models become available, these coarse data and assumptions can easily be replaced.
- The river basin model was linked to a search algorithm which filters through the billions of possible combinations of projects and operating rules to find those which perform best. Specifically it seeks investment portfolios that maximize (or minimize) each of the metrics until no further improvements can be found in one dimension of performance without simultaneously decreasing one or more other metrics. This process identifies the non-dominated or 'efficient' set of hydropower investment portfolios (grey points in Figure 1, page 8), which can be displayed in trade-off plots.

TABLE 4. Performance metrics, definitions and search goals

Metric	Targeting to Maximize or Minimize	Definition
Fish Biodiversity	Max	Number of species in Myitnge sub-basin
Navigation	Max	Lowest monthly average flow, in m^3/s
Annual Generation	Max	Average annual generation in kWh
Flood Control	Min	Highest monthly average flow, in m^3/s
Firm Generation	Max	Monthly generation that can be reached in more than 90% of all months, in kWh
Capital Expenditure	Min	Capital expenditure on additional dams, in USD
Fishery Support	Max	Contribution of Myitnge sub-basin to overall fish biomass in the Irrawaddy basin
Sediment Load	Max	Sediment delivery, tons/year
Displaced People	Min	Number of people living in reservoir area
Forest Loss	Min	Hectares of forest in reservoir area

RESULTS CAN BE USED TO DISCUSS TRADE-OFFS ASSOCIATED WITH DIFFERENT PORTFOLIOS OF DAMS

The approach generates "trade-off curves" (in two dimensions) or trade-off surfaces (in multiple dimensions), which allow decision-makers to better visualize their options and balance performance across many factors. Table 5 shows which stakeholder interests are not compatible with each other; it is these trade-offs that would become the focus of discussion.

TABLE 5. Trade-offs between performance metrics are indicated by an X at the intersection of rows and columns

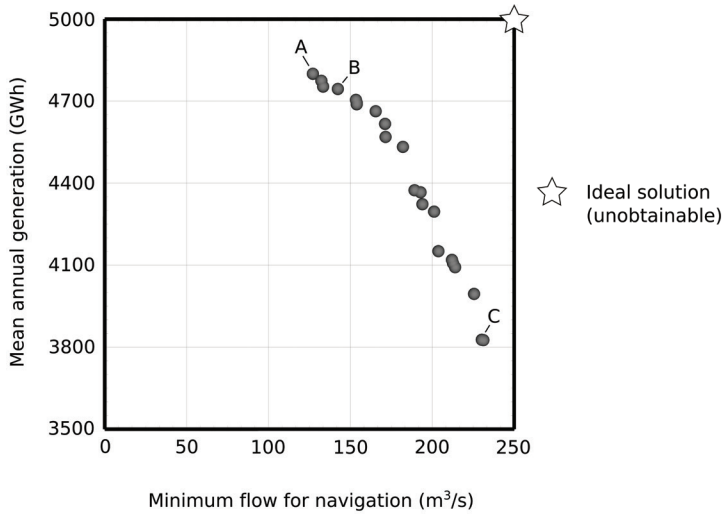
	Fish Biodiversity	Navigation	Annual Generation	Flood Control	Firm Generation	Investment Costs	Fishery Support	Sediment Load	Displaced People	Forest Loss
Fish Biodiversity			X		X		X	X		
Navigation			X	X	X	X	X			
Annual Generation				X	X	X	X	X	X	X
Flood Control					X	X	X	X	X	X
Firm Generation						X	X	X	X	X
Capital Expenditure							X			
Fishery Support								X	X	X
Sediment Load										
Displaced People										
Forest Lost										

In practice, it will be difficult for stakeholders to understand how the performance of different portfolios can be compared across ten metrics (i.e., in a ten-dimensional decision space). To illustrate how results could inform such dialogue, here we present how decision-makers and/or stakeholders could use the results to explore investment options. Below we show a sequence of trade-offs between a subset of two metrics, and then add additional metrics, to show how the approach reveals high performance system designs that would be unlikely to emerge through a project-by-project approach.

TRADING-OFF HYDROPOWER AND NAVIGATION BENEFITS

We first consider how various levels of hydropower generation might impact navigation downstream. Figure 6 shows how annual generation from Myitnge River hydropower dams could be balanced with flow releases to promote downstream river navigation. Each of the points in the plot represents the performance achieved by a set of existing and proposed dams and their operations. Each point can be considered an option for intervention in the Myitnge Basin, although some options may only involve changing the operations of existing dams.

FIGURE 6. Modelled trade-offs between mean annual hydropower generation and minimum flow for navigation



Each point shows the performance achieved by a unique combination of infrastructure investment and operating rule interventions, representing an option for decision-makers.

Parties interested in the supply of electricity to the grid would be likely to favor Option A, which maximizes mean annual generation. By contrast, those interested in maximizing downstream navigation would be likely to favor Option C. The 'cost' of Option C's improved navigation in terms of reduced power generation from Option A is over 900 GWh per year, on average (or around 20 percent of the maximum). These two parties could negotiate based on this information to find a balance or compromise between their interests. They might hypothetically settle on Option B, where around 55 GWh per year of hydropower generation is exchanged (traded) for increased low flows of around 150 cubic meters per second. Other compromises could be reached based on the parties' more intimate knowledge about their needs such as details around timing of low flows or generation, which were not available for this demonstration study. Balances based on such details could be investigated by refining the model and/or metrics of performance. The infrastructure portfolio behind each of the options is shown in Table 6.

TABLE 6. Infrastructure combinations and performance of intervention options

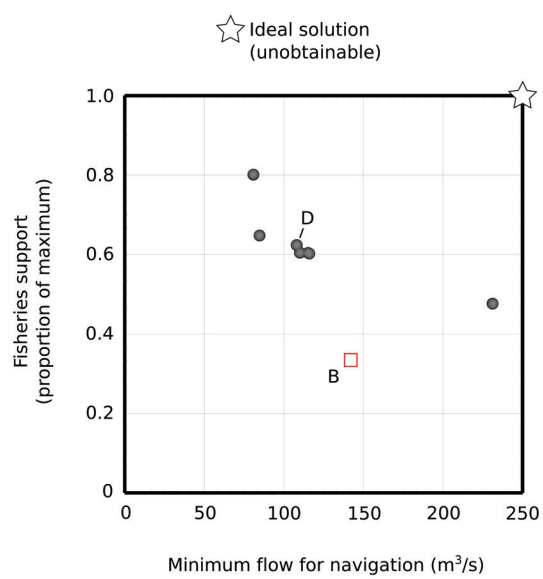
	Intervention option		
New projects	A	B	C
Deedoke	x	x	
Middle Yeywa (low)	x		
Middle Yeywa (high)		x	
Hsipaw	x	x	

Infrastructure combination which is required, in conjunction with unique operating rules, to achieve the performance of intervention options from Figure 6.

IMPACTS ON OTHER STAKEHOLDER INTERESTS: SUPPORTING FISHERIES

Assuming, in the interests of discussion, that a negotiation between the parties represented in Figure 6 resulted in Option B being selected as an acceptable balance, then we can investigate implications of this choice for other stakeholders. In Figure 7, the performance of Option B from Figure 6 is plotted alongside the intervention options which most efficiently balance support for fisheries and minimum flows for navigation. This shows that Option B does not perform well in terms of support for fisheries, so stakeholders interested in fisheries would be unlikely to support this option. Figure 7 shows a 'step' in the relationship between support for fisheries and minimum flows for navigation at Option D. Such steps represent opportunities to increase performance toward one objective without substantially affecting the other. Given the requirement stated by Win Kyaw et al. (2006) for a 100 cubic meters per second 'riparian release' from Yeywa Dam, Option D could be an attractive balance between the interests of navigation and fisheries. Option D involves adding the Deedoke and Middle Yeywa (low) dams to the basin.

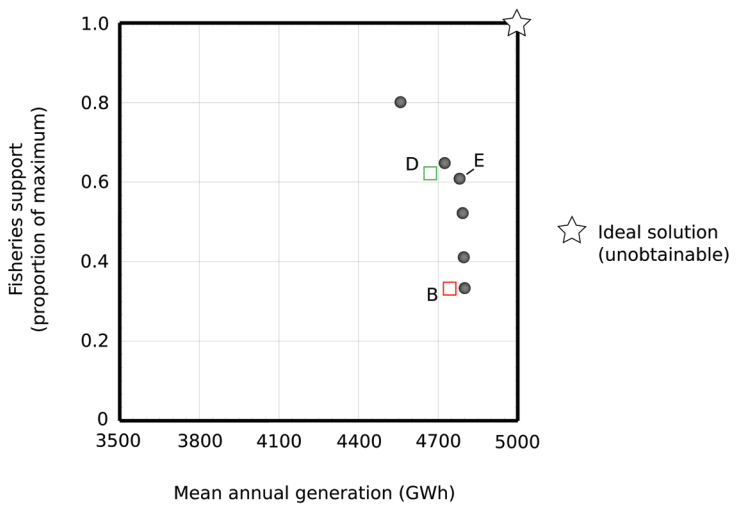
FIGURE 7. Trade-off between support for fisheries and minimum flow for navigation



Each point shows the performance achieved by a unique combination of infrastructure investment and operating rule interventions, representing an option for decision-makers. A red square shows the performance obtained by Option B from Figure 6 in terms of the two metrics on the axes.

Hydropower interests still need to be considered, however, so Figure 8 shows the best options for balancing support for fisheries with hydropower generation from the basin. The performance of options B and D are shown for reference, both of which perform close to the best options for balancing hydropower generation with fisheries support. Option E lies at a 'tipping point' where the unit decrease in hydropower generation for a unit gain in fisheries support changes. This makes Option E attractive as a balance between the two interests. Option E involves adding Deedoke, Middle Yeywa (high) and Hsipaw dams to the basin, but with different operating rules than Option B.

FIGURE 8. Trade-off between support for fisheries and mean annual hydropower generation



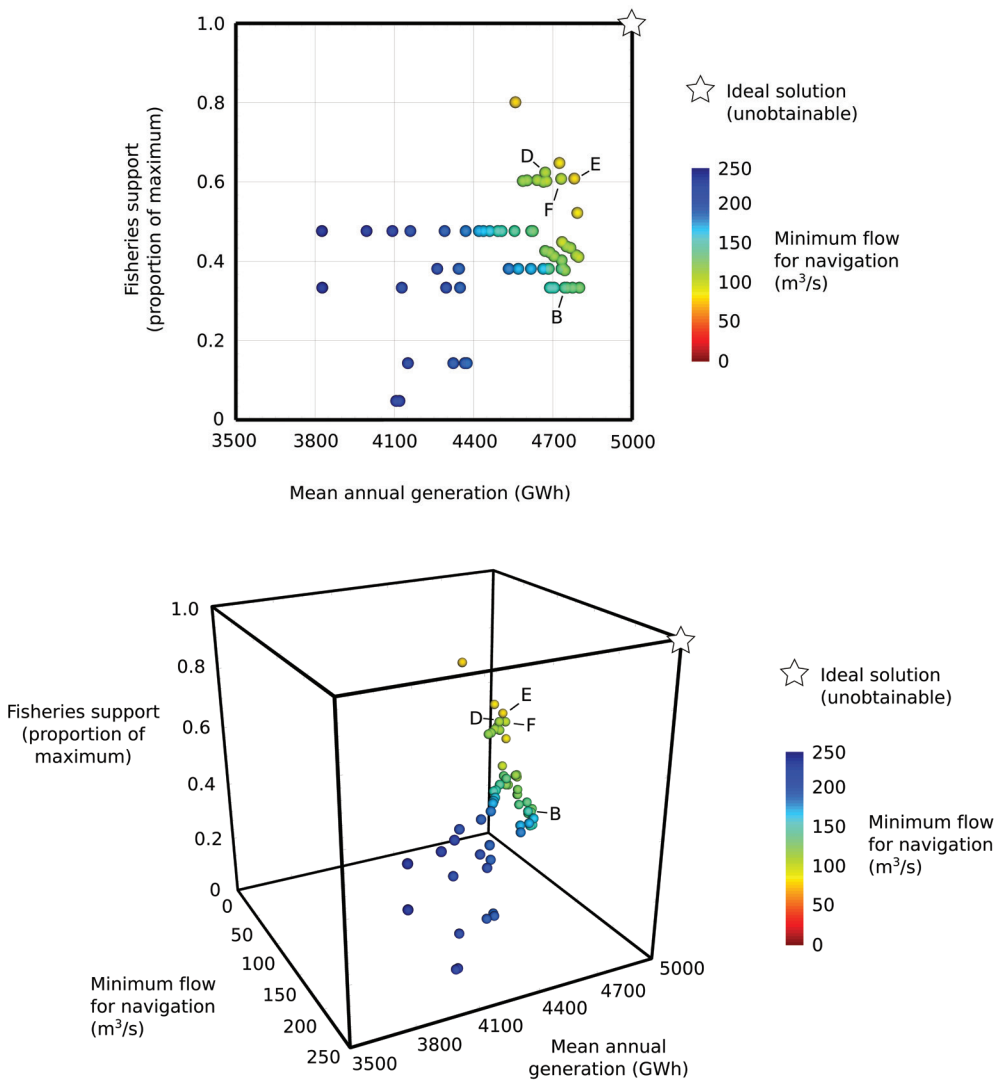
A red square shows the performance obtained by Option B from Figure 6 (page 39) and a green square shows the performance of Option D from Figure 7 in terms of the two metrics on the axes.

PHOTO: © Mutt Lunker

EXPANDING THE OPTIONS - CONSIDERING THREE METRICS SIMULTANEOUSLY

Figures 6 to 8 (pages 39-41) helped identify three different options B, D and E that provide different balances between performances for three metrics. None of these three is ideal because they resulted from considering only two metrics at a time. The number of ways to trade-off benefits increases as more benefits are considered simultaneously, so considering all three together may help to identify a better all-round performing portfolio than the three discussed thus far. Figure 9, below, shows that there is an Option F between Options D and E which provides higher generation than Option D but is more favorable to navigation than Option E. Option F was not included in any of the previous figures and was only revealed by considering the objectives together. Option F involves adding Deedoke, Middle Yeywa (low) and Hsipaw dams to the basin.

FIGURE 9. Trade-off between support for fisheries, minimum flows for navigation, and mean annual generation

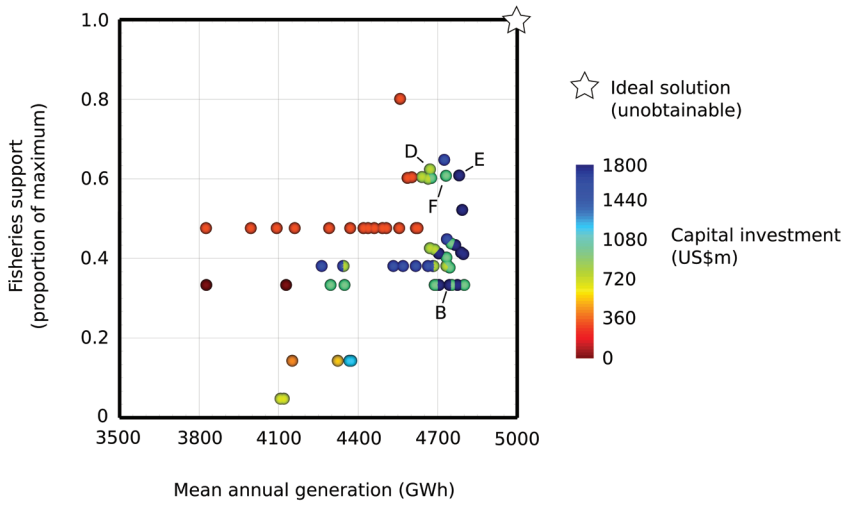


The top panel is a two-dimensional version of the plot, the bottom panel is a 3D version of the same plot. The performances of Option B from Figure 6 (page 39), Option D from Figure 7 (page 40) and Option E from Figure 8 are all shown in terms of the three metrics. Intervention package F is discussed in the next figure.

Figure 10, below, shows the same trade-offs from Figure 9, but with options colored to indicate their associated investment cost (a fourth metric), rather than their performance in terms of minimum flow for navigation. This shows that Option E was at the extreme end of the capital investment scale while Option F requires only a relatively small increase in investment over Option D–another reason to believe Option F could be attractive to all three sets of stakeholders.

In a real-world application of this system-scale approach, stakeholders would preferably be involved in defining the features of the system model and the metrics of performance used, as well as negotiating around the trade-offs revealed by the analysis. The approach is expected to be iterative, whereby stakeholders suggest changes or additions to the metrics or model as their understanding of the system increases and they require different information from the analysis.

FIGURE 10. Trade-offs between support for fisheries, mean annual generation and investment costs



The same trade-offs from Figure 9 but with portfolios colored according to the capital investment required. Hydropower portfolio F performs similarly to D with regards to the environment but produces more hydropower yet costs much less than portfolio E; perhaps it is a promising design.

SPATIAL ANALYSIS CAN ALSO INFORM DECISIONS AT LARGER SCALES

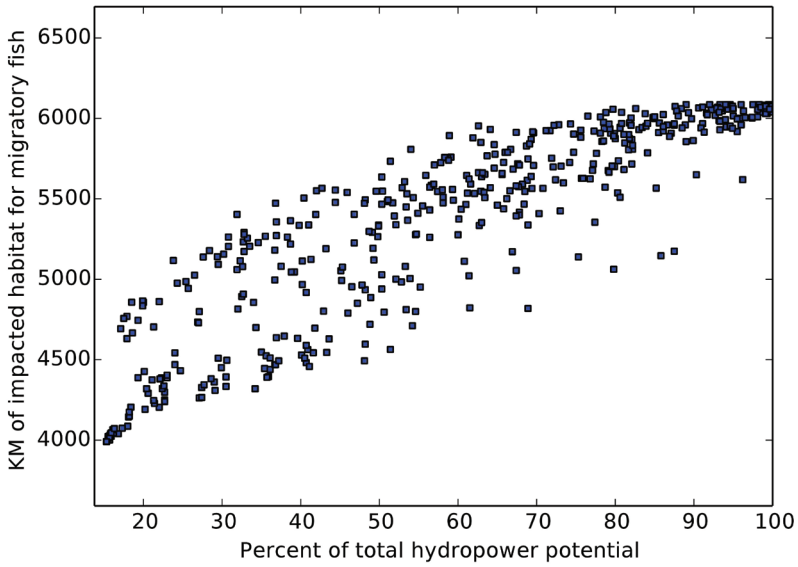
Trade-off analyses can be performed at a range of spatial scales. For illustration purposes, above we focused on the Myitnge basin. However, analyses at larger spatial scales can reveal additional insights about trade-offs that are not apparent at the scale of the Myitnge. For example, it may not be necessary to generate a certain amount of power in a given sub-basin because there are other sub-basins available. Also, resources may not be sufficient for building a river simulation model for a large basin, but would allow for simple spatial analysis in that large basin. In this case we examined hydropower and fragmentation of the Irrawaddy basin by dams. The same type of spatial analysis was performed as an intermediate step in the Myitnge model, for purposes of calculating fishery support. Here we look at fragmentation directly, with the understanding that barriers affect resources like migratory fish, navigation, and sediment transport, and fragmentation can serve as a proxy indicator for these impacts.

Figure 11 results from an analysis conducted for the Irrawaddy River basin using a basin-scale fragmentation metric (Grill and Lehner, 2015). There are already multiple dams in the basin, mostly irrigation dams, which result in some 4,000 km already affected as a baseline. The scenario model was set up to run a total of five hundred iterations for additional hydropower development in the Irrawaddy River basin. During each iteration, the model arbitrarily selected a random combination of dams from a proposed set of dams in the basin. For each scenario, it calculated the number of stream kilometers significantly affected by fragmentation.

One of the important insights gained by this analysis is that scenarios with similar levels of energy development can vary widely in terms of their impacts on fragmentation, representing a variety of social and environmental values. For example, Figure 11 shows that at 50 percent of the Irrawaddy's hydropower potential, the number of stream kilometers affected by fragmentation ranges approximately between 4,400 km and 5,500 km. In other words, without sacrificing any hydropower potential, up to 1,000 km of fish habitat can be protected from fragmentation, if the right combination of dams is chosen. Annex 3 shows fragmentation maps for the baseline and for these two 50 percent development scenarios. Planning at the scale of the Myitnge–or even a series of planning processes at the level of sub-basins comparable to the Myitnge–could not reveal the trade-offs that become apparent by an assessment at the scale of the entire Irrawaddy basin.

Without sacrificing any hydropower potential, up to 1,000 km of fish habitat can be protected from fragmentation, if the right combination of dams is chosen.

FIGURE 11. Variability among hydropower development scenarios and habitat impacted



Plot showing variability among five hundred random scenarios of hydropower development in the Irrawaddy basin in terms of kilometers of impacted, i.e. significantly fragmented, habitat for migratory fish.

PHOTO: © Jeff Opperman

Chapter 5: Implications for Myanmar, and for Other Countries

International experience on hydropower, and the brief analysis in the previous chapter on a sub-basin in Myanmar, suggests that there are large differences in performance between different hydropower investment options, and that Myanmar has the opportunity to carefully choose which projects it wants to prioritize. It also demonstrates that some of these differences can only be detected by looking at the system scale, rather than by evaluating projects one-by-one. Applying these types of analyses can identify win-win solutions and can identify trade-offs to be discussed and negotiated in a rational and constructive process. However, while clearly desirable from a public policy perspective, system-scale planning always has to be introduced in a specific political and institutional context. This concluding chapter addresses lessons learned and possible next steps, both for Myanmar and also for other regions with significant hydropower potential.

While clearly desirable from a public policy perspective, system-scale planning always has to be introduced in a specific political and institutional context.

Whatever decisions the government makes in terms of managing existing hydropower or developing new hydropower, those decisions can be informed by a system-scale approach.

HOW RELEVANT IS THIS FOR MYANMAR'S NEW GOVERNMENT?

The previous government's approach to hydropower development was to attract the maximum possible amount of hydropower investment. This was related to commercial interests, a focus on capital inflows and employment, and the belief that there were no major differences between projects. As a result, essentially all interested developers were encouraged to go forward with their proposed projects. However, after an initial wave of Chinese interest in the past decade, relatively few projects have actually progressed because of security issues in ethnic minority regions, political uncertainty, and conflicts over environmental and social impacts leading to the suspension of some large-scale projects. Thus, even from a narrow commercial perspective, this non-selective approach now seems to have had limited ability to meet economic needs, let alone to deliver benefits across a range of social and environmental needs. Those companies that promoted problematic projects have contributed to negative public perceptions of hydropower, in effect 'poisoning' hydropower for themselves and for others, and brought about a situation where the incoming government won the 2015 elections with a platform that expressed serious concern about the impacts of large hydropower.

The Election Manifesto of the National League for Democracy (NLD) suggests that the new government will take a fresh look at the role that hydropower will play in future energy plans (Box 1). Thus, the new government has the opportunity to evaluate the potential for the system-scale approach described in this report. Whatever decisions the government makes in terms of managing existing hydropower or developing new hydropower, those decisions can be informed by a system-scale approach that seeks to deliver broad development benefits.

The incoming government has two major advantages in terms of adopting system-scale approaches. First, it still has a lot of choices. Unlike in most countries, no mainstream dams have been built, and many different configurations and combinations ('portfolios') of projects are still possible. Second, it has a clear mandate to apply high standards to the hydropower sector.

We see system-scale planning as an opportunity to introduce a more accountable and transparent decision-making process.

Beyond technical models and planning processes, moving from a project-based approach to a system-scale approach will also require the institutional structures and regulatory processes to select those projects that are consistent with a desired system plan, avoid those that are not consistent, and to sequence projects to meet objectives over time. In general, the earlier a system-scale approach is adopted, the wider the range of potential system solutions; each project built prior to adopting a system-scale approach has the potential to preclude potentially preferred portfolios. Below we describe a set of short, medium and long-term opportunities for the Myanmar government to move toward and adopt a system-scale approach.

Before considering how government might address its selection challenge, it is useful to first get a sense of scale. Depending on the proportion of projects in the pipeline that need to be selected, different approaches might be useful.

In a country where energy planning is just for domestic demand, the decision problem would be relatively straightforward. Generation would be constrained by domestic demand and by the pace with which the domestic transmission and distribution infrastructure can be expanded. Even just looking at regional neighbors like Vietnam, where per capita consumption is eight times higher, it is clear that Myanmar requires a great deal of investment to reach an electricity system comparable to its neighbors. But power demand is essentially finite, and generation can be expanded gradually. In the high demand growth scenario described in Chapter 3, after deducting exports, the previous government estimated a maximum required hydropower capacity of 23.5 GW in 2030, compared to the 43.7 GW under preparation. In other words, even in the government's own estimates, a maximum of only about half of the projects under preparation would need to be built over the next 15 years (though note that the government can also consider other generation sources for meeting this demand). They could be sequenced according to a strategic plan, and investment decisions could be taken if and when that demand actually materializes and always in view of the alternatives at the time. The rest could be kept in reserve.

Arguably, even that is an overestimate of the capacity that is actually required for domestic demand. Demand growth is likely to be lower, and WWF's Energy Vision for Myanmar demonstrates that new renewables can take a much larger role than previously thought. If that is the case, the country can be even more selective about new hydropower projects.

Introducing cross-border trading options makes power planning more complex. The potential import demand of neighboring countries is practically unlimited, and with sufficient transmission infrastructure, Myanmar could rapidly scale up exports as much as it wanted, as long as costs are competitive. For some smaller countries like Paraguay, Georgia, Bhutan and Laos this has become a central part of their development strategy.

Exports may not be as attractive for Myanmar in the short run, as most sites that are conveniently close to the borders are also in areas of conflict and the priority may be closing the domestic supply gap. But in principle, the same selection issues apply to export as they do for generation for the domestic market.

THERE ARE SHORT-, MEDIUM- AND LONG-TERM OPPORTUNITIES FOR SYSTEM-SCALE PLANNING

Short-Term Opportunity

Full application of a system-scale planning approach is not possible in the short term, because there would not be sufficient time to engage stakeholders, gather data, and build a model at the national scale with the features described in this study. However, in the absence of a full system-scale approach, some initial low risk or "no regrets" projects can be identified – those projects which are highly likely to be consistent with societal expectations for a sustainable energy system. For example, a relatively simple screening process using generic risk-management rules of thumb could be applied, such as avoiding projects with significant local opposition and displacement, and avoiding projects with locations which will significantly constrain the future ability to design an overall balanced system. Conversely, projects built within existing cascades—as illustrated by options for development of the Myitnge—will generally have lower impacts and are more likely to be consistent with a future balanced system.

Medium-Term Opportunity

In the medium-term, over the next 12-18 months, the Strategic Environmental Assessment (SEA) for the hydropower sector in Myanmar, funded and contracted by the International Finance Corporation (IFC), will provide an opportunity to expand the discussion about system-scale issues. The terms of reference for the SEA leave considerable room for different methods and emphasize buy-in from different stakeholders as an important determinant of success. In the absence of a hydropower master plan, the SEA will have to contain significant planning components and might want to consider using the kind of trade-off and system modeling approach described in this report. The IFC is also considering support for a cumulative impact assessment (CIA) in the Myitnge sub-basin where the two projects Deedoke and Middle Yeywa are being prepared for financing. The SEA and the CIA processes could greatly advance, refine and expand the preliminary analyses in this report.

Over time, the expectation is that positions would increasingly be replaced by evidence.

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Stakeholders may want to focus on different aspects of the approach and apply it in different ways—rapid screening of projects, building a comprehensive model, institutional reform of the project selection process, or all of the above.

Long-Term Opportunity

In parallel and in the longer term, government may want to consider building a comprehensive hydropower planning and selection mechanism to prioritize projects that are clearly in the public interest. Projects supported by bilateral or multilateral funders could support this process. For example, the World Bank is financing the US$100 million 'Ayeyarwady Integrated River Basin Management Project', which includes a component to prepare individual projects, including hydropower projects. These projects will need to be selected and undergo early feasibility assessments and screening through some coordinated process, and thus this World Bank project could also draw on the ideas advanced in this report. The Japanese International Cooperation Agency (JICA) is supporting a power sector master plan, which could be revisited and expanded to include a ranking of future hydropower projects, or a separate master plan could be prepared.

SETTING UP A LONGER-TERM PLANNING MECHANISM OFFERS MANY CHOICES, AND PITFALLS

There are many ways to establish a more permanent planning capacity and some investment in institutional capacity building for hydropower planning would be highly beneficial for Myanmar, given the strategic importance of hydropower.

Learning from Other Countries

Learning from other countries' examples can give Myanmar a sense of its range of choices. Brazil, for instance, has established a separate Energy Planning Agency (EPE), which prepares a hydropower inventory and environmental assessment studies within a river basin and then recommends projects for auction that are consistent with its basin plan. It is partly financed by developers who win the auctions and then reimburse the agency for its planning outlays. China has assigned its major rivers to different state-owned power companies, which are expected to establish basin plans. Iceland has established a process whereby every four years, the new parliament appoints an independent master plan committee and, at the end of its term, votes on the committee's recommendations to place projects into three categories: develop, not develop, and hold for further consideration.

Planning at Different System Scales

Different countries prepare plans at different spatial scales, such as sub-basins, basins or countrywide. They can address hydropower only, or other water resource management and development issues. They can be prepared by or for a specific line ministry, such as the Ministry of Electric Power, or a coordination body such as the National Water Resources Committee. They can be a one-off exercise, or be regularly updated. Some of these options will fit better into Myanmar's evolving institutional framework than others.

Enforcing Planning Results

What will be critical in any case is to ensure that the results of the planning process are actually followed. Planning a portfolio of projects only makes sense if it is binding (i.e., if there is no parallel process through which a developer can obtain a license for a project that is not part of the portfolio). This can be a problem, for example, if the planning authority is only responsible for a certain class size of projects. In many countries, including Myanmar, small projects go through a simplified licensing process at the level of regional governments. But small projects have some of the same impacts as larger ones— for example, regarding fragmentation—and licensing them separately can undermine the overall outcome. The same may apply if other agencies, such as the irrigation department, plan and operate their infrastructure projects separately. At least some coordination mechanism is then needed to ensure that plans at different levels of government are compatible with each other.

System-scale planning is obviously more than just a technical challenge. It is essentially a governance challenge, which can be made more manageable by tools that are reliable and easy to interpret. We see system-scale planning as an opportunity to introduce a more accountable and transparent decision-making process, contributing to the legitimacy and public acceptance of the new democratic government and its decisions.

If a convincing approach is offered, we believe that many government agencies, development banks, foundations and other donors will see the strategic benefits and will be willing to fund this type of effort.

SYSTEM-SCALE PLANNING IS STILL EVOLVING

The type of analysis presented in this study—what we call 'integrated, quantitative multi-criteria and multi-project planning' and also called Hydropower by Design by TNC—is still relatively new. To date, it has not been consolidated into one single best practice planning approach. One of the reasons is that it has multiple origins, including integrated water resource management; hydropower options assessment and master planning; engineering and hydro-economic optimization; high conservation value assessments or 'conservation blueprints'; sustainability; and cumulative and strategic environmental assessment. Over the past years, it has become increasingly clear how these perspectives can inform and strengthen each other, but also that they contribute different tools and approaches, and that there is not just one correct way of making complex decisions. Ideally, the different perspectives will over time provide a toolbox for stakeholders and decision makers to better plan and operate hydropower at a system scale.

We believe that the particular approach we used in Myanmar has shown some strengths, that the technical analysis at the core of it could become an important tool in the toolbox, and that it should be further developed and replicated. Although it was relatively quick and cheap to apply, largely using publicly available data from global datasets, it was able to generate a plausible first approximation of the situation in a basin. Stakeholders did not seem concerned with the lack of precision, but instead seemed to appreciate that this was an illustration of the approach that could be improved in multiple ways—with better data, model assumptions, and metrics that stakeholders find relevant.

INCLUSIVENESS AND ABILITY TO FOCUS THE DISCUSSION MAKE THIS APPROACH ATTRACTIVE

One strength in this approach seemed to be its inclusiveness, as all stakeholders could see that their particular interests were represented in the model. This is reassuring to the energy sector, which may often feel that discussions about environmental impacts and standards are not taking energy benefits seriously enough. By modeling the operation of a whole hydropower system, this approach may actually supply information that was not previously available to energy specialists, and help reconsider design and operational criteria, such as reservoir operating rules. Hydropower engineers are familiar with dealing with 'internal' trade-off and optimization situations (such as, what is the net effect on generation of keeping the reservoir full, considering the positive impact of a higher head against the negative impact of spilling more water?). The quantitative analysis may provide some credibility for this approach and make them more willing to consider other trade-offs.

At the same time, the approach provided reassurance to other sectors, such as fisheries and navigation, that their interests were taken just as seriously. This seemed to be a new and empowering experience, but would also encourage stakeholders to become more explicit and rigorous about their objectives and the impacts they expect from hydropower. For example, if the fisheries department wanted to become an important counterpart to the hydropower department in these discussions, it would have to invest in data and ecological models that can predict how fishery support is impacted by migration barriers and changes to flow. Over time, the expectation is that positions would increasingly be replaced by evidence.

Another feature of the approach that is intuitively attractive is its ability to identify and eliminate sub-optimal portfolios, or from a more positive perspective, to identify win-win solutions. Because of the complexity of these planning issues, an important step in building confidence is an assurance that the preferred portfolio is not 'completely wrong' (i.e., should be replaced with another portfolio that offers equal or better outcomes to everybody). Once stakeholders see that the approach is able to accomplish this, they seem willing to engage with the second step, discussing trade-offs. They also intuitively understand the concept of 'tipping points' (i.e., the idea that often major gains for one objective can be made with only minor sacrifices for another objective, until a point is reached where the trade-offs become more pronounced, and where perhaps a political decision is needed).

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Stakeholders also seemed intrigued by the opportunity that this approach may provide to overcome institutional habits and interests. Complaints over decision making in 'silos' are universal, across different cultures and types of organizations. The approach recognizes legitimate different interests, but provides a platform for stakeholders to engage constructively with each other, to identify solutions that are in everybody's interest. The business case for Ministries of Energy, for example, to engage in this type of planning is that—while they may have to acknowledge negative impacts more explicitly than in a traditional approach and may have to compromise with stakeholders—they might be able to identify a portfolio that still meets most of their objectives and has a fair chance of being implemented because it represents an informed compromise with other interests.

THE SYSTEM-SCALE APPROACH CAN BE TAILORED TO FIT DIFFERENT CONTEXTS

The initial application in Myanmar opens up many future options. Stakeholders in the country may want to focus on different aspects of the approach and apply it in different ways—rapid screening of projects, building a comprehensive model, institutional reform of the project selection process, or all of the above. Other countries may also look at this approach and recognize that it has something to offer for their particular planning context.

Because the system-scale approach is still emerging, with every new application offering new insights and progressing the methods, there is no easy way of matching a particular planning context to one specific tool, and the tools that do exist are not necessarily self-explanatory at this stage. Ideally, future applications would be demand-led (i.e., based on an interest expressed by a government agency or other hydropower stakeholder). The approach would then be discussed and tailored to the specific objectives, data availability and institutional context, and in some cases, new versions of tools may have to be built.

For example, in a context where there already is a master plan, but there is a lack of understanding of one particular aspect (say, the cumulative impact of a hydropower portfolio on barriers to fish migration), a relatively simple desktop spatial analysis could be sufficient. In a context where projects are being selected and prepared separately, there may be an interest in building a river simulation model as in the Myanmar application, to inform basic siting, design and operational questions, such as the best storage capacity and use. Other countries may already have done all of the technical analysis, and would be most interested in the stakeholder engagement and consensus building process.

While there would be some differences in metrics and specific tools, this approach could be applied in a fully developed basin to consider options for re-operation or removal. Some applications would emphasize uncertainties and undertake sensitivity analyses to see which portfolios of hydropower projects perform better. Some applications would deal with other infrastructure sectors, most obviously, with irrigation dams and other water resource infrastructure. We are confident that the approach is adaptable enough to add value in all these different situations.

WHAT ARE THE NEXT STEPS TOWARDS BROADER UPTAKE OF THE SYSTEM-SCALE APPROACH?

Promoting a broad uptake of the approach requires an understanding of the current obstacles or barriers to implementation. Some of these may be linked to different institutional frameworks and capacities. In deregulated markets, individual developers generally do not have a mandate or incentive to pursue system-scale planning. Some countries may even have specific legal obstacles. For example, in Colombia, competition laws make it difficult for companies to cooperate, even if there would be a clear public benefit from coordinated investment and operations in a hydropower cascade. If governments want to involve developers, they may need to reconsider the institutional setup of the generation sector. As an initial step, developers could be required to address cumulative impacts in the project preparation process.

Other countries may not have sufficient capacity to deal with the complexities. As described above, hydropower master planning is not widely practiced today. Even where there is some capacity left from the time before deregulation, it would rarely cover the technical and stakeholder engagement skills required by Hydropower by Design. Training and capacity building would be required in most countries that want to develop their own planning capacity. Initial steps to spread these skills could be pilot applications involving local institutions and government agencies in countries like Myanmar and 'training the trainers' programs for system-scale approaches.

Perhaps the most obvious barrier to implementation is a lack of funding. Few countries have recognized the strategic value of hydropower planning like Brazil, which created its own energy research and planning agency, with an annual budget of US$27 million in 2014. While system-scale planning is not expensive, compared to the amounts developers spend on studies for individual projects, there is often no dedicated funding available and, in most applications, funding would have to be identified ad hoc. If a convincing approach is offered, however, we believe that many government agencies, development banks, foundations and other donors will see the strategic benefits and will be willing to fund this type of effort. For example, TNC is in discussions with the Inter-American Development Bank to design a revolving early stage planning fund, that would provide more consistent and predictable support to system-scale approaches. In some situations, it may be sufficient to provide seed funding for such efforts and to have developers reimburse planning costs once they obtain licenses. Initial steps that could raise awareness of the importance of system-scale approaches, and could generate support for it, include research on the business case for system-scale approaches (including quantifying benefits of improved risk management and better delivery of development benefits) and exploration of available funding mechanisms, such as multilateral development bank trust funds.

Better information on the distribution of social and environmental resources is also needed for an effective system-scale approach to planning and design. In the short term, funding to support the development of "conservation blueprints" in Myanmar could provide an important part of the foundation for system-scale approaches.

In conclusion, the system-scale approach holds great promise to improve the performance and reduce conflicts around hydropower. The application in Myanmar has demonstrated the potential of this approach, generated significant interest in the country and among international observers, and allowed the project partners to develop and test methods. Variations of these methods should be applicable in many other regions and in many other infrastructure sectors. We are grateful to stakeholders and government officials in Myanmar for their feedback and contributions in taking this work forward and hope that the study will give them some insights into the options that are available today. Increasing electricity supply through sustainable approaches is one of the most important challenges for the new government in its quest to improve the country's economy and the well-being of its people. System-scale planning and design offer the best opportunity for the government to evaluate the role of hydropower in addressing that challenge.

Annex 1: Project Schedule

From November–December 2015, the initial project partners (DFID, TNC and WWF) confirmed the country where this study would be conducted as well as objectives, contractors and schedule. The project team went on three in-country missions between December 2015 and March 2016. The first mission, November 30–December 4, 2015, was to lay the groundwork by developing an initial network and garnering a more comprehensive understanding for the hydropower landscape and context in Myanmar. The second mission, February 1–5, 2016, was to follow-up on the connections made during the inception mission through more in-depth interviews, while also introducing ourselves to the key government ministries relevant to our study.

The project concluded with several meetings and workshops during the third mission from March 1–19, 2016. These included meetings to acquire data for our modeling analysis, a technical workshop to finalize the analysis, discussions of the project team with the steering group to present findings and agree on messaging, a broad workshop to discuss and disseminate findings with stakeholders and project partners, and a meeting with government officials from all relevant departments to conclude the project and discuss implications and follow-up. In between each in-country mission, the project team held multiple weekly phone calls to organize mission agendas and interviews, report analytics and format, as well as in-country workshop agendas and logistics. A detailed outline of the schedule of this project is described below.

The project is a collaborative effort between DFID, WWF and TNC, with DFID providing funding and conceptual support, and TNC and WWF providing in-kind contributions. It also involved researchers from two universities (University of Manchester, UK, and McGill University, Canada), and two regional partner organizations, the Myanmar Institute for Integrated Development (MIID) and the Water, Land and Ecosystems (WLE) Program of the CGIAR. It was delivered through an implementation team comprised of project partner staff and consultants; coordinated by two project managers from TNC and WWF; and guided by a steering group. Annex 2 lists all project participants.

The team engaged with, and supported debate amongst, a cross section of stakeholders and civil society including key decision-makers around future hydropower development options and the scope for system-scale planning. The outreach process was intended to generate interest and demand for ongoing cooperation, and to challenge the project's assumptions and verify its approach. Project messages were communicated through meetings during in-country missions and workshops, newspaper op-ed articles, and presentations at conferences (such as the launch of the IFC environmental and social advisory program for the hydropower sector in Naypyidaw in December 2015; the World Water Day conference in Naypyidaw in March 2016; and World Bank Water Week in April 2016), with an emphasis on visualization approaches. Communications will be a longer term process, beyond the time horizon of the funding for this project, and will depend on interest of the incoming government and opportunities identified by the project partners.

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MYANMAR MISSION I

Date & Location	Activity
Monday, November 30 Bangkok	Arrival and preparations in Bangkok
Tuesday, December 1 Nay Pyi Taw	IFC's Inception Workshop: Environmental and Social Standards in the Hydropower Sector Program
Wednesday, December 2 Nay Pyi Taw	Invitations for meetings in Yangon sent to priority follow-ups Meeting with IFC: Kate Lazarus & Pablo Cardinale Brief introductions with Gov't Ministries • Ministry of Electric Power (MOEP): Ms. Khin Seint Wint (Deputy Director, International Relations Department) • Ministry of Environmental Conservation and Forestry (MOECAF) Dinner meeting with Prof. Dr. Khin Ni Ni Thein (AIRBMP Component (1) Director and Secretary of Advisory Group, NWRC)
Thursday, December 3 Yangon	Meeting with WWF-Myanmar Meeting with Myanmar Institute for Integrated Development (MMIID) Meeting with CGIAR's WLE Program, Stewart Motta (Network Coordinator), and McGill University's Gunther Grill (Post-Doctorate)
Friday, December 4 Yangon	Meeting with DFID-Myanmar

MYANMAR MISSION II

Date & Location	Activity
Monday, February 1 Yangon	Meeting with Myanmar Institute for Integrated Development (MIID): Joern Kirstensen (Managing Director) and David Abrahamson (Programme Manager) Meeting with WWF-Myanmar: Nicholas Cox (Conservation Programme Manager), Gaurav Gupta (Sustainable Business Manager), Shoon So Oo (Energy Manager), Jean-Philippe Denruyter Meeting with European Union delegation to Myanmar: Delphine Brissonneau (Programme Officer) and Claudia Antonelli (Programme Officer) Meeting with Prof. Dr. Khin Ni Ni Thein (AIRBM Project Component (1) Director and Secretary of Advisory Group, NWRC)
Tuesday, February 2 Yangon	Meeting with JICA: Mamoru Sakai (Representative) Meeting with IFC: Kate Lazarus (Senior Operations Officer, Environment, Social and Government Dept.) Meeting with Smithsonian Conservation Biology Institute: Aung Myo Chit (Country Director) Meeting with CGIAR's Program on Water, Land, & Ecosystems (WLE) Greater Mekong: Stew Motta (Network Coordinator)
Wednesday, February 3 Yangon	Work time at MIID offices: Joern Kirstensen (Managing Director) and David Abrahamson (Programme Manager)
Thursday, February 4 Nay Pyi Taw	Meeting with MOEP: Tint Lwin Oo (Deputy Director General, Dept. of Electric Power Planning) and Khin Seint Wint (Deputy Director, Dept. of International Relations) Meeting with MOECAF: Dr. San Oo (Director, Dept. of Environmental Conservation) and Sein Htoon Linn (Deputy Director, Dept. of Environmental Conservation) Meeting with Asian Development Bank: Jim Liston (Principal Energy Specialist)
Friday, February 5 Yangon	Meeting with DFID-Myanmar: Declan Magee (Team Leader and Senior Economic Advisor, Inclusive Growth Team) Meeting with Earth Rights: Adam Moser (Myanmar Legal Coordinator) Meeting with NVE: Paul Christian Rohr (Resident Energy Advisor) Meeting with EcoDev/Alarm: Katie LaJeunesse Connette (Environmental Conservation Consultant, Smithsonian Conservation Biology Institute) Meeting with Another Development: Mai Hla Aye, ZinZin Kyaw

MYANMAR MISSION III

Date & Location	Activity
Tuesday , March 1 Yangon	Arrival of technical team, meeting at MIID offices
Wednesday, March 2 Yangon	Meeting at MIID offices
Thursday, March 3 Mandalay	Travel to Mandalay, team meetings
Friday, March 4 Mandalay	Meetings at Mandalay Technological University with departments of electrical power engineering and civil engineering
Saturday, March 5 Mandalay	Field visit to confluence of Irrawaddy and Myitnge rivers, return travel to Yangon
Sunday, March 6 Yangon	Team meetings
Monday, March 7 Yangon	Project team to discuss initial modeling results and agenda for the remainder of the trip: MIID offices
Tuesday, March 8 Yangon	Meeting with DFID-Myanmar Project team meeting to finalize the modeling results and compile key messages for our upcoming workshops and final report: MIID offices
Wednesday, March 9 Yangon	Project team meeting to prepare for Friday, March 11 consultation with civil society organizations and INGOs: MIID offices.
Thursday, March 10 Yangon	Finalizing presentations, agenda and participants list for CSO/INGO Friday 3/11 consultation: MIID offices
Friday, March 11 Yangon	Half-day CSO/INGO consultation with approximately 30 participants Project team consultation debrief
Saturday, March 12 Nay Pyi Taw	Travel to Nay Pyi Taw Project team preparations for March 13th – 14th World Water Day Celebration hosted by The National Water Resources Committee (NWRC)
Sunday, March 13 Nay Pyi Taw	Project team attended Day 1 of the World Water Day Celebration Presented our project in Session 3: Creating an Enabling Environment for the IWRM implementation
Monday, March 14 Nay Pyi Taw	Project team attended Day 2 of the World Water Day Celebration Presented our project in Parallel Session: IWRM
Tuesday, March 15 Nay Pyi Taw	Project team preparation for government ministry consultation on Wednesday 3/16
Wednesday, March 16 Nay Pyi Taw	Half-day consultation with relevant government ministries. In attendance: MOEP, MOECAF, Ministry of Transport, Ministry of Livestock, Fisheries and Rural Development and Ministry of Agriculture and Irrigation. Travel to Yangon, Myanmar
Thursday, March 17 Yangon	Presentation at DFID-Myanmar Project team mission III debrief Report drafting
Friday, March 18 Yangon	Report drafting Mission III concludes; travel home

Annex 2: Project Team

JEAN-PAUL PENROSE

Department for International Development, Senior Water Resources Adviser

Jean-Paul Penrose is a Senior Climate and Environment Adviser directing water security policy and programming across DFID's £11 Bn development agenda. He has worked in international development for 18 years primarily for DFID leading programmes in Africa and the Middle East and including a secondment to the International Finance Corporation where he managed environmental and social safeguards in a forestry investment in Peru. As an independent consultant he led climate and environment projects for institutions including AFD, DFID, EC, UNDP, UNEP, Christian Aid and WWF. Before joining DFID he worked for the Environment Agency and its predecessor the National Rivers Authority leading on catchment management planning and environmental assessment of water infrastructure.

JEFF OPPERMAN, PH.D.

The Nature Conservancy, Great Rivers Program, Director and Lead Scientist

Jeff Opperman, Director and Lead Scientist of The Nature Conservancy's Great Rivers Program, has been working to protect rivers and lakes for nearly 15 years. He has provided strategic and scientific guidance to freshwater conservation projects across the United States as well as in China, Africa and Latin America. Through scientific research and collaborations and technical support to field projects, Jeff focuses on improving the environmental sustainability of hydropower and protecting and restoring river-floodplain ecosystems. Jeff earned his B.S. in Biology from Duke University and a Ph.D. in Ecosystem Science from the University of California, Berkeley. He then studied floodplain ecology during a post-doctoral fellowship at the University of California, Davis. His scientific and policy research has been published in journals such as *Science, BioScience* and *Ecological Applications*. Jeff strives to communicate the challenges and opportunities of protecting fresh water through op-eds, articles and blog posts in such places as *The New York Times, Outside, Grist* and *The Guardian*.

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AMY NEWSOCK

The Nature Conservancy, Great Rivers Program, Assistant Director

Amy Newsock is the Assistant Director of The Nature Conservancy's Great Rivers Program, part of the Global Water Unit. Working in river basins in Asia, Africa, Europe, North and South America, Amy supports in managing the Great River Program's efforts to use the Conservancy's latest science, innovative solutions and collaborative approaches to the sustainable management and conservation of river systems. Prior to joining the Great Rivers Program in 2013, Amy worked as a Legal Assistant in the Conservancy's Legal Department. She holds a B.A. in Environmental Studies and Geography from the University of Richmond, Virginia.

EMILY CHAPIN

The Nature Conservancy, Geospatial Specialist

Emily Chapin is a geospatial specialist for The Nature Conservancy's Global Water Program. She supports the Great Rivers Program by conducting innovative spatial approaches to basin-scale planning, which aim to balance hydropower energy demands with ecological protection of some of the world's largest rivers. She holds a Masters of Environmental Management and a Certificate in Geospatial Analysis from the Nicholas School of the Environment at Duke University.

JORGE GASTELUMENDI

The Nature Conservancy, Policy Innovation Lead, Global Water

Jorge Gastelumendi is the Policy Innovation Lead for Global Water at The Nature Conservancy, where he has overseen the global water policy practice (sustainable hydropower, source water protection, and water markets) since 2015. Previously, Jorge was the Senior Policy Advisor for International Climate Policy at The Nature Conservancy where he led the Conservancy's Climate Finance team supporting in-country financial arrangements. In this capacity he is lead advisor to the Government of Peru in its dual role as UNFCCCC COP20 Presidency and as co-chair of the Green Climate Fund's Board. Before joining the Conservancy in 2008, Jorge was Carbon Fund Manager at The World Bank's Carbon Finance Unit. In Peru, he headed the Environmental Law Department at Grau Law Firm and provided expert analysis on Peru's Policy Framework for the Clean Development Mechanism. Jorge was a professor at Georgetown University Law Center until 2012, and was a teaching fellow for community organizing courses at Harvard University. He holds a J.D. from Peru's Catholic University, an MSc. in Energy and the Environment from the University of Calgary, and a Masters in Public Administration from the Kennedy School of Government at Harvard University.

JIAN-HUA MENG, PH.D.

WWF International Freshwater Program, Water Security Lead

Jian-hua Meng is leading WWF's International Water Security Team. He is working on sustainable water infrastructure and specifically on hydropower, both at the technical and policy level, and through field support for WWF freshwater programs worldwide. He is member of the Governance Committee of the Hydropower Sustainability Assessment Protocol. Before joining WWF in 2008, he worked as engineer and project manager with a consulting group in Germany, planning and implementing water and urban infrastructure projects, river restoration, flood protection, and energy projects. He was also a lecturer and research member at Technische Universität Berlin. He holds a Ph.D. in Civil Engineering.

JOERG HARTMANN, PH.D.

Independent Consultant

Joerg Hartmann works as an independent consultant for sustainable water resources management. He has worked in over 40 countries and has led many water and natural resource project appraisals and assessments. He is an accredited lead assessor for the Hydropower Sustainability Assessment Protocol, and accredited service provider with the Alliance for Water Stewardship. From 2011 to 2013, he chaired the global multi-stakeholder Governance Committee of the Protocol. From 2007 to 2011, he led WWF's global hydropower and water security work, at the policy level and through field support for WWF's river basin programs. From 1996 to 2007, he worked for Germany's development bank KfW, first in Eastern Europe and then in Latin America. In his last three years at the bank, he was Country Director for Tanzania and chaired the water donors group. He holds a Ph.D. in Environmental and Development Economics.

JULIEN HAROU, PH.D.

University of Manchester, Professor of Water Management and Chair of Water Engineering

Julien Harou has been Professor of Water Management and Chair of Water Engineering at the University of Manchester since 2013 and holds an Honorary Professor appointment at University College London. He has a Ph.D. from the University of California Davis in water resources management and economics and an Masters in Engineering from Cornell University in Environmental Systems Engineering. His group's research interests relate to water resources planning and management, with a focus on managing water scarcity and planning infrastructure investments using hydro-economic and multi-criteria approaches. His group builds modelling tools to help utilities and governments achieve water security in the U.K. and worldwide. Recent collaborator organisations include DEFRA, the European Commission, U.K. water regulators, U.K. water companies, the World Bank, IUCN, TNC, WWF, IWMI, and consulting firms.

ANTHONY HURFORD, PH.D.

University of Manchester, Research Associate

Anthony Hurford is a Research Associate at the University of Manchester and a Senior Scientist at HR Wallingford. He previously undertook Ph.D. studies at University College London on trade-off analysis for river basin infrastructure investment decision-making under uncertainty. He has completed river system investment analyses in Brazil, Kenya and most recently Nepal for the World Bank.

DAVID ABRAHAMSON

Myanmar Institute for Integrated Development, Program Manager: Agriculture, Natural Resources and Rural Development

At Myanmar Institute for Integrated Development (MIID), David manages environmental and livelihood projects to help poor communities increase income and adapt to climate change. David came to Myanmar as a Fulbright-Clinton Public Policy Fellow in 2013. Prior to Myanmar, David worked in China for ten years, including managing projects and setting up a new office for the nonprofit CWEF in Guangdong, leading to microcredit loans for farmers and scholarships for hundreds of students. He also worked in the CSR sector with BSR and later for Intertek. David has also held positions at the Clinton Global Initiative in New York, The Nature Conservancy and Habitat for Humanity International in Yunnan and WWF in Myanmar. He received a Masters in International Affairs from Columbia University and lives in Yangon with his wife and son.

JOERN KIRSTENSEN

Myanmar Institute for Integrated Development, Managing Director

Joern Kristensen is a socio-economist with extensive experience in management of international multi-sector development, research, humanitarian- and disaster response programs. He was Resident Representative of UNODC in Myanmar (1991-1994), Vietnam (1994-1997), and Director at UNODC Headquarters, responsible for Southeast Asia, including Myanmar (1997-1999). From 1999 through 2003 Mr. Kristensen served as Secretary General of Mekong River Commission, established by Cambodia, Lao PDR, Thailand and Vietnam, with China and Myanmar as observers. Following five years (2004-2009) as Director of Norwegian Refugee Council in Sri Lanka and Myanmar, engaged in conflict resolution and disaster response, he re-joined the United Nations in charge of coordination of the international response to the natural disaster caused by Cyclone Nargis that struck Myanmar in 2008. In 2011 Mr. Kristensen founded Myanmar Institute for Integrated Development (MIID), specializing in Myanmar's upland regions with high proportion of ethnic minorities and a history of armed conflicts.

STEW MOTTA

CGIAR's Program on Water, Land, & Ecosystems (WLE) Greater Mekong, Regional Network Coordinator

Stew Motta is the regional network coordinator for CGIAR's Program on Water, Land, & Ecosystems (WLE) Greater Mekong, which is a research for development program coordinated out of Naga House, Vientiane, Lao PDR. In the Mekong Region, WLE works on the Ayeryarwady, Salween, Mekong and Red river basins. WLE seeks to improve the governance and management of water resources in the Greater Mekong Region by generating and sharing the knowledge and practice needed to do so. When Stew is not managing the network of partners in the GMS, he focuses his research on the geopolitics around hydropower and natural resource management in the region.

GÜNTHER GRILL, PH.D.

McGill University, Post-Doctoral Research Fellow

Günther Grill earned his Masters of Science in Geography at Friedrich-Alexander-University, Erlangen, Germany and obtained an MSc in Geographic Information Science and Systems at the Center of Geomatics, University of Salzburg, Austria. After graduating from his MSc, he supported local river development planning and contributed to assessment reports of the European Water Framework Directive. Before starting his Ph.D. at McGill University, he worked as a GIS-consultant to the Pan American Health Organization, Washington, D.C.. During his Ph.D. with Prof. Bernhard Lehner, he focused on environmental modeling at large-scales to assess human effects on freshwater integrity. He is currently a Global Hydrology Post-Doctoral Research Fellow at McGill University, Montreal.

Annex 3: Technical Description of Myitnge River Simulation Model

Inflows to the river basin model were generated by combining Lehner and Grill's (2013) long-term mean monthly river discharge data for each existing and proposed dam location on the Myitnge, with 11 years of observed monthly flow data for Sagaing gauging station supplied by the Global Runoff Data Centre. Lehner and Grill's (2013) data were derived through geospatial downscaling techniques from global runoff estimates of the hydrological model WaterGAP between 1971 and 2000 (Alcamo et al., 2003; Döll et al., 2003). The Sagaing gauging station is on the Irrawaddy main stream just upstream of its confluence with the Myitnge. The data were combined in three steps as follows:

1. The variation of each month of the Sagaing discharge data from this dataset's overall mean discharge was calculated to provide 11 variation factors for each month (one from each year of the record).
2. These variation factors were randomly applied to corresponding months of Lehner and Grill's (2013) mean monthly discharge to create a 50-year time series of monthly inflows at each existing and proposed dam location on the Myitnge River.
3. To avoid double counting inflows, upstream inflows were subtracted at each location.

This approach assumes that flow patterns on the Myitnge match those on the Irrawaddy. Owing to data and resource constraints, this assumption was deemed appropriate for demonstrating the system-scale planning approach.

The model represents the impacts of decisions from adding infrastructure to the basin and operating any projects present. The Myitgne River basin has one existing dam, one dam under construction, and three proposed dams. For the purposes of this study, both the Yeywa (existing) and Upper Yeywa (under construction) dams were assumed to be existing. Given that the Upper Yeywa is currently under construction this decision cannot be reversed. The proposed dams include Deedoke, Middle Yeywa and Hsipaw. Middle Yeywa was considered to have two mutually exclusive design options, "high" dam height and "low" dam height (Table 7). The locations of these dams are shown in Map 5.

TABLE 7. Proposed dam options included in model

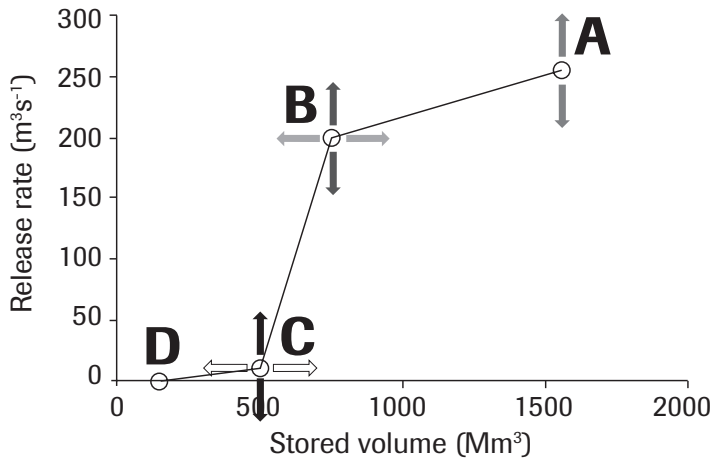
Dam name	Dam height (m)	Installed capacity (MW)
Deedoke	14	60
Middle Yeywa (low)	60	150
Middle Yeywa (high)	110	700
Hsipaw	80	100

(Middle Yeywa options are mutually exclusive).

PHOTO: © Public Domain

In terms of investment decisions, there are 12 possible combinations of the proposed dams but many more possible combinations including the potential to operate these dams differently. Each dam's releases were controlled by a storage-dependent release rule curve which dictates how much water should be released at each model time step. The model was run at a monthly time step, as higher resolution flow data were not available during this study. Releases from the dams went first to hydropower turbines then to support downstream flows.

FIGURE 12. Storage-dependent release rule curve for each dam in the simulation model



Stored volume varies according to the dam's design and Point A is always at the maximum storage to control release rate when the storage is full. Points B and C allow for hedging of the release to prevent the reservoir running dry during low inflows (adapted from Hurford and Harou, 2014).

Ten performance metrics were developed to represent a diverse range of stakeholder interests in the performance of the basin (Table 8).

TABLE 8. Performance metrics, definitions and search goals

Metric	Targeting to Maximize or Minimize	Definition
Fish Biodiversity	Max	Number of species in Myitnge sub-basin
Navigation	Max	Lowest monthly average flow, in m^3/s
Annual Generation	Max	Average annual generation in kWh
Flood Control	Min	Highest monthly average flow, in m^3/s
Firm Generation	Max	Monthly generation that can be reached in more than 90% of all months, in kWh
Capital Expenditure	Min	Capital expenditure on additional dams, in USD
Fishery Support	Max	Contribution of Myitnge sub-basin to overall fish biomass in the Irrawaddy basin
Sediment Load	Max	Sediment delivery, tons/year
Displaced People	Min	Number of people living in reservoir area
Forest Loss	Min	Hectares of forest in reservoir area

Some of the performance metrics involved pre-processing of data using tailor-made geospatial tools and models within a Geographic Information System (ESRI ArcGIS 10.3). The main data source for the Myitnge sub-basin and the entire Irrawaddy river basin is provided by the HydroSHEDS database, which represents global scale inventory of spatial hydrographic and hydrological information, including river networks, watershed delineations, and flow regions (Lehner et al., 2008). These metrics are described in more detail below.

Displaced People

The metric for displaced people is calculated as the number of people presently living in the predicted reservoir footprint of a planned hydropower plant. The analysis used LandScan, a global population distribution database, to quantify the number of people within the reservoir boundary (Bright et al., 2012). For each development option, the metric for displaced people was calculated by finding the sum of people in all the reservoir boundaries included in the development portfolio.

Forest Loss

The forest loss metric is calculated in a similar fashion compared to the metric for displaced people. The total number of forest hectares that will be inundated by the reservoir is calculated using the Myanmar Forest Cover Change map (Bhagwat et al., 2015). Pixels originally classified as intact forest, degraded forest, and newly degraded forest were included in the calculation of forest loss. For each development option, the forest loss metric was calculated by finding the sum of hectares of forest inundated across all the reservoir boundaries included in the development portfolio.

Fishery support

Fishery support was calculated based on a combination of three sub-indicators: 1) river connectivity, 2) sediment trapping, and 3) river flow alteration. Values for each specific indicator under fishery support were calculated and then normalized between 0 and 1/3. The normalized values for each indicator were summed together for each hydropower development option to derive a final calculation for fishery support, with potential values ranging between 0 and 1. The value 1 would be assigned to the maximum sustainable yield in the basin. Data are normalized because data on the current catch are considered unreliable, and the sustainable yield is unknown. The trade-off analysis aims to maximize the metric for fishery support.

River Connectivity

Impacts to a river that alter the connectivity of fish habitat are assumed to negatively impact fishery support. In this analysis, river connectivity was calculated by measuring the number of stream kilometers of fish habitat affected by an indicator called Degree of Fragmentation (DOF). DOF aims to measure the reduction in longitudinal connectivity of a river system by a hydropower dam and is an indicator of "local" river fragmentation because it is calculated at the scale of every river reach in the river system. It gives a gradient of fragmentation impact both upstream and downstream of the dam, which dissipates as the size of the river alters from the size of the river at the location of the dam. This type of indicator assumes that fragmentation is highest in similar types of environments because it also assumes that species that live in a specific type of environment prefer similar types of environment. The calculations which incorporated degree of fragmentation were performed using the HydroROUT river routing model (Grill et al., 2015). HydroROUT is based on the HydroSHEDS database at a 500m (15 arc-second) spatial resolution (Lehner et al., 2008). Under each development option, all river reaches that had a degree of fragmentation greater than or equal to 50 percent were deemed affected habitat and summed together. Scores for the river connectivity metric were normalized between 0 and 1/3 and then inversed in order to maximize the metric for fishery support.

Sediment Load

One important property of river flows is that they transport sediment, nutrients and organic particles, which are highly influential on fishery support. Thus, the trapping of sediment by hydropower dams is assumed to negatively impact fishery support. The trade-off analysis aims to maximize the amount of sediment which is modeled to reach the Irrawaddy River. In this analysis, the indicator is measured as a function of the number of dams built along the Myitnge River. The basic assumption for sediment trapping as it relates to fishery support is that each dam has an average trapping efficiency over time of 50 percent. Thus, each additional dam reduces sediment and nutrient delivery into the Irrawaddy River by 50 percent (Eq. 1). The Watershed Conservation Screening Tool was used to estimate the annual sediment load (3,332,000 tons) at the outlet of the Myitnge River basin just before its confluence with the Irrawaddy River (http://watershedtool.org/).

Equation 1:

$S = 3{,}322{,}000 * (.50)^n$

n = number of dams built on Myitnge river cascade

After sediment values are calculated for each development option, the range of sediment values were normalized between 0 and 1/3.

Flow Alteration

This analysis assumes that the natural variability of a river's flow regime represented by the unregulated flow frequency curve is most likely to support the highest amount of fishery support in the Myitnge River. The flow alteration metric is computed near the outlet of the river basin, immediately downstream of Deedoke, by assessing the difference between 10 corresponding deciles of the regulated and unregulated curves. The flow alteration metric assesses the deviation of the regulated flow from the unregulated flow frequency curve. The model aims to minimize the flow alteration metric.

Fish Biodiversity

The metric for fish biodiversity is calculated as an impact to freshwater fish species due to fragmentation and disruption in the latitudinal and longitudinal connectivity of riverine habitats from hydropower dams. Therefore the model aims to minimize the metric for fish biodiversity. The Myitnge River basin was divided into sub-basins based on Level 8 HydroBASIN boundaries and an impact score is assigned to each sub-basin. Within each HydroBASIN boundary, the average degree of fragmentation was calculated for those river reaches and multiplied by the number of unique freshwater fish species according to the IUCN Red List of Threatened Species (IUCN 2014), which is a spatial dataset that includes freshwater fish species ranging from the least concern category to critically endangered (Eq. 2). The impact score for each HydroBASIN boundary is then summed together to get a total impact score for the Myitnge River basin.

Equation 2:

$\sum_{1}^{n}(\text{Average DOF})j * (\text{Count of Unique Fish Species})j$

n = number of unique HydroBASINs

j = unique HydroBASIN ID

Sediment Load

In addition to the impact of sediment on fishery support, sediment is included in the model as its own metric. Sediment also plays an important role in shaping the river geomorphology and influencing the rich productivity of the Irrawaddy delta (Hedley et al, 2009). The assumptions made for the sediment load metric are equivalent to the assumptions made for the sediment trapping indicator within the fishery support metric. The metric values are also calculated so that each additional dam built on the Myitnge cascade reduces sediment and nutrient delivery into the Irrawaddy River by 50 percent. Unlike fishery support, values for sediment load are not normalized, but they are still maximized by the model.

Planning Formulation: Objectives and Constraints

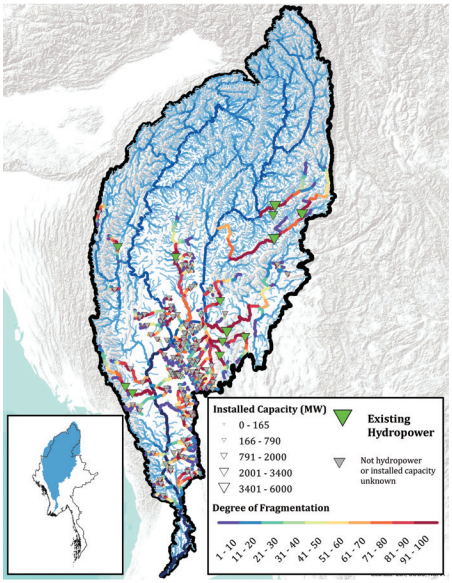
The simulation model of the Myitnge River system was linked to a multi-criteria search algorithm to filter the billions of possible combinations of projects and operating rules to find those which maximize efficiency of water use while also trying to improve performance in each metric simultaneously. Each performance metric has a search objective (i.e., to minimize or maximize its value). The search algorithm appraises different sets of dams and operating rules using their relative performance as evaluated by the metrics. Where high performance in metrics conflict, trade-offs are revealed between them at the performance limits of the system. No constraints were imposed on the search.

Spatial Analysis

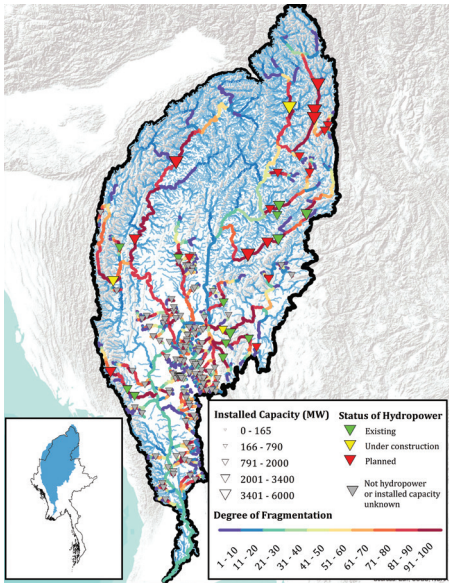
The spatial analysis described in the last section of Chapter 4 is based on a fragmentation analysis that uses an index of fragmentation. This is based on a scale of 0-100 percent fragmentation. The river reach directly at the dam site is considered 100 percent fragmented, and this value decreases with increasing distance from the dam, where river discharges are either larger or lower, on the basis of the habitat requirements of the aquatic organisms affected by fragmentation. Values above a threshold of 80 percent are considered 'fragmented', and river kilometers above 80 percent are counted towards the affected habitat of migratory species.

The maps below show fragmentation of the Irrawaddy basin for three scenarios: the current baseline with only a few percent of the hydropower potential developed, but many existing irrigation dams; a 50 percent development scenario with dams randomly chosen and with a low fragmentation outcome; and a 50 percent development scenario, also with dams randomly chosen but with a high fragmentation outcome. These correspond to the outlying dots in the point cloud shown in Figure 11 (page 44), Chapter 4, for 50 percent development.

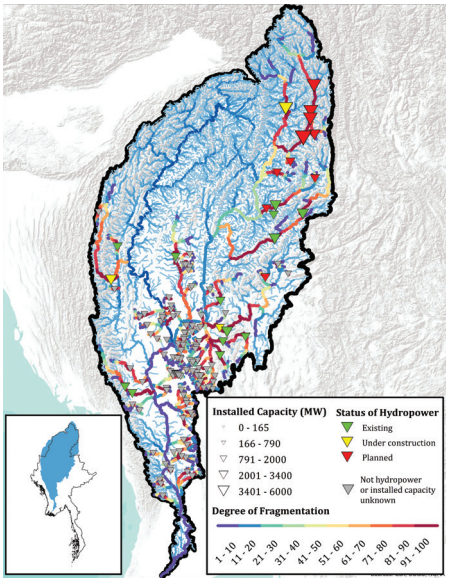
MAP 6. Baseline



MAP 7. High impact at approximately 50 Percent



MAP 8. Low impact at approximately 50 Percent



Annex 4: References

ADB (2012) Myanmar: Energy sector initial assessment.

Alcamo, Döll, Henrichs, Kaspar, Lehner, Rösch, & Siebert (2003). Global estimates of water withdrawals and availability under current and future "business-as-usual" conditions. Hydrological Sciences Journal, 48, 339-348.

Anonymous (2012) Electrical Industry of Burma/Myanmar On-Line Compendium. Fourth Edition.

Aung Din (2011) Killing the Irrawaddy. Asia Sentinel.

Branche (2015) EDF and World Water Council: Multipurpose Water Uses of Hydropower Reservoirs.

Bhagwat, Hess, Horning, Khaing, Thein, Aung., Aung, Phyo, Tun, Oo, Neil, Thu, Songer, LaJeunesse Connette, Bernd, Connette, Leimgruber (2015). Myanmar 2002-2014 forest cover change dataset. Retrieved from [http://geonode.themimu.info/layers/geonode%3Amyanmar_forestcoverchange/].

Bright, Coleman, Rose, Urban (2012). LandScan 2011. Digital dataset, Oakridge National Laboratory, Oakridge, TN, USA. web.ornl.gov/sci/landscan/index.shtml

Burma Rivers Network (2011) Stop damming in War-Zones on Burma's Major Rivers: A Briefer on Conflicts at Dam Sites in Burma.

Dapice (2015) Hydropower in Myanmar: Moving Electricity Contracts from Colonial to Commercial. Harvard Kennedy School Ash Center. Prepared for Proximity Designs Myanmar.

Dapice (2016) Big Dams and Federalism in Myanmar. Harvard Kennedy School Ash Center. Prepared for Proximity Designs Myanmar.

Döll & Lehner (2003). A global hydrological model for deriving water availability indicators: model tuning and validation. Journal of Hydrology, 270, 105-134.

Doran (2015) DFDL: Attracting Investors in Hydropower: What's Needed–Lessons from Laos. World Bank/IHA Sustainable Hydropower and Regional Cooperation in Myanmar Workshop 20 January 2015, Nay Pyi Taw.

Doran (2014) Hydropower in Myanmar: Sector Analysis and Related Legal Reforms. The International Journal on Hydropower & Dams. Volume Twenty One, Issue 3.

ESRI (Environmental Systems Resource Institute) (2014). ArcMap 10.3, ESRI, Redlands, California

FAO (2011) Fishery and Aquaculture Country Profile for the Republic of the Union of Myanmar.

FAO Fisheries and Aquaculture Department (2014) The State of World Fisheries and Aquaculture 2014. Rome: Food and Agriculture Organization of the United Nations.

FAO (2011) Irrigation in Southern and Eastern Asia in Figures – AQUASTAT Survey. Myanmar chapter.

Furuichi et al (2009) Discharge and suspended sediment transport in the Ayeyarwady River, Myanmar: Centennial and decadal changes. Hydrol. Process. 23, 1631–1641.

Geressu & Harou (2015). Screening reservoir systems by considering the efficient trade-offs–informing infrastructure investment decisions on the Blue Nile. Environmental Research Letters, 10(12), 125008.

Grill and Lehner (2015) Dam impact assessment for the Greater Mekong Region: Overview of Methods. Presentation at WWF Workshop.

Grill, Lehner, Lumsdon, MacDonald, Zarfl, & Reidy Liermann, (2015). An index-based framework for assessing patterns and trends in river fragmentation and flow regulation by global dams at multiple scales. Environmental Research Letters, 10

Hartmann, Harrison, Opperman, and Gill (2013) The Next Frontier of Hydropower Sustainability: Planning at the System Scale. Report prepared for the Inter-American Development Bank (IDB) by The Nature Conservancy.

Hedley et al (2010) Evolution of the Irrawaddy delta region since 1850. The Geographical Journal, Vol. 176, No. 2.

Holsen (2014) The urgent power need in Myanmar. NABS Bangkok, Yangon April 2014.

Hurford, Huskova and Harou (2014). Using many-objective trade-off analysis to help dams promote economic development, protect the poor and enhance ecological health. Environmental Science & Policy, 38(0), 72-86.

Hurford & Harou (2014). Balancing ecosystem services with energy and food security; assessing trade-offs for reservoir operation and irrigation investment in Kenya's Tana basin. Hydrology and Earth System Sciences, 11 (1), 1343-1388. doi:10.5194/hessd-11-1343-2014

IFC (2013) Good Practice Handbook: Cumulative Impact Assessment and Management: Guidance for the Private Sector in Emerging Markets.

IUCN (2010) The Status and Distribution of Freshwater Biodiversity in Eastern Himalaya.

IUCN (2012) The Status and Distribution of Freshwater Biodiversity in Indo-Burma.

IUCN 2014. The IUCN Red List of Threatened Species. Version 2014.1. http://www.iucnredlist.org. Downloaded on 2-20-2016.

Kattelus et al (2014) Myanmar under reform: Emerging pressures on water, energy and food security. Natural Resources Forum 38, 85–98.

Khin Maung Soe et al (2015) Myanmar Inland Fisheries - Ayeyarwady Delta and Central Dry Zone 2003 -2013. WorldFish.

Kristensen (2016) Transforming Myitsone into a win-win. Myanmar Times; March 4, 2016.

LandScan (2011). Oak Ridge National Laboratory, Oak Ridge, TN, July 1, 2012 ed. ,http://www.ornl.gov/landscan/>.

Lehner and Dallaire (2014) River reach classification for the Greater Mekong Region. Final report on behalf of WWF Greater Mekong Programme.

Lehner (2008). New global hydrography derived from spaceborne elevation data.EOS, Transactions of the American Geophysical Union, 89, 93-104.

Lehner, Liermann, Revenga, Vörösmarty, Fekete, Crouzet, Döll (2011). High resolution mapping of the world's reservoirs and dams for sustainable river-flow management. Frontiers in Ecology and the Environment, 9, 494-502.

Hedley, Bird & Robinson (2010). Evolution of the Irrawaddy delta region since 1850. Geographical Journal, 176(2), 138-149.

Matrosov, Huskova, Kasprzyk, Harou, Lambert & Reed (2015). Many-objective optimization and visual analytics reveal key trade-offs for London's water supply. Journal of Hydrology, 531, Part 3, 1040-1053. doi: http://dx.doi.org/10.1016/j.jhydrol.2015.11.003

Min Khaing (2015) Department of Hydropower Implementation: Status of Myanmar Electric Power and Hydropower Planning. World Bank/IHA Sustainable Hydropower and Regional Cooperation in Myanmar Workshop 20 January 2015, Nay Pyi Taw.

Min Khaing (2015) Assessing Climate Change Impacts on Hydropower Generation in the Myitnge River Basin, Myanmar.

Ministry of Agriculture and Irrigation; Ministry of Livestock, Fisheries & Rural Development; FAO and WFP (2015) Agriculture and Livelihood Flood Impact Assessment in Myanmar.

Ministry of Electric Power / Hydropower Generation Enterprise (2013) Presentation 2nd July 2013.

Myanmar Information Management Unit (2015) Overview of flood inundated area in Sagaing. 24.7.2015.

Nam et al (2015) Power Sector Development in Myanmar. ADB Economics Working Paper Series No.460.

National League for Democracy (2015) Election Manifesto.

Opperman, Grill and Hartmann (2015) The Power of Rivers: Finding balance between energy and conservation in hydropower development. The Nature Conservancy.

Parker, Helen and Yates (2016). ODI: How do healthy rivers benefit society? A review of the evidence. Working Paper 430.

Peel (2014) Villagers count the cost of Myanmar dam project. Financial Times.

Royal HaskoningDHV, Arcadis, Rebel Group, UNESCO-IHE, Dutch Water Authorities, Tygron (2014) Myanmar Integrated Water Resources Management Strategic Study.

Simmance (2013) Environmental Flows for the Ayeyarwady (Irrawaddy) River Basin, Myanmar. UNESCO-IHE Online Course on Environmental Flows.

Watts (2011) Dozens killed in Burma amid clashes over Chinese dams. Fighting over hydropower projects ends 17-year ceasefire between Burmese government and Kachin militia. Guardian.

Win Kyaw et al (2006) Yeywa Hydropower Dam, An Overview.

World Bank (2009) Energy Strategy Approach Paper. Annex 2.

World Bank (2014) Project Appraisal Document on a Proposed Credit in the Amount of SDR 67.5 million (US$100 million equivalent) to the Republic of the Union of Myanmar for an Ayeyarwady Integrated River Basin Management Project. Report No: PAD987.

The World Bank (2016), "Toward Climate-Resilient Hydropower in South Asia", Live Wire publication No. 60, The World Bank Group.

Zarfl, Lumsdon, Berlekamp, Tydecks & Tockner (2015). A global boom in hydropower dam construction. Aquatic Sciences, 77, 161-170.

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