Integrated Long-term Energy Planning for Rapidly Developing Economies: A Case Study of Megaprojects in Borneo

Rebekah Shirley[1], Daniel Kammen[1,2]*

[1]Energy and Resources Group, University of California, Berkeley, California, USA
[2]Goldman School of Public Policy, University of California, Berkeley, California, USA
* Corresponding Author: daniel.kammen@berkeley.edu

Motivation: Mega-dam Renaissance in Borneo prompts a need for comparing alternatives

The rapid economic growth sustained in Southeast Asia throughout the new millennium has led to a surge in large-scale infrastructure projects to facilitate industrial productivity and consumption [1], [2]. The state of Sarawak, located along the northern coast of the island of Borneo (Fig 1), is the poorest and most rural state in Malaysia but has long been a focal point for the development of large-scale hydroelectric power given its characteristically heavy rainfall and elevated topography. At least six dams are scheduled to be completed in Sarawak by 2020 as part of a high hydro-potential corridor in central Sarawak (Fig 1). One of these dams (Bakun Dam) is now operational while two others (Murum and Baram Dams) are in advanced stages of development [3]. Together these three dams represent 4.5 GW of generation capacity and 1355km^2 of flooded forest land. Local opposition to the state-led development plan, and in particular to the Baram Dam – the dam next in line for construction – has garnered significant regional and international attention [4], [5]. In addition to the displacement of roughly 100,000 indigenous people, the development of the full twelve mega-dam portfolio would result in at least 2,425 km^2 of direct forest cover loss [6].

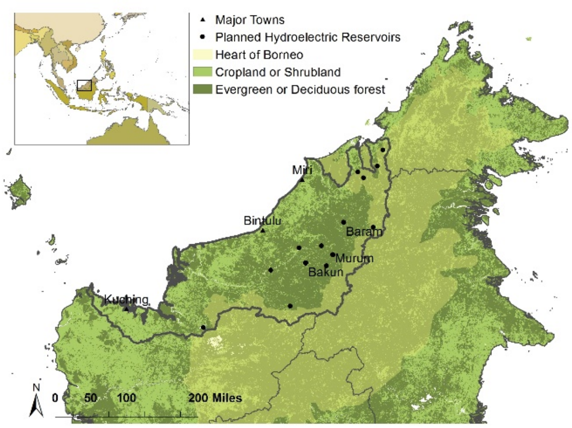

Figure 1 Hydroelectric Reservoirs planned for Sarawak

Borneo's forests are large stores of natural capital, from extractable forest products to the numerous direct and indirect ecosystem services they provide. These forests have undisputed global and local significance, however neither the economic value of its functional ecosystem services nor the economic value of its intrinsic worth to humans have been well documented. Estimation of these values is a crucial step toward harmonizing government development plans quantifying and discussing avenues to integrate the economic value of natural capital into mainstream decision making. The Heart of Borneo (HoB) Initiative, for instance, recently used a non-linear macroeconomic system dynamics model to show that shifting toward a green economy can promote faster long term growth for Borneo, as land use trends are tightly coupled with social and economic drivers [7].

Further studies that analyze the feasibility of alternative solutions at higher resolution of impact, demand and disaggregated generation can complement these assessments of the green economy. The Renewable and Appropriate Energy Laboratory (RAEL) of the University of California, Berkeley has conducted an in-depth analysis that addresses this gap through an integration of modeling tools to explore the scope of clean energy solutions for Sarawak. Our research agenda has three main project areas: (a) modeling long-term utility scale electricity generation alternatives in Sarawak to determine trade-offs across different technologies; (b) exploring the potential for rural communities in dam-affected areas to satisfy energy access needs using local resources; (c) demonstrating a rapid assessment method for estimating the impact of mega-projects on biodiversity. Each of these studies provides information useful to the discussion of alternatives and furthers the analysis of green economy costs and benefits. A summary of our results and findings is below. The full reports can be found on our webpage: http://rael.berkeley.edu/sustainableislands

Comparing Industrial Scale Energy Alternatives

In this study we compare the generation and environmental costs of different energy technologies through modeling the capacity expansion necessary to meet Sarawak's demand in 2030 under four different energy demand growth assumptions: continued Business as Usual (BAU), an aggressive 7% p.a. growth, 10% p.a. growth and the SCORE expectation. To do this we use PLEXOS, a commercial capacity expansion model built on a mixed integer linear program and collect (i) publicly available data on fossil fuel, hydro, solar and wind resources and biomass waste availability; (ii) data on build, operation and maintenance costs; (iii) local emission factors from generation technologies and (iv) data on local policy incentives such as Feed in Tariffs (FiT). We use this data in our model to predict the most optimal (ie least cost) generation mixes for meeting demand under various policy scenarios.

Under an extremely aggressive 10% growth energy demand peaks at 3,635 MW in 2030 (30,000 GWh/year). Our study shows that there are a number of alternative capacity expansion choices that meet future demand at this rate. We find the two existing dams (Batang Ai and Bakun) and recently installed combined gas and coal-fired generators - are sufficient to meet this demand. Where the Bakun Dam, Murum Dam and Baram Dam are all built and committed, there is a large excess of undispatched energy (note Capacity Reserve Margin). Policy incentives such as a Renewable Portfolio Standard (RPS) or the existing FiT scheme allow solar PV, palm oil biomass gasification and methane capture to be major contributors. Interestingly, we find that SCORE has a greater total cost and levelized cost than other policy scenarios. While it has a low fuel cost and low emissions cost, the high annual build cost and associated fixed costs are high since the system is overbuilt. Consistent across the 7%, 10% and SCORE growth assumptions, policy tools such as FiT can help to diversify the generation portfolio, integrate local renewable resources and create the lowest net present cost over the fifteen year time horizon.

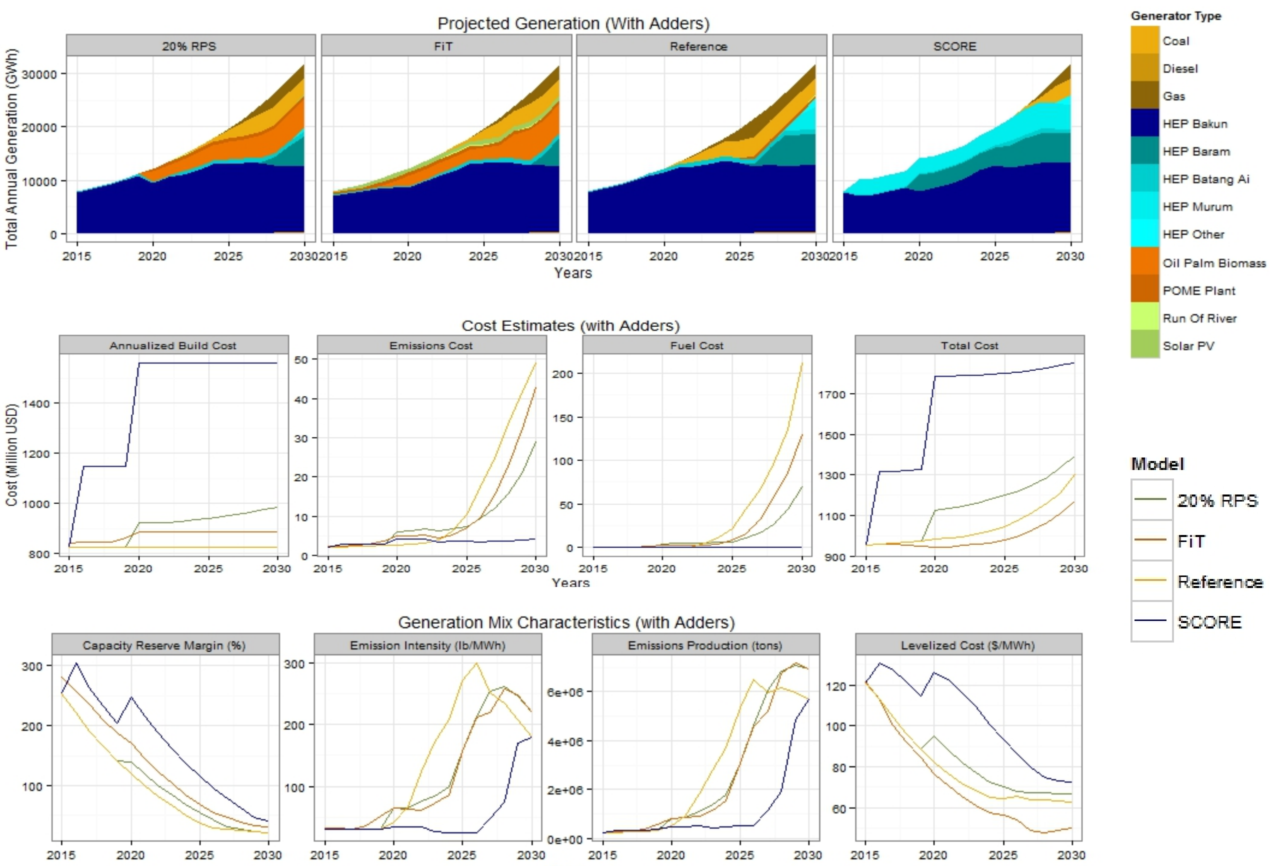

Figure 2 Generation Profile, Cost Components and Generation Characteristics of Scenarios under 10% Demand Growth

Capacity for Sustainable Rural Energy Access

Most rural villages in East Malaysia are not grid connected, and rely heavily on high-cost diesel fuel for electricity and transportation. Improved rural energy access has been a key component of sustainability advocates, however little quantitative data on demand and potential is often available. We conduct a case study in the Baram Basin – the next basin to be flooded for a SCORE dam reservoir - which explores the potential of renewable energy as a bottom-up solution to satisfy the energy needs of these impacted communities. First, based on interviews and site visits we record the number and type of generators operational within each village, along with time of use and total fuel consumption, and appliance use to estimate current energy demand and supply. We find that while 60-70% of homes in a village may own a diesel generator, they are typically operated at very low efficiencies, which increases the effective cost of electricity in rural areas (approximately $0.34/kWh compared to the $0.10/kWh SEB rate for grid connected domestic customers). Village households can spend twice as much as urban households on monthly electricity.

We use a popular optimization model (HOMER), and provide it with resource and technology inputs including monthly biomass residue availability, daily solar insolation and monthly averaged flow rates. Our model simulates load following over the course of one year to deliver a ranking of the least net present cost micro-grid generator combinations for each village. We find that micro-hydro turbines are often the least cost generator, given the abundant river resources (with high annual average stream flow) in close proximity to village communities. Small scale biogasification is also technically feasible for these rice-farming villages where rice husk waste is readily available, though maintenance can be costly. In each village modeled a micro-hydro based system can be a third of the cost of the diesel base case. The main drawback of such renewable systems is reliability, especially during the dry season. To ensure zero energy shortage, batteries often become necessary, which increases total system cost. Our study highlights the potential of villages in rural Sarawak to satisfy their own energy access needs with local and sustainable resources and suggest a need for exploring a radically different strategy for expanding rural energy access.

Village	Category	System Specification	Initial Cost (US$)	Annual Operating Cost (US$)	Total NPC ((US$)	LCOE (US$/kWh)	Average Fuel per Day (L/day)	Capacity Shortage (%)	Annual Operating Cost Ratio	NPC Ratio	LCOE Ratio
Tanjung Tepalit	Least Total Cost	9 KW Hydro + 60kWh Battery	29,170	2,166	54,408	0.150	0.00	5.3	0.16	0.33	0.35
	Diesel Base Case	20kW Diesel	8,800	13,470	165,771	0.433	27.60	0.0	0.00	1.00	1.00
Long Anap	Least Total Cost	7kW Hydro + 20kW Diesel + 120kWh Battery	62,870	18,018	272,847	0.354	35.29	4.6	0.66	0.81	0.85
	Diesel Base Case	40kW Diesel	17,600	27,334	336,145	0.416	57.17	0.0	0.00	1.00	1.00
Long San	Least Total Cost	11kW Hydro + 40kW Diesel	18,900	27,444	338,723	0.306	57.74	5.8	0.68	0.68	0.72
	Diesel Base Case	60kW Diesel	26,400	40,650	500,115	0.426	84.00	0.0	1.00	1.00	1.00

Figure 3 HOMER Outputs: Optimization Results for Three Villages Surveyed

Estimating Biodiversity Impacts of Energy Projects

In this study we analyze the direct biodiversity impact of direct land use change from the clearing and flooding of tropical forest lands to prepare the three dams (Bakun, Baram and Murum). To date there has been little quantitative information on the impact of major land use changes, such as palm oil development, or reservoir inundation available for discussion. Direct biodiversity impact assessments based on field surveys are often unavailable or incomplete due to time and funding limitations. Indirect methods for estimating impact based on non-local data sources are useful complementary solutions. In this study we use global species range data, GIS tools and revised species/endemics area scaling relationships to predict three distinct measures of biodiversity impact for four major taxonomic groups (mammals, birds, plants and arthropods): the total number of species with ranges affected by the dams, the number of individuals affected and the number of potential species extinctions that could result.

We find that at least 331 bird species and 164 mammal species will be affected by the dams. This represents 57% and 69% of Bornean bird and mammal species. The affected species include a number of IUCN Critical and Endangered species such as the *Manis javanica* (Sunda Pangolin), *Catopuma badia* (Bay Cat), *Cynogale bennettii* (Otter Civet), *Hylobates muelleri* (Grey Gibbon*), Lutra sumatrana* (Hairy Nosed Otter), *Prionailurus planiceps* (Flat-headed Cat), *Pteromyscus pulverulentus* (Smokey Flying Squirrel), and birds *Ciconia stormi* (Storm's Stork) and the *Polyplectron schleiermacheri* (Bornean Pheasant). We also estimate two-thirds of all tree and anthropod species will be impacted resulting in 4 tree and 35 anthropod local species extinctions. Given Borneo's high rate of endemism, these are significant species impacts. Our method now allows stakeholders to gauge the risk to species population that the dams represent to these specific land areas for more informed opinions and discussion of tradeoffs.

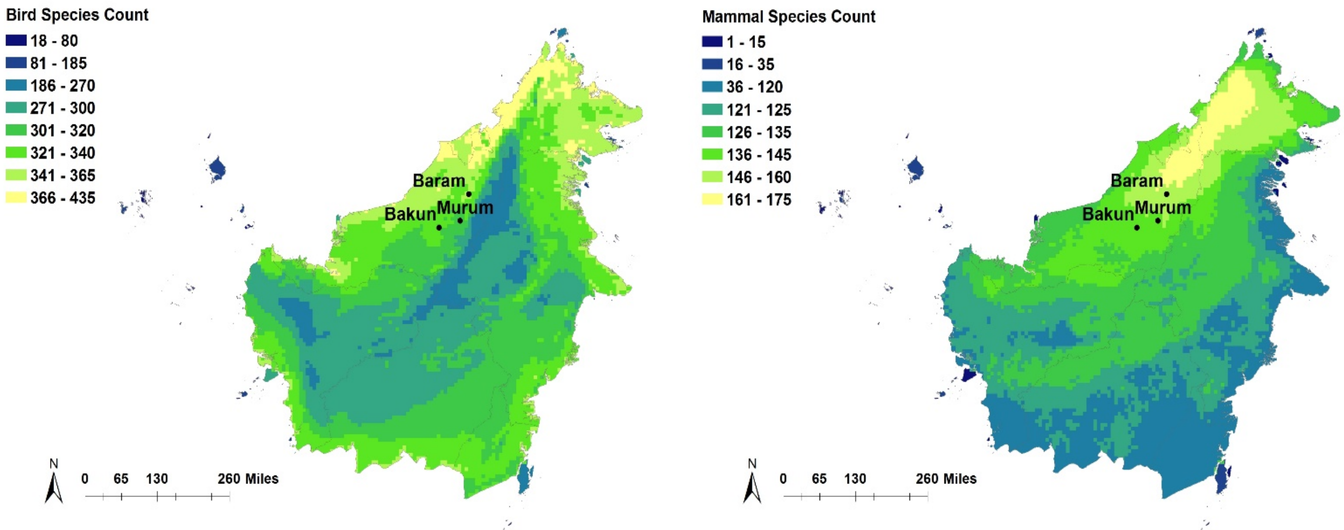

Figure 4 Results Showing Dams to be built in (left) High Bird and (right) High Mammal Species Dense Areas

Contributing to Informed Discussions and a Sustainable Development Pathway

The need to satisfy growing industrial demand in Sarawak represents a development crossroads common to many emerging economies. Together our studies provide quantitative components that are key to integrated analysis – the analysis of development alternatives that includes an attention to cost, scale, feasibility, environmental impacts and local stakeholder interests. Using Sarawak as our case study we provide insight into (i) large-scale commercial energy alternatives to the SCORE mega-dam portfolio, (ii) bottom up solutions for improved rural energy access and (iii) rapid environmental impact assessment tools for data-constrained contexts. This information is necessary for incorporating the value of natural stocks and in anticipating the direct and indirect trade-offs that development projects present.

Our Collaborators

This research was conducted in collaboration with Green Empowerment and Tonibung - NGO organizations involved in rural energy access in South East Asia. We wish to acknowledge their role in facilitating surveying and data collection, and in providing information on past projects. This research was funded by the Bruno Manser Fonds and the Rainforest Foundation Norway.

[1] International Energy Agency, “Southeast Asia Energy Outlook: World Energy Outlook Special Report.” OECD Publishing, 2013.
[2] OECD, *Economic Outlook for Southeast Asia, China and India 2014*. OECD Publishing, 2013.
[3] B. K. Sovacool and L. C. Bulan, “Energy security and hydropower development in Malaysia: The drivers and challenges facing the Sarawak Corridor of Renewable Energy (SCORE),” *Renew. Energy*, vol. 40, no. 1, pp. 113–129, Apr. 2012.
[4] B. K. Sovacool and L. C. Bulan, “Behind an ambitious megaproject in Asia: The history and implications of the Bakun hydroelectric dam in Borneo,” *Energy Policy*, vol. 39, no. 9, pp. 4842–4859, Sep. 2011.
[5] Choy, Yee Keong, “JSTOR: Pacific Affairs, Vol. 77, No. 1 (Spring, 2004), pp. 50-68.” [Online]. Available: http://www.jstor.org/discover/10.2307/40022274?uid=2134&uid=2&uid=70&uid=4&sid=21104574114871. [Accessed: 17-Nov-2014].
[6] Bruno Manser Fonds, “Sold Down River: How Sarawak Dam Plans Compromise the Future of Malaysia’s Indigenous Peoples.” 2012.
[7] Van Paddenburg, A., Bassi, A., Buter, E., Cossiett, C, and Dean, A, “Heart of Borneo: Investing in Nature for a Green Economy,” WWF Heart of Borneo Global Initiative, Jakarta, 2012.