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Locally Appropriate Energy Strategies for the Developing World: A focus on Clean Energy Opportunities in Borneo

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Locally Appropriate Energy Strategies for the Developing World:
A focus on Clean Energy Opportunities in Borneo

by

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ABSTRACT

Locally Appropriate Energy Strategies for the Developing World:
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This dissertation focuses on an integration of energy modeling tools to explore energy transition pathways for emerging economies. The spate of growth in the global South has led to a global energy transition, evidenced in part by a surge in the development of large scale energy infrastructure projects for the provision of reliable electricity service. The rational of energy security and exigency often usher these large scale projects through to implementation with minimal analysis of costs: social and environmental impact, ecological risk, or opportunity costs of alternative energy transition pathways foregone. Furthermore, development of energy infrastructure is inherently characterized by the involvement of a number of state and non-state actors, with varying interests, objectives and access to authority. Being woven through and into social institutions necessarily impacts the design, control and functionality of infrastructure. In this dissertation I therefore conceptualize energy infrastructure as lying at the intersection, or nexus, of people, the environment and energy security. I argue that energy infrastructure plans and policy should, and can, be informed by each of these fields of influence in order to appropriately satisfy local development needs.

This case study explores the socio-techno-environmental context of contemporary mega-dam development in northern Borneo. I describe the key actors of an ongoing mega-dam debate and the constellation of their interaction. This highlights the role that information may play in public discourse and lends insight into how inertia in the established system may stymie technological evolution. I then use a combination of power system simulation, ecological modeling and spatial analysis to analyze the potential for, and costs and tradeoffs of, future energy scenarios. In this way I demonstrate reproducible methods that can support energy infrastructure decision making by directly addressing data limitation barriers. I offer a platform for integrated analysis that considers cost perspectives across the nexus. The management of energy transitions is a growing field, critically important to low carbon futures. With the broader implications of my study I hope to contribute to a paradigm shift away from the dominant large-scale energy infrastructure as a means of energy security discourse, to a more encompassing security agenda that considers distributed and localized solutions.

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CHAPTER ONE
Introduction: The People, Environment and Energy Security Nexus

1.1. Introduction

Energy infrastructure is critical to the future of any rapidly developing economy. Unprecedented rates of growth in the global South have quickly raised the stakes for finding optimal energy technology mixes to keep pace with development needs, where the term 'optimal' usually derives from a techno-economic perspective. Yet the number of projects deployed in developing countries over the last two decades that perform poorly with regard to their economy, the environment and public support, illustrates a major disconnect between planners, their tools and their project stakeholders. My dissertation is situated in this space. My goal is not to develop a singular method that determines optimal energy infrastructure choices, but to move toward a method that better supports the entire planning process. I use methods from political ecology, power systems modeling and spatial data analysis to explore an integrative approach for envisioning energy pathways. In this chapter I will discuss my aims, my research questions and methods. I will briefly introduce my case study and describe the flow of the chapters that follow. But first, let us begin by exploring the concept of energy infrastructure and the intersectionality that it represents.

1.2. Background: Energy Infrastructure as Socio-technical Systems

The economic separation of early industrializers from the rest of the world during the Industrial Revolution, often termed 'the great divergence', has characterized the global hierarchy for the past two centuries. Now, a historic change is taking place. A 'great convergence' is underway as less developed countries quickly adopt the technology, competence and policies that propelled the developed world ("Economist," 2011). Economists project that today's four most populous emerging markets – China, India, Indonesia and Brazil – alone, will make up to two-fifths of global GDP by 2030. But the convergence has spread beyond these four. Studies find that on average, non-oil, non-small developing countries have seen GDP per capita increasing at a rate of 3% per year over the US since the 1990s (Subramanian, 2011, p. 73). While there have been periods of rapid growth for individual countries in the past, seldom in the last 50 years have we seen episodes where a large number of poor countries have simultaneously done as well as in the decade preceding the recent crisis (Subramanian, 2011).

This growth has brought an unprecedented improvement in human development and an increasing demand for basic services – water, waste management and energy. Increasing water access and ensuring reliable energy service have become major millennium development goals. Provision of these services entails a major infrastructural component. We are now witnessing a surge in large-scale infrastructure projects to facilitate industrial productivity and consumption (International Energy Agency, 2013; OECD, 2013). Infrastructure has moved from being a 'simple precondition for production and consumption to being at the very core of these activities' (Flyvbjerg, Bruzelius, & Rothengatter, 2002, p. 2).

Large infrastructure, however, is characterized by the involvement of a number of actors with varying interests. Balancing the need for large infrastructure with local and contextualized solutions thus presents a major government challenge. Though no one theory completely explains this historic phenomena, infrastructure tends to co-evolve with socio-economic institutions, being deeply intertwined with social structures (von Tunzelmann, 2003). We can conceptualize infrastructure then as socio-technical systems – technological systems embedded within the surrounding socio-environment. It is this embeddedness that allows infrastructure to exist, function and evolve (Goldthau, 2014).

Conceptualizing infrastructure as socio-technical systems, however, also points to the inherent inertia against leaving established, centralized patterns of control. In other words, technology's embeddedness can also cause resistance to fundamental change and lock-in occurs – both at the level of the individual technology but at the level of the whole governance system. Lock-in may perpetuate centralized patterns of technology. The risk here is that these socio-technical systems become incapable of reacting to fundamental changes such as price shocks, climate change or other stressors (Goldthau, 2014; L. Hughes & Ranjan, 2013).

This is especially important for the power sector, which is currently witnessing unprecedented growth in demand. This spate of growth is seen clearly amongst the emerging economies of Southeast Asia, collectively growing at more than 5% per year (International Energy Agency, 2013). According to the International Energy Agency (IEA) total energy demand in Southeast Asia is expected to double by 2035. The region will be responsible for 40% of global primary energy demand increase by 2030 (International Energy Agency, 2013). The power sector accounts for half of this expected increase, highlighting the importance of the electricity fuel mix and also making the power sector a crucial target for low-carbon policy.

This brings us to another crucial aspect of energy infrastructure: scale. Countries differ in population density, rural to urban population ratio, level of established connectivity, primary types of industry and more. Appropriate scale, then, is an important consideration. Scale becomes a key element in determining how to manage infrastructure challenges (Goldthau, 2014). Nevertheless, the mantra of energy security is commonly employed by governing elites in the South to pursue large scale energy projects that are often inappropriate for local development needs (Simpson, 2007). There is therefore a strong local versus national dimensionality to energy access, and 'one size fits all' infrastructure will not necessarily be appropriate for all contexts.

Large-scale energy infrastructural projects are now central to planning policy in the global South as solutions to increasing energy demand. The mega-dam, for instance, has returned to lending bank portfolios after a decade of stagnation in the 1990s (Bank, 2009). New and resumed construction of mega-dams is underway across the globe – from Brazil to Paraguay, Egypt and Somalia. The Three Gorges was completed in 2006, the Lao Nam Theun was completed in 2010, while many other dams are being built in the Mekong Basin and in East Malaysian Borneo a series of twelve mega-dams are under development (Goh, 2007).

Even as their numbers grow such projects often perform poorly with regard to economy, environment and public support generating significant conflict (Flyvbjerg et al., 2002). At the same time that such large-scale state-led energy developments are underway, over one-fifth of the region's population still lacks access to grid connected electricity. Many rural communities are still not grid connected, currently relying heavily on diesel fuel for all electricity and transportation needs. Yet these are the communities most heavily affected by dam-related forest loss, environmental damage and displacement.

Furthermore, while security remains a largely contested concept, the field is expanding beyond its original state-centric focus and within it the concept of environmental security is now being established as a significant area of interest. One definition of environmental security 'considers the way in which environmental degradation threatens the security of people' (Barnett, 2001). Under the umbrella of environmental security themes such as climate vulnerability and adaptation (or managing the risks of extreme events and disasters), and ecological risk and resilience, have taken on prominence in international discussion (IPCC, 2012; Struebig, Fischer, et al., 2015). Furthermore, there is an established literature that links the degradation of environmental security to an erosion of human rights and which demonstrates clear linkages between the exploitation of abundant resources and the propensity for civil strife (Doyle & Risely, 2008).

Political attention often comes to communities most greatly affected by environmental risks only when larger national or international geopolitical forces come into play. Tension grows between civil communities and policy makers as decisions affecting resources, ecology, inhabitants and industry are being made with little public consultation or open analysis of energy alternatives, socio-ecological impacts, or the effects of land use tradeoffs. National and international campaigns against many such projects are gaining notice. Rather than safeguarding marginalized communities from depravation, these energy mega-projects often serve to exacerbate existing social tensions and conflict, intensifying various manifestations of insecurity (Simpson, 2007). Thus we see several key elements come together at the nexus of people, environment and energy security to define energy infrastructure development: local context, scale, co-evolution of technology with institutional structures and the discursive dimensions of power.

We see the dynamic problem that energy policy design and assessment quickly becomes when considering this nexus. Model-based analysis for energy policy design has seen phenomenal growth during the past several decades. Large scale optimization and econometric approaches, including input-output analysis and computable general equilibrium methods, are now widely applied for strategic decision-making. Yet a number of scholars acknowledge the limitations of such models when addressing the complex, informal, non-linear characteristics of modern energy infrastructure systems (Pandey, 2002; Qudrat-Ullah, 2013; Urban, Benders, & Moll, 2007). This brings us to my particular research interest in the potential adaptation of existing methods for integrative, inclusive approaches to energy planning.

1.3. Research Agenda

1.3.1. Research Questions

The cost benefit breakdown for many large energy infrastructure projects would likely look different were these broader concepts of security, risk and cost included in the planning process. The value of resources lost and opportunity cost of pathways foregone as a result of large, centralized system lock-in are rarely a formal consideration. The sheer number of unresolved resource conflicts erupting across the emerging economy landscape precipitated by recent energy infrastructure developments raises the question of whether 'the resource curse' – that is, the abundance of a new found or untapped resource – is able to lend itself to sustainable development, and in particular to locally appropriate and sustainable energy infrastructure alternatives. There is clear need for a paradigm shift away from the dominant large-scale energy security discourse to a more comprehensive, scale appropriate and localized environmental security agenda. I want to understand the role of analytical tools in supporting this shift.

My aim is to contribute to long term energy planning and analysis tools appropriate for emerging economy contexts using hydro development plans in the state of Sarawak, Malaysian Borneo, as a case study. Borneo has abundant natural resources, immense global ecological importance and a very primary economy based largely on agriculture but on the cusp of major industrial transformation. These features create an informative case study to explore whether synergies between clean energy technology and abundant exploitable natural resource can exist and, more importantly, how we can actively consider the complication of institutional and political embeddedness in accessing those synergies.

The Malaysian state government's economic growth strategy involves building at least twelve mega-dams in the central highlands of Borneo, East Malaysia to attract energy-intensive industry to the state (Sovacool & Bulan, 2011a; Choy, 2005). Local opposition to the development plan has garnered regional and international attention (Bruno Manser Fonds, 2012; Oh, Chua, & Goh, 2011). It is estimated that in addition to the displacement of 30,000-50,000 indigenous people, the development of the twelve mega-dams would result in at least 2,425 km^2 of direct forest cover loss and major ecological damage in one of the world's most important tropical forest areas (Bruno Manser Fonds, 2012). This plan represents a development strategy based distinctly on an abundant and low cost energy source. It exemplifies many other areas pursuing rapid economic expansion in the region and in developing countries more generally.

A critical analysis of the strategy extends beyond the question of energy options for a state to questions of how development planning takes place and which stakeholders are able to participate in that conversation. It involves a discussion of land rights and allocation, access to rights, wealth distribution, political interests, public discourse, as well as valuations of energy resources, carbon storage, biodiversity and other ecosystem service functions. How can integrated energy analysis fit into the discussion about development pathways for developing economies? I explore ways that these themes interact with each other and their implications for clean energy solutions.

The actionable questions that govern my research are:

Q1: What are feasible alternative energy futures for East Malaysia that meet future energy demand for the local population given priorities of (a) cost, (b) reliability and (c) environmental impact?

- What is the potential for renewable resources to satisfy (a) rural energy needs and (b) utility scale needs?
- What are the implications of different energy market scenarios on optimal generation mix?
- What ecological impacts can we measure in a data constrained context?
- What are the implications of including ecological (biodiversity) in assessment of energy alternatives?

Q2: How can these conclusions collectively contribute to a development discourse (and subsequent agenda) that prioritizes both social and environmental objectives?

- Who are the stakeholders involved and what claims are being made to land?
- How does scientific information contribute to this discussion? What context does new information come into and how can it be useful?
- What does this case study reveal about contemporary energy management in developing countries?

My research agenda addresses these questions in three focal ways: (a) modeling long-term utility scale electricity generation alternatives for Northern Borneo to determine cost trade-offs across different technologies; (b) demonstrating methods for the integration of non-economic criteria (such as biodiversity loss and rural energy needs) into planning tools despite data limitations; (c) exploring the actors involved in the mega-dam conflict through a critical political ecology lens to identify existing frameworks for discussion and to identify information gaps. Each of these areas advances the discussion of alternatives and furthers the analysis of costs and benefits. My thesis thus presents an assembly of tools integrated to provide new perspective on designing locally appropriate energy development solutions.

In a broader sense, this research provides a proving ground as I argue for the need to integrate methods of energy and power system modeling with stakeholder analysis and for the need to incorporate characteristics such as urban-rural divide, power system operability and biodiversity impact in locally appropriate frameworks for designing and assessing development agendas. These tools having constraints and inherent biases and so while being incomplete efforts to describe real phenomena, they can serve as powerful means by which stakeholders with different perspectives debate critical assumptions of development strategies (King & Kraemer, 1993a). Thus, rather than arguing for a particular mix or policy portfolio this body of work aims to encourage discussion.

The following sections provide an outline of my research methods, data collection process and how the chapters of this dissertation will proceed.

1.3.2. Research Methods

I draw on methods from three distinct fields of study for this research. I use actor-based critical analysis techniques from *Political Ecology* to first lay a foundation for the many stakeholders, interests and interactions represented in the hydro development conflict. I use both large-scale and small-scale energy resource optimization methods from *Power Systems Modeling* to create a basis for comparing different energy development scenarios. I use two methods from *Spatial Data Analysis* to explore ways that non-economic stakeholder criteria can be incorporated into the energy planning and assessment process. Here I discuss these methods in their loosely chronological order.

As noted, conceptualizing energy infrastructure as socio-technical systems points to the inherent inertia against leaving established, centralized patterns of control. It is thus important to observe Sarawak's hydro development plans in the context of previous development projects as a frame of reference and to gain insight into how established patterns of control and stakeholder interaction influence the local planning process. Using an actor-oriented analysis approach I draw on insights from interviews, site visits, discussions, local media and classical political ecology theory to identify and distinguish among key stakeholders, their claims and mobilization strategies. My goal is to understand the socio-cultural asymmetries created and reinforced through hydro development and the implications these have for local planning and decision-making.

I then prepare a long-term capacity expansion optimization model for the state which includes existing generation, resource stocks, resource constraints, and system operability constraints. Into this model I incorporate environmental constraints through metrics such as emissions cost and forest land value. I use this model to explore the economic, technical and direct land use trade-offs of various potential energy infrastructure mixes under different assumptions of future demand growth, policy incentives and market conditions. I opted for a commercially available analytic software (PLEXOS) for this project so that my scenario analysis is directly accessible to state planning agencies. I simultaneously explore the role of alternative energy resources in also satisfying rural scale energy needs using another commercially available but small-scale hybrid optimization model (HOMER) to compare local energy technologies for village energy supply. I focus specifically on villages of the Baram River Basin in Sarawak where my local collaborators are currently installing a number of village micro-hydro systems. This is also the next basin scheduled for mega-dam construction (the Baram Dam), which will affect and displace many settlements.

In addition to these techno-economic studies, I use spatial data analysis to better understand the ecological risks associated with energy infrastructure. I conduct this study with Dr. Justin Kitzes, ERG Post-Doctoral fellow and specialist in ecological modeling. We use global species range data and revised species-endemics area scaling relationships to estimate biodiversity impacts from direct forest cover loss associated with various energy infrastructure projects. For any project footprint we are able to estimate the total number of individual mammals, birds, plants and arthropods that would be lost, the extent of their respective global and local species ranges affected, and the number of potential species extinctions that would result.

Finally, I integrate results from these techno-economic and ecological analyses into a decision support tool using a spatial multi-criteria decision analysis approach. Combining results from my analyses with relevant publicly available datasets I develop a spatial model that performs suitability analysis for energy infrastructure configurations with respect to social, economic and ecological objectives. This tool can be used to explore optimal infrastructure mixes under varying assumptions of the priority placed on different objectives. In this way we expand the definition of 'optimal' to be more inclusive of stakeholder concerns. Readily useable tools that explicitly consider trade-offs amongst criteria that are important to stakeholders, other than economic costs and technical feasibility are critical for informing the planning process. I demonstrate the application of such a tool to the hydro development case study of Sarawak with implication for many developing regions.

1.3.3. Data Collection and Research Collaboration

I use both primary and secondary data for the research described above. Between March 2013 and March 2015 I made five research trips to Malaysia totaling seven months. I spent time in five major cities in Malaysia and in over 20 villages in Sarawak and neighboring Sabah. During this time I conducted interviews with researchers, government agencies, village leaders, civil society groups, project developers, academic and research institutions, local and international environmental NGOs, independent consultants, journalists, activists, politicians. I did field visits to resettlement villages and villages now being affected by dams currently under construction. I also conducted site visits to many renewable energy project sites, including biomass waste projects at palm oil mills and timber processing plants, as well as many solar and hydro project sites and local fabrication facilities.

I used a purposive non-probability sampling technique, identifying agencies, NGOs and village communities that would be appropriate for the study. In total I conducted over 75 open-ended and semi-structured interviews with participants from 40 institutions that represent a cross section of stakeholders involved in the dam conflict. In total I conducted over 75 open-ended and semi-structured interviews with participants from 40 institutions or communities, representing the cross section of stakeholders involved in the dam conflict. Interviews were qualitative, employing semi-structured interview techniques.

For each village visited I conducted both individual interviews with headmen, religious leaders and community group liaisons as well as small focus group interviews with multiple families. I was also able to sit in on many communal village meetings and take detailed notes. In villages interviews revolved around energy needs, desired energy use, land use practices, local developmental and environmental concerns, and perspectives on state involvement in community affairs. Data were also collected through observation of regional conferences, seminars and local public forums. I also obtained secondary data from respective utility companies and government agencies to populate the various models I developed.

This research project stems from a long developed collaboration with grass roots community organizations in East Malaysia through the Renewable and Appropriate Energy Laboratory (RAEL) and a consortium of Malaysia-based environmental NGOs including Sabah-based

NGO Land, Empowerment, Animals and People (LEAP)[1], the grass roots campaign group Save Sarawak Rivers and Sabah-based Friends of Village Development (Tonibung)[2]. We also work closely with Oregon based NGO Green Empowerment[3], which operates extensively in Southeast Asia, the Bruno Manser Funds (BMF) out of Switzerland, and the Borneo Project based in Oakland, California.

These groups are currently engaged in conservation and rural development and expanding practical solutions for rural energy access in the neighboring states of Sarawak and Sabah. Green Empowerment has already installed micro-hydro plants in a number of villages across Borneo and has plans for multiple installations in villages communities where efforts to prevent dam displacement are focused. In 2010 our Berkeley team played a core role in developing a viable alternative clean energy intensive program for Sabah (McNish, Kammen, & Gutierrez, 2010).

1.4. Dissertation Overview

The next five chapters will describe the detailed methodology, findings and implications of my research. Here is a brief chapter overview:

Chapter Two presents my critical study of the hydro conflict. It makes the case for examining SCORE through a lens of cultural politics. Beyond economistic, technocratic analysis of impact and mitigation, I argue it is also important to consider the complex, locally engrained cultural histories and precedents within which hydro resource exploitation is entangled and through which development plans evolve. I find that the dam conflict parallels other local conflicts precipitated by neo-colonial state-led capitalist approaches to development involving major resource commodification. I use these parallels in unpacking the nature of the dam conflict, its actors and their claims and discuss the implications of situating hydro development plans within this context for inclusive approaches to planning and decision-making.

Chapter Three begins to address the lack of analytical information on infrastructure options and impacts supporting the local and global conservations on Borneo's hydro development. I describe my process of building the capacity expansion model and present a comparison of sixteen different scenarios based on four different demand growth assumptions and four different policy incentive schemes. I interpret the resulting cost, performance and environmental trade-offs these scenarios present. I find that under financial incentive alternative technologies, particularly solar and biomass waste conversion technologies, can feasibly contribute to future energy supply at lower total system cost and impact than additional dam construction. My study is the first instance of a commercial energy model being applied to SCORE, and one of the first instances of PLEXOS being used for Southeast Asia in the academic literature.

[1] http://www.leapspiral.org/
[2] http://tonibungrenewables.blogspot.com/
[3] http://greenempowerment.org/

Chapter Four presents my biodiversity impact assessment study. I discuss our findings on species level impacts of direct habitat loss from the clearing and flooding of forested land in preparation of the three most imminent mega-dams currently being debated in Sarawak. The biodiversity of Borneo has undisputed global and local significance, however the value of biodiversity's ecosystem service has not been well documented in the literature. Our study complements further investigation in this direction by providing a simple and scalable methodology for assessing ex-ante species diversity in un-surveyed forest areas.

Chapter Five discusses my integration of analyses through spatial modeling. I present a GIS based multi-criteria model to assess future distributed energy resource options on the basis of social, economic and ecological factors. I also describe the results of my rural energy study which explores the role of distributed energy resources in satisfying rural energy demand by comparing local small-scale energy technologies via a hybrid optimization model. Rural energy access is commonly ignored in the infrastructure planning conversation. Together these model outputs illustrate a range of potential energy resources that can be utilized for electricity supply while considering a broad range of techno-economic and socio-ecological priorities.

Chapter Six is a concluding reflection on the contributions of my research. My dissertation has focused on an assembly of energy modeling tools to explore energy solutions for developing regions where data limitations and multi-stakeholder conflict are often defining characteristics of energy infrastructure development. The aim of the support tools I explore are to (i) demonstrate effective methods for identifying present environmental and social hotspots; (ii) provide an outlook on potential future distribution of land use change for energy technology through simple scenario-driven land conversion modeling and (iii) provide spatial guidance in earmarking environmentally and socially sound areas for energy development.

CHAPTER TWO
The Political Ecology of Energy Resource Management in Malaysian Borneo

The return of the 'mega-dam' to planning policy in developing countries across the world as a solution to increasing growth and energy demand has been met with international concern over social and environmental impacts, and has created many local conflicts. Such contention recently came into sharp focus in the central highlands of Borneo, Southeast Asia. The forested Baram Basin of Sarawak, East Malaysia is home to numerous indigenous and ethnic minorities such as the Kayan, Kenyah, Iban and Penan. Dozens of villages string along the Baram River, on land historically and legally acknowledged through Native Customary Rights (NCR). The Baram Basin is the next basin scheduled for dam construction according to the state's development agenda to create cheap hydroelectricity to attract heavy industry to the state for economic development – called the Sarawak Corridor of Renewable Energy (SCORE). Highly controversial, the 2.4 GW Bakun Dam was commissioned the year before in the neighboring Rajang Basin, causing massive displacement and major civil unrest. There had since been rumors of another 1.2 GW dam planned for Baram.

One morning in August 2013 a notice appeared in the local newspaper. A government gazette announced that the Ministry of Resource Planning and the Environment had legally acquired 4,000 hectares (ha) of NCR land for building an access road. The Ministry's authority to acquire native lands came directly from the Sarawak Land Code. Persons had sixty days from the date of notice to submit all documents required for compensation claims. No provision for objections. With the failures of the Bakun resettlement scheme still fresh, a local alliance of affected communities formed almost immediately to raise awareness on the land acquisitions and the dispossession they represent. The Baram Protection Action Committee, supported by the Sarawak-wide network SAVE Rivers and the national coalition of Indigenous People (JOAS), established two road blocks in the basin – one at the access road near Long Lama and one near the dam site itself - to prevent construction, surveying work and logging at the proposed dam location. For a year preparatory construction work remained stalled.

In December 2014 another gazette was posted, this time announcing the acquisition of over 38,000 ha of NCR lands for the construction of the dam and its reservoir. By this time the local Baram alliance had a number of cases in high court that challenged the State's legality in extinguishing the rights of indigenous people to ancestral land. They found that twenty six villages would be displaced by the Baram dam and its 400 km² flooded reservoir area, affecting more than 20,000 people. Furthermore, both gazette announcements were issued before a Social and Environmental Impact Assessment (SEIA) had been completed for the project and certainly before any public consultation had been solicited. In fact, it was not clear that the state had any intention to seek community participation or consent before construction. This, argued the alliance, was in clear violation of the United Nations Declaration of Rights for Indigenous Peoples, to which Malaysia is signatory, and which requires the free, prior and informed consent (FPIC) of affected indigenous peoples prior to any project's development.

Both roadblocks have gradually transformed into constantly manned blockades with living facilities. The Forestry Department has dispatched forest officers to dismantle the blockades on numerous occasions to allow logging companies to move tractors and bulldozers into the dam site for land clearing. Each time the blockades are dismantled, protesters rebuild the barriers. Through social media stories of the Baram movement have spread to other indigenous communities across the state, across the neighboring state of Sabah, and across the straits to Peninsula Malaysia. As the blockades stretch into their third year - making this the longest dam blockade in Sarawak history - much international support and attention has also amassed, bringing new voices to the conflict. To today, it remains to be seen whether the Baram Dam will be built.

2.1. An Argument for the Importance of Cultural Politics in Resource Planning

This story highlights a number of issues in contemporary hydro development and decision-making, and in particular, discriminatory use of the law to deny access to rights. Sarawak's river system has been framed as an immensely valuable resource that is almost completely uncommodified. The 'manufacture' of a storyline (Huber & Joshi, 2015) about hydropower and its economic benefits for the state along with the exclusionary use of the law evokes earlier discursive constructions and action strategies that served to legitimize controversial development schemes during colonial and post-colonial regimes of the twentieth century.

Furthermore, as our Baram example illustrates, hydro development can be not only a means to commodification and wealth accumulation from water resources, but also a means of extending state control into predominantly rural areas. Water resources then, I posit, can be thought of as a new frontier in neo-capital resource commodification. Building on aged, entrenched cultural relationships, hydro development represents a new era in the long history of resource conflict that has plagued Borneo and Southeast Asia.

Borneo's mega-dams have now attracted tremendous media attention and have prompted a small but growing academic literature. Writers primarily appraise the dams with respect to cost recovery, technical performance and their contribution to energy security (Choy, 2005; Oh et al., 2011; Sovacool & Bulan, 2011a, 2011b, 2012a). More recently, Aiken and Leigh provide a comprehensive and extensive analysis on the aftermath of dam development induced displacement and resettlement in East Malaysia (Aiken & Leigh, 2015). While descriptions of impact are an important part of the discussion, my aim is to extend the SCORE conversation a step further. Analysis of the hydro development planning process must not only ask about the distribution of costs and benefits, but must also investigate the history of local cultural dynamics and its role in the very construction and use of narratives. In so doing we examine the processes that give rise to projects, not just their impacts and the mitigation thereof. We consider the roots alongside the consequences.

I begin with the proposition that hydro development is a new frontier in an old pattern of territorialization and that this articulation has implications for the development planning process. In this chapter we ask the question: what evidence supports this argument? More specifically, what claims and methods for mobilization can we identify being used in the SCORE conflict and how do they parallel those used by actors in older conflicts? What are the implications for development planning in Sarawak in light of these findings?

My key findings are that: (i) the particular evolution of government structure in Sarawak has concentrated authority within a small clutch of individual actors; (ii) the use of social identities to access this authority, the use of land law and the use of the SEIA process are three main mechanisms employed by state and state related actors to territorialize hydro resources; (iii) revival of the local protest movement, adoption of specific language from the international environmental discourse and the promotion of rural energy technology are three central mechanisms for advancing indigenous counter-claims; (iv) however the complexity within the social movement itself partly limits its own effectiveness as a defense; (v) this pattern of actions is a reiteration of that from previous conflicts over access to forest lands in Sarawak and shows the systemic inertia inherent in creating negotiation platforms.

The chapter is structured as follows. In Section 1 I give a very brief overview of a few theoretical debates in the political ecology space that are relevant to this case study. Ideas and concepts such as anti-politics or the depoliticization of development projects, the role of cultural difference in resource conflict, and the use discourse itself as an arena for hegemony, will weave through the following pages as the story unfolds. So I provide a brief discussion of those debates and my research methods. In Section 2 I provide an introduction to SCORE and outline the main narratives in the conflict. Section 3 explores the history and evolution of claims and actions by state and non-state actors and how they interact with each other. Section 4 concludes with policy implications for planning.

2.2. Relevant and Emerging Political Ecology Concepts of Resource Conflict

There has been a recent renaissance in international lending for dams combined with an explosion of private investment as local wealth burgeons in emerging economies -- new dams are now under construction across Laos, Cambodia, India, Ethiopia and Brazil (Goh, 2007).The World Bank alone has pledged more than USD 2 billion in loans since 2010 for projects from Nepal to Zambia (Bank, 2009). This follows a decade of stagnant investment from the World Bank in the 1990s when concern over the social and environmental impacts of dams was garnering international attention (Bank, 2009). The Word Commission on Dams (WCD) was established in 1998 by the World Bank and the World Conservation Union (IUCN) as an independent, multi-stakeholder body to review the effectiveness of large dams and to develop internationally acceptable criteria and guidelines for their planning and operation (World Commission on Dams, 2000).

Produced by a team of internationally recognized experts, the 2001 report of the WCD was indeed a milestone in the evolution of dam development and a novel experiment in global policy design. Distilling findings from extensive case study analysis, the Commission concludes that dams often perform poorly both with regard to cost recovery and targets for power generation or delivered irrigation services. It finds a pervasive and systematic failure to assess the range of potential impacts and alternative options. It clearly highlights the fact that groups bearing the social and environmental costs and risks are often not the same groups that receive the resulting services or benefits. To reconcile competing needs, the Commission offers a negotiation approach - coached in the principles of equity, efficiency, accountability, sustainability and participation - that begins with the recognition of legitimate claims and entitlements.

Identifying the legitimate claims and entitlements that may be affected by a project adds an important dimension to assessing risk. But where the law itself is used as a means to deny access to rights, legal claims can be an ambiguous starting place to determine who has a place at the negotiation table and what issues to include in its agenda. The law is often a tool used in maintaining the cultural hegemony that exists in many ethnically diverse developing countries, and this history is critical to the rights context. With regard to corruption the WCD's executive summary simply states that "in some cases, the opportunity for corruption provided by dams as large-scale infrastructure projects further distorts decision-making" (American University, 2001, p. 1443). Anecdotally, this illustrates that even in highlighting the need for inclusion of diverse stakeholders, sanitized language can help depoliticize dam projects and the complex cultural politics involved in establishing such a negotiation process.

Blueprints for action like the WCD guidelines discussed or those of the International Energy Agency (IEA) and the International Hydropower Association (IHA), are notorious for simplifying the complex issue of representation and the political nature of planners (Nüsser, 2003). Ferguson coins this 'forgetting' as anti-politics or the presentation of development planning as an apolitical process (Ferguson & Lohmann, 1994). The techno-managerial language of 'sustainable development' used by development agencies, for instance, clearly reflects this absence of politics, often blurring 'who formulates and implements these strategies and in whose interest' (Huber & Joshi, 2015, p. 15). State actors themselves often employ simplification strategies, or retreat into purely technocratic arguments to rationalize projects. This can effectively undermine the public participation process and detract from political challenges to decision-making.

Ferguson holds that neither engagement in anti-politics, nor its effects, are necessarily intentional. Rather, anti-politics occurs for deeply structural reasons. As he suggests, 'such apparent political naiveté is not a ruse, but simply a low-level manifestation of the refusal to face local politics which, for institutional reasons, characterizes the entire 'development' apparatus' (Ferguson & Lohmann, 1994, p. 178). While Ferguson's concept of anti-politics has been popularly received, many scholars challenge his assumptions on intentionality, or the lack thereof. Segregating development projects from the entrenched politics of state-non-state relations and casting the social dimensions of poverty as 'technical problems' to be solved through the intervention of technical experts and development projects is a deliberate strategy to contain a challenge, many authors find (Büscher, 2010; Huber & Joshi, 2015; Kakonen & Hirsh, 2014; Li, 2007).

Overlooking the political and structural causes of inequity can be interpreted as a means to close down political spaces while extending the controlling powers of the state under cover of a neutral and technical mission. Especially considering that failed interventions are often readily repeated, as Huber and Joshi note (Huber & Joshi, 2015), this is an equally well received perspective in the literature. Others even extend this intentionality to players in the global conversation on 'development', arguing that concepts such as 'sustainability' are carefully presented as apolitical humanitarian causes such that their consequent directives become impossible to disagree with, obscuring the idea that all natures are socio-ecologically produced and are therefore, by definition, political constructs (Swyngedouw, 2011).

I relate strongly to this concept of anti-politics, especially after the interviews I was able to conduct with state actors. I found a conspicuous aversion to the discussion of alternatives and an unflagging deference to SCORE's economic promise which (apparently) justifies limits on choice and nullifies any discussion of options. The debate on anti-politics informed my reflection on and interpretation of information collected during field work. My research findings complement arguments of anti-politics as a deliberate mobilizing strategy. I discuss implications in the closing section.

A related theoretical conversation which informs our discussion of SCORE is the place of cultural difference, or 'cultural distribution' in conflict. Escobar defines the term 'cultural distribution conflicts' as those that arise from the relative power, or powerlessness, accorded to various cultures and cultural practices in a historical context' (Escobar, 2006, p. 8). He finds there are different levels of analysis that circumscribe environmental conflicts. In the first instance, environmental economists focus on the unequal distribution of income and economic resources as the basis for conflict.

A second level of analysis comes as ecological economists resist the inclination to internalize ecological services into this definition of economic resource. They argue that these services cannot be reduced to market values and posit the need for a rebalancing of ecological distribution as separate to income distribution. He argues for a third level of analysis which acknowledges culturally diverse models of nature – analysis that questions the technocratic approaches that dominate development experience and critiques the use of cultural resources in the definition of social norms and goals (Escobar, 2006).

Many scholars identify with the issues that cultural distribution raises and find that the very definition of water as a 'resource' erases the complex intersectionalities and relations to water that underlay the conflict (Baviskar & Amita, 2007; Mehta, 2007). Baviskar uses case studies of struggles around water resources in India to highlight how certain cultural values can be rendered inconsequential through the effects of cultural difference. She argues that representations of resource that exceed concern with immediate material use are also valid and this larger 'economy of signification' should shape modes of resource appropriation (Baviskar, 2003, p. 5052). However, she cautions that productive appreciation of the symbolic dimensions and varied cultural relations to resource requires a more complex landscape than the 'vicious state' versus the 'virtuous peasant' dichotomy often depicted in literature (Baviskar, 2003). There is now a movement in political ecology away from the unitary analysis and emphasizing the right to culture.

Less of a debate at this stage and more of a developing framework, I found the concept of cultural distribution very helpful in searching for and identifying different voices in the SCORE conflict. Evidences of cultural hegemony became clearer as I traced the interactions between dominant narratives. This chapter is thus an attempt at Escobar's 'third level' of analysis. While the current literature explores the economic distribution and ecological distribution issues surrounding SCORE, I aim to shed some light on the conflict's cultural dimensions and encourage redistributive thought.

Finally, another relevant debate for our story occurs over knowledge production and the construction of concepts. In discussing the inequalities that underlay resource conflict, many scholars highlight the asymmetries in access to knowledge. In analyzing similar hydro development conflicts in the Mekong, Hirsh and Kanonen discuss the failing SEIA process and point to the lack of information on dam impacts, risks and alternatives, the exclusive selection of technical experts for evaluation of research findings, even the very forms of science and modeling (and their inherent simplifications) used to produce information (Kakonen & Hirsh, 2014). They argue that science itself can be used to avoid debate and the need to struggle over politically charged questions, thereby closing off spaces.

Agreeing that the politics of knowledge production is critical to understanding a conflict, other writers argue for an extension of this idea to the very definitions of 'problem' and 'solution' that drive said knowledge production (Bakker, 1999; Escobar, 1998; Mehta, 2007). Dominant narratives influence the way issues are framed and discussed in the public domain. But dominant narratives also influence the very production of knowledge which supports discourse and the language of decision-making. Escobar began this debate in the late 1990s, using the example of 'biodiversity'. He argues that although biodiversity has concrete biophysical referents, it is a discursive invention of recent origin, created through the dominance of certain biocultural perspectives over others (Escobar, 1998). Using biodiversity and its globally imagined connotations as a prism for defining problems and solutions serves to perpetuate western cultural hegemony over physical and discursive spaces of the South.

In Sarawak, the state has defined supply of future energy demand as the 'problem' to be solved. The clever naming of the agenda as a Corridor of *Renewable Energy* plays on the positive imagery that use of the term itself evokes - this even though large hydropower is not classified as a renewable energy resource. This narrative thus defines a solution to the problem while disguising the political intentions of planners. It is important then to explore how this problem of energy demand has been constructed over time. How has energy demand emerged as the meta-narrative that justifies controversial schemes such as the dams? Does this language artificially orient the conversation around energy and energy economics? Does the dominant narrative itself encourage simplistic portrayals of property rights and other complex issues comprising the resource conflict?

This discussion is of particular importance to me as an academic trained in a western institution exploring the role of alternative energy as a solution space for this and other energy-related resource conflicts in developing regions. The subsequent chapters of this dissertation explore opportunities for incorporating diverse objectives into energy planning tools in severely data-limited contexts, such as Sarawak. It is important for me to be aware of myself, of the narratives that inform my research questions and methods, and of the influence that my research will have on the local conflict discourse. I discuss these reflections more in the concluding chapter (Chapter 6). With these theoretical frameworks in mind, let us now turn to the task of deconstructing the SCORE conflict.

2.3. Research Methods

To explore actors and relations I carried out field work investigations in both East and West Malaysia. I conducted 50 open-ended and semi-structured interviews with participants from 36 institutions that represent a cross section of stakeholders involved in the dam debate. I conducted interviews with state and federal agency officials (nine), civil society groups (three), Malaysian environmental NGOs (four), regional governance agencies (three), international NGOs (seven), local renewable energy project developers (five), local academia (four) and indigenous villages (twelve).

I selected villages from areas that have been and will be affected by SCORE dams. I visited the Bakun resettlement village Sungai Asap; Long Lawen – the only village in the Bakun area where residents declined to be resettled; villages surrounding the Murum Dam and villages in the Baram basin. These villages represent Iban, Kenyah, Kayan and Penan indigenous groups. I also interviewed protesters at both Baram blockade sites. Interviews revolved around drivers for SCORE, the rationale of individual and collective responses to hydro development and relationships between actors.

I conducted a number of technical site visits. I visited the operational Bakun Dam, the sites of both blockades, palm oil plantations, and a number of renewable energy technology projects from local developers including micro-hydro project sites, solar installation sites and biomass waste-to-energy plants. This field work was conducted over the course of roughly one year, from March 2013 to August 2014. I derived additional information from contemporary local media and academic literature focused on East Malaysia. Throughout this chapter I maintain all interviewees as anonymous due to the request of participants and the particularly sensitive nature of the dams in Malaysia. I cite direct quotes from interviewers without attribution and provide a list of institutions that were visited and interviewed in Appendix A.

2.4. Hydropower Conflict in Sarawak, East Malaysia

2.4.1. A Brief Introduction to the Sarawak Corridor of Renewable Energy

In 2006, the Federal Government of Malaysia embarked on a number of initiatives to promote balanced regional development and accelerate growth in designated geographic areas through the Ninth Malaysia Plan ("Tenth Malaysia Plan," 2014). The Plan describes a philosophy of development focused on decentralizing economic growth away from the federal capital through the establishment of *economic corridors* in different states[4]. The Sarawak Corridor of Renewable Energy (SCORE) is a corridor in central Sarawak, an East Malaysian state on the island of Borneo. SCORE differs fundamentally from the other Malaysian economic corridor projects in its predominant emphasis on hydropower ("RECODA," 2015).

[4] The five prescribed corridors are: Iskandar Malaysia in Johor; The Northern Corridor Economic Region (NCER) covering the states of Kedah, Pulau Pinang, Peris and Perak's four northern districts; The East Coast Economic Region (ECER) covering the states of Kelantan, Pahang, Terengganu and Johor's Mersing district; The Sarawak Corridor for Renewable Energy (SCORE) and The Sabah Development Corridor (SDC).

Sarawak, located along the northern coast of the island of Borneo is the poorest and most rural state in Malaysia. It has a population of 2.47 million, more than half of which are indigenous groups living in rural village communities (State Planning Unit, 2011b). An increased focus on cheap electricity to attract manufacturing and industry is the state's approach to achieving high income economy status. The current peak annual energy demand in Sarawak is 1250 megawatts (MW), met by a mix of diesel, coal and natural gas generation either operated or purchased by the state utility company. Over the long term SCORE involves building out 20,000 WW of hydroelectric capacity through a series of 50 dams.

At least 12 large hydroelectric dams and two coal power plants, together constituting over 9300 MW of capacity, are scheduled to be built before 2030 (Sovacool & Bulan, 2012a)(Harris & Lang, 2014). Six dams are scheduled to be completed by 2020 with three major dams already under different stages of development. In 2012 the 2400 MW Bakun dam became operational (Oh et al., 2011). At 205 meters high it is Asia's largest dam outside China. The dam's reservoir submerged 700 km^2 of land and displaced about 10,000 people (Sovacool & Bulan, 2012a). In 2013 the 944 MW Murum dam was completed and its reservoir is currently being filled. Access roads for the 1200 MW Baram dam have been cleared but preparatory construction work has been stalled since 2013 due to road blockades by local community protesters (Lee, Jalong, & Meng-Chuo, 2014).

With this hydropower backbone the SCORE plan involves attracting investment to promote a number of priority industries in hubs across the state. These priority industries include heavy industry such as glass, steel and aluminum (Sovacool & Bulan, 2012a). One executive from the local utility company Sarawak Energy Berhad (SEB) explained:

> *"There is nowhere else these companies will be able to go to get the package we offer. Cheap land, cheap labor, low cost electricity. There isn't anywhere else in Asia they can go to get this package."*

Though energy demand projections have been criticized as being overinflated, they are the justification for immediate ramp up of dam building and are the basis upon which major institutional players are engaging in development strategy. The state anticipates these projects will attract over 334 billion Malaysian Ringgit (RM) (US$100 billion) in investment – 80% as private funding for the hydropower projects and industrial development, 20% as government funding for basic infrastructure and human capital. Indirect benefits through job creation and local spill-over effects on the economy are also expected. There is also discussion of Asian Development Bank (ADB) funding for a transmission line to export power across Borneo from Sarawak to West Kalimantan. Though two of the dams have already been built the private investment is yet to realize. The cost of the Bakun Dam has escalated over many years of delay to RM7.3 billion (US$2.3 billion) – more than double initial price estimates. Construction has been funded primarily through loans from the Malaysia Employees Provident Fund and the Malaysia Pension Fund (Oh et al., 2011).

2.4.2. Main Actors and Common Narratives of SCORE

Sarawak's hydropower wealth comes from it natural hydrology. Owing to bountiful precipitation Borneo has been etched by an abundance of intricate river systems. The natural drainage of Sarawak is dominated by two main river systems: the Baram and the Rajang. The Rajang is the largest river in Malaysia, on which both the Bakun and Murum Dams have been built. In the state perspective these rivers were an untapped source of mechanical power that should be commoditized and exploited.

Strikingly similar perspectives grounded the narratives about harnessing unproductive land which rationalized the distribution of native customary lands as forest concessions for timber logging and palm oil in the 1970s and 1980s. For instance, in the 1980s the government popularized claims that in Sarawak, 'there are 2.2 million ha of land under Native Customary Land being inefficiently used 'largely due to traditional agricultural practices'. To overcome this 'problem', the aim is to 'rehabilitate' the 'large tracts of idle land' through 'integrated agricultural development projects' which 'will introduce modern and highly productive agricultural practices to the people' (Colchester, 1993, p. 175).

In fact, Sarawak's forest area declined almost 50% in just these two decades largely due to indiscriminate concession and license distribution for timber logging and land conversion to oil palm plantation (FERN, 2006). Crude and processed oil palm exports alone were worth over RM 4.6 billion (USD 1.3 billion) in 2013, making oil palm the third largest foreign exchange earner for the state behind petroleum and liquefied natural gas (Economics and Industry Development Division, Malaysian Palm Oil Board, 2014). Today oil palm covers 1.2 million ha or 10% of Sarawak's total land area, representing more than two-thirds of the area under agricultural crop cover. Expansion continues at roughly 10% per year and the official government target is 2 million ha of oil palm by 2020 (Cooke, Toh, & Vaz, 2011).

More than 720,000 ha of this is NCR land claimed by indigenous communities. Nevertheless, the government has pursed policy that favors large-scale estates over smallholder production, to the extent that over 80% of the total planted area is now managed by private oil palm plantation owners or privatized government agencies - such as Sime Darby Bhd, Rimbunan Hijau Group, Ta Ann Holdings Bhd and Samling Group – which are granted long-term leases over state lands despite claims of customary ownership. Meanwhile, independent smallholders only contribute represent 7% of total planted area ("Borneo Post," 2014a). Thus, as Cramb summarizes, 'Sarawak's agricultural sector, once almost exclusively in the hands of smallholders, has been transformed by politico-legal means into one that is dominated by private estates' (R. A. Cramb & Sujang, 2013, p. 131). This centralization of wealth through processes such as the conversion of collective property rights into exclusive private property rights, forcible removal of people and state redistribution, is termed accumulation by dispossession by David Hardy (Harvey, 2009).

A number of writers highlight how the concept of 'idle' land was erroneously used to describe native lands, legitimating large scale agrarian transformation through these processes (Ribot & Peluso, 2003; Barney, 2008; Mccarthy & Cramb, 2009; R. Cramb & Sujang, 2011; Robert Cramb, 2013; R. A. Cramb & Sujang, 2013; Bissonnette, 2011). In the case of Sarawak's hydro resource the value of rivers has been defined by the state as the total power capacity in megawatts that it can sustain. Since the 1970s surveys have been conducted by the state utility company to identify all potentially feasible hydroelectric sites (Tate & Sarawak Electricity Supply Corporation, 1999).The CEO of the state energy company is often quoted in the media explaining that SCORE allows Sarawak to realize its full potential and that protesters are stifling growth in the same way as they are currently trying to suppress the palm oil industry ("Borneo Post," 2014b). This narrative of the 'unproductive' hydro resource has been documented elsewhere in the literature (Sovacool & Bulan, 2011a). Indeed, as one SEB executive repeatedly explained to me:

> *"Finding demand will not be the problem. We are limited only by supply. If there were more hydro we would develop that too, and sell it."*

From the local community perspective however, Sarawak's river systems are a direct source of livelihood and support the health of forest ecosystems needed for survival. Limiting rights and access to rivers has huge impact on how indigenous communities live and subsist, including their physical livelihoods, security, health, education, mobility and identities (FERN, 2006, p. 11). Interviewing villagers displaced from the Bakun Dam's Rajang Basin to the resettlement village Sungai Asap revealed many of the struggles that families are dealing with now that access to the river as a source of livelihood has been cut off. As one resettled respondent now living in Sungai Asap described:

> *"Each family was to get three acres of land. Some of us are still not even sure where our land is. They are far from the village. Two hours away by foot and far from the river. Back in our village we used boats to get to our land. Even old people could do it. Now you need a motorbike now. Some farm land of other villagers instead. This is risky and causes many conflicts in the village."*

According to another resettled villager:

> *"We were promised free electricity and free water. But now I pay 60 ringgit a month for lights and the water is always brown and smells."*

Many women and older villagers described that with the difficulty of getting to the distant farm lands they were assigned through compensation, they were now less able to grow crops and had to spend more buying food in the markets. They noted that waged employment has become the major means of income earning (which disadvantages women and the elderly given well-document discriminatory employment practices). While villages previously had their own schools or arrangements to send children to schools in neighboring villages for short boarding periods, resettlement schools do not have boarding facilities, so the daily transport of children to and from school has now become complicated and expensive. Others noted the lack of free land to forage for fuelwood so they now also have to purchase LPG for cooking in addition to electricity.

These changes put families accustomed to subsistence living into a situation where they were now part of a cash economy with even less land to produce surplus for trade. Sarawak has the highest rates of poverty in Malaysia and the most impoverished are its ethnic minorities. Many ethnic groups record poverty levels of over 50% where the poverty line is RM 910 (USD 275) per household per month (UNDP, 2007a). For the typical rural household, these new expenses can be difficult to support, especially as income-earning opportunities become scarcer under resettlement. This also has grave gender implications as women, who formerly played a vital role in food production, become reliant on men for money, materials and transport, increasing their vulnerability to abuse and exploitation (Gabungan, 1999).

In particular, the allocation of a small plot of land per household has been felt as a severe restriction on the movement of the Penan, the most nomadic of Sarawak's tribes. Whereas Penan communities were once able to catch river fish, hunt, and gather forest products, they now have severely limited access to forests. With little land or resources these minority indigenous groups are now being absorbed through intermarriage into more culturally dominant groups (Hong, 1987). Indeed, I found that frustrations expressed by displaced families were not just about financial compensation but about these cultural issues – loss of land, loss of traditional heirlooms and assets, loss of income from cash crops during initial year, the loss of sacred burial grounds and starting life over in an unfamiliar place.

These Sungai Asap responses are identical to sentiments documented from previous communities resettled for Batang Ai (Hong, 1987). In Evelyn Hong's words, resettlement is not just an issue of compensation, it is also an issue of the cultural extinction of ethnic minority groups whose identities are tightly tied to their rivers and land (Hong, 1987). An excellent description of the dams' displacement effects is found in (Huber & Joshi, 2015). A complete description of resettlement impacts is beyond the scope of this chapter.

While land rights and the effects of displacement are the common narrative of indigenous communities, I found other arguments being forwarded by urban civil society. Let us consider for argument sake just the dams currently being built (Murum and Baram) along with Batang Ai and Bakun (already built and operational). Together these four dams represent over 4,600 MW of capacity, four times larger than the annual peak demand of 1250 MW. The SCORE plan revolves around a targeted nine-fold increase in energy output between 2010 and 2020.

This translates into a 16% energy demand growth rate per annum – an incredibly aggressive rate not seen by the likes of economic powerhouses such as China, and certainly unprecedented by Sarawak's economic (GDP) growth history (Sarawak Energy, 2010). Furthermore, as generation capacity grows, SEB still does not yet have firm commitments from commercial businesses to purchase Bakun's power (Oh et al., 2011). In fact since it began operating in 2012 Bakun Dam has been running at half capacity or less.

This accelerated rate of dam construction in the face of low demand has prompted questions about necessity. As one professor from the Kuching-based state university UNIMAS asked in our interview:

> *"I mean aside from their social impacts to our indigenous groups. Let us put that aside. It is not really clear to me. Are the dams necessary for these great industrialization*

goals? Are these economic goals even reasonable? If not, what interests benefit from excessive hydro development? Who is answering that? See this is my question."

I found this type of economic necessity based argument very common in interviews with participants from urban civil society, and in particular from the local academic community. These groups felt that the onus is on the government to explain the economic justification for SCORE and to identify the economic gains that came from Bakun dam, the most recent mega-dam to come into operation, prior to any more construction.

This question of necessity is compounded by the lack of information on dam impacts available. Borneo has been identified as one of earth's 34 biodiversity hotspots and a major evolutionary hotpot for a diverse range of flora and fauna. Borneo's forests house the highest level of plant and mammal species richness in Southeast Asia (de Bruyn et al., 2014) (Struebig, Wilting, et al., 2015). The lowland forests of Northwest Borneo are among the most floristically diverse forests in the world. Individual hectares of forest in this area often have species richness that is matched only by forests in western Amazonia (Orme et al., 2005).

Thus the indirect cost to the development of this 20 GW of mega-dam capacity would lie in in at least 2,425 km^2 of direct habitat loss from one of the oldest forests in the world at a time when accelerated efforts to conserve Borneo's rainforests is globally acknowledged (Mittermeier et al., 2005). It is not clear that the ecological repercussions of this loss have been calculated or considered in decision-making. This is an emerging claim coming from both the local and international environmental NGO community.

Therefore we see that while indigenous rights are the main front of the community protest movement, and economic rationale the concern of urban civil society, issues of ecological distribution are also gaining importance, now part of the basis for fierce international criticism of SCORE. In the next section I will show how the state claims we have identified stem from Sarawak's political evolution. I will briefly outline the material mechanisms that have become available to state actors over time, how they have been practiced in the past, and how cultural asymmetry influences decision-making. I start with the use of social identity to access power and then explore legal mechanisms.

2.5. A History of State Claims and Mobilization Strategy

2.5.1. Access to Social Relations and the Precedent for Power Asymmetry

2.5.1.1. The Evolution of Ethnic-Based Asymmetries in Sarawak

Modern Malaysia began with the Federation of Malaya's independence from the British Empire in 1957. After a brief Japanese occupation during WWII, an anti-colonial insurgency emerged in 1948 and fought for almost a decade to secure its independence. Six years later in 1963, Malaya united with Northern Borneo and Singapore to form Malaysia for closer political and economic cooperation. Singapore was eventually expelled in 1965. The Federation of Malaysia now consists of eleven states on Peninsular Malaysia, and Sabah and Sarawak on Northern Borneo (Colchester, 1993).

The Malaysian constitution which to today governs this federation was established in 1957 and is written with language that distinguishes between ethnic groups. Specifically, it states that while all Malaysian citizens are equal, *Bumiputera* (which translated to 'son of the soil' and refers to the indigenous people of Malaysia, particularly Muslim Malays) are entitled to special privileges and preferential treatment (Cooke, 1997). The logic behind this designation was that Chinese and Indian immigrants to Malaysia had been favored during British rule, and both had subsequently gained economically while Malays and others remained in poverty.

After independence, these economic disparities had begun to cause problems, causing race riots throughout the 1960s and the eventual expulsion of Singapore from the Federation. In 1971, economic measures referred to as the "New Economic Policy" (NEP) were implemented to specifically favor Bumiputera. The NEP sanctioned the use of affirmative action or positive discrimination in employment, education and scholarships, civil service, access to housing, assisted savings and in business (government contracts, loans, grants and mandatory shares in publicly listed companies) to improve their economic standing (Cooke, 1997; FERN, 2006).

This policy disadvantaged non-Muslim indigenous groups in Malaysia who did not benefit directly from the affirmative action measures. These policies soon transferred to East Malaysia and had great significance there, given that Sarawak and Sabah have high percentages of non-Malay citizens. The ethnic mix of Sarawak is particularly diverse, with more than forty sub-ethnic groups, each with its own distinct language, culture and lifestyle. These include the Iban, Bidayuh, Melanau, Kayan, Kenyah, Kelabit, Bukitan and other groups. The Iban form the major ethnic group, with about 30% of the state's total population. There are also semi-nomadic hunter-gather peoples of the Borneo interior, such as the Penan and the Ukits, which are most severely affected by land encroachment due to the nature of their movement (FERN, 2006).

While the indigenous Iban quickly got to playing a prominent role in state politics and were well represented through the Sarawak National Party in the late 1960s, their representatives were largely removed by 1971 through a series of vilification campaigns (Colchester, 1993). Since 1971, the post of Chief Minister in Sarawak has been exclusively occupied by members of the Bumiputera elite, and the federal, state and local governments are active in promoting Bumiputera participation in all economic, social and political activities.

This establishment of a political and economic elite has invariably led to widespread political patronage, which has been difficult to counter due to the lack of established regulatory mechanisms. The alliance of Malay forces in Sarawak with those on the Peninsula has thus led to a progressive distortion of the state's democratic process, frustrating native attempts to gain representation and thereby denying their sovereignty in governance. The result has been to reinforce the profound feelings of powerlessness that were already well established in the native communities through colonial and post-colonial manipulation and control (Colchester, 1993).

These ethnic-based power asymmetries persist to the current day and, some argue, have intensified. For instance, in Sabah there has been tremendous debate over a popular Islamic cleric's proposal in 2013 for a program to 'Malayanise' the state's non-Malay communities. 'Malayanisation' – or the formal conversion to Malay of all natives that embrace Islam – is justified citing a need to unite the country's Muslims. There are also claims that the Kadazan is an "invented" ethnic group made of non-Muslim Dusun people, who are mostly Catholics. This prompted a very polarized debate over the individuality of indigenous groups of Sabah and Sarawak and has caused flared racial tensions.

In my interviews many other personal examples of ethic discrimination were offered from both Bumiputera and non-Bumiputera alike. Non-Bumiputera students spoke of the difficulties of getting into well reputed Universities; many people spoke of the frustrations in securing housing, bank loans, even vehicle registrations; meanwhile government employees were almost always Bumiputera and they acknowledged this. As mentioned earlier, even the distribution of shares in license-holding firms (such as timber processing companies) to Bumiputera state officials, family members and Sarawak representatives in Federal Parliament is well documented.

This social power asymmetry directly influences the politics of extractive industry. In particular, it encourages state actors to engage in rent-seizing behavior to gain the right to allocate licenses or rents. Patronage practices and their effects can span across sectors and across generations. For instance, after licenses are distributed, existing communities resettled, and the lands logged for timber, the cleared forests with convenient access routes now in place become prime lands for planting other commodities or for inundation to create a dam reservoir. Meanwhile, the property rights and ability to accumulate wealth remain with the original license grantee. The access to social identity and its relation to authority and the planning process therefore shapes an individual's ability to benefit from both public and private resources. Let us now see how this is relevant to SCORE.

2.5.1.2. The Role of Social Relations to Power in SCORE

We begin by looking at the authority for planning and assessment of SCORE's projects. As we noted, the Chief Minister is not an elected position, but rather an appointment, and until 2014 the Chief Minister of Sarawak had not changed since 1981 ("RECODA," 2015)("State Planning Unit," 2011a). Within that time government agencies had been strategically arranged under his portfolio, so that even agencies with conflicting interests fell under his direct purview. For instance, the Sarawak State Planning (SPU) is the strategic planning agency which designed and coordinates the SCORE plan. The Regional Corridor Development Authority (RECODA) state agency oversees SCORE's infrastructural development (Sovacool & Bulan, 2012a). The Ministry of Planning and Resource Management manages the SEIA evaluation. All three of these agencies come directly under the Department of the Chief Minister. Thus the planning, assessment and approval authority are conveniently concentrated within one office – the same office that also controls land classification, acquisition and issuance of licenses - rather than across independent agencies.

Let us also look at some of the key business interests involved in SCORE. We find that the benefits that come from business involvement in the dams are also narrowly distributed.

SEB is an energy investment holding company owned by the state government. It has a monopoly on production, transmission, distribution and sale of electricity across the state meaning no other project developers have access to Sarawak's grid system (Sarawak Energy, 2010). Sarawak Hidro is the state owned development company which revived the Bakun Dam plans in 2000 (Tate & Sarawak Electricity Supply Corporation, 1999). The civil construction contractors Sarawak Hidro used in building Bakun were investigated and found to be subsidiaries of a number of Malaysian companies which the Chief Minister and his Bumiputera family own or had shares in, such as Cahya Mata Sarawak. Bakun's civil works also involved Sime Darby, a Malaysian based conglomerate with strong political ties and one of the major recipients of timber contracts in the state.

Much uncertainty exists over the cost of the dams but some estimates suggest that costs escalated to RM 7.3 billion (USD 2.3 billion) from initial estimates of RM 3 billion (USD 0.94 billion), more than a 600% overrun (Oh et al., 2011). Experts attribute these overruns to: (i) artificially low contract bids, (ii) the awarding of government contracts to politically connected companies with no demonstrated experience in dam construction (such as Sime Darby Bhd) leading to the need for many complicated sub-contractual arrangements, and (iii) the dam's suboptimal electricity sale performance during its operational phase due to lack of demand. In fact some experts speculate that Bakun will continue to make further losses as Sarawak Hidro will have little bargaining power against buyers in negotiating power purchase agreements due to this surplus (Sovacool & Bulan, 2011a, 2012a). Cost overruns are typical and well-documented in hydropower finance (Ansar, Flyvbjerg, Budzier, & Lunn, 2014), flying in the face of SCORE's economic rationale.

This debt accrual is particularly controversial given the project's primary funding source. Most of the loans for Bakun came from the Malaysia Employee Provident Fund and the Pension Fund (Sovacool & Bulan, 2011c) (Oh et al., 2011; Sovacool & Bulan, 2012a). Sarawak Hidro was thus able to use federal loans to fund Bakun's construction, pay these funds out to subcontractors owned by the Chief Minister and his associates, and then supply power at artificially low rates to SEB effectively amounting to a major subsidy from tax payers. More egregious is that this level of spending and issuance of contracts happens without an independent regulator. Sarawak energy policy is very independent of federal policy so that neither SEB nor any of its subsidiaries fall under regulation of the Federal Malaysia Energy Commission, which regulates the power sector in Peninsular Malaysia and Sabah. To date Sarawak has not established a state utility regulator allowing rampant over-expenditure and patronage to go largely unchecked. A thorough investigation of Bakun's economic controversies can be found in (Oh et al., 2011; Sovacool & Bulan, 2011a). A complete description of each controversy is outside the scope of this chapter.

Thus both the business interests that benefit from the dams as well as the assessment and approval authority are concentrated among few state actors that openly protect Bumiputera welfare, representing major conflicts of interest. Ironically, despite the amount of blatant cronyism taking place, SEB takes a strong anti-political stance when questioned about dam development. The SEB executives I interviewed were quite defensive of the utility's role in merely carrying out a higher mandate. One explained to me:

> *"SEB is strictly an arm of the government. The government has decided that the best economic development plan for Sarawak is bulk energy for heavy industry. This is the best thing for the economy and for the people. If this is so, then developing all the cheap hydro power possible is the optimal strategy. There are many differing views on whether the government's economic policy is appropriate, but this is inconsequential to us."*

When discussing SEB's (non-)exploration of alternative energy resources that might offer less damage as a solution to satisfying projected energy demand, another executive stated:

> *"We are mandated by the government to make the cheapest cost electricity for the foreign investors that it wants to attract. Cheap is all that matters. Why increase the total system cost by including more expensive renewable technologies? Especially when those projects often have no benefit for anyone beyond the project proponent?"*

The very companies benefiting and profiting from the development plans are thus able to conveniently defer to the government's authority when necessary, absolving themselves of political leveraging. The tone of conversations was quite different when speaking to other government agencies that should, in theory, have some regulatory control or watchdog function, such as the Department of Irrigation and Drainage or the Forestry Department. The Sarawak Forestry Department, for instance, is responsible for the issuance of forest land concessions and licenses for logging. These licenses are issued so that land can be cleared before reservoir inundation. Rather than being defensive, officials were merely tight lipped - very hesitant to offer information or to discuss the dams at all. This almost fearful posture anecdotally represented the lack of lateral authority and the tight fist of control exercised by higher offices of government.

We see access to social relations being available to an elite set of decision makers. Through careful selection of management and consulting expertise within SEB and patronizing particular private companies, the state government is essentially consolidating access to and control over water resources into the hands of largely Bumiputera interests for wealth accumulation and closing the space to other ethnic groups with less political leverage.

2.5.2. The Evolution of Legal Mechanisms as Tools for Mobilizing State Claims

2.5.2.1. Land Law as a means of State Territorialization

Another major characteristic of the two-tiered federal and state government structure in Malaysia is the level of autonomy states have in the exercise of regulatory power. Individual states have their own constitutions and executive legislature. Sabah and Sarawak, who joined the federation later, retain largely independent control over matters of local government, religion and natural resources including the ability to formulate their own land laws and resource management policies. For example, the federal government has introduced legislation relating to matters of environmental and forest policy for the purpose of maintaining uniformity of law and policy between states. These include the Protection of Wildlife Act, the Environmental Quality Act and the National Forestry Council all established in the 1970s. However such legislation is only enforceable in individual states if it is accepted by state legislature. This makes for numerous contradictions between federal and state policies on lands, forests and the environment. As a result national coordination of environmental law between local and federal authorities is often difficult (Hezri & Nordin Hasan, 2006).

In Sarawak in particular the state crafts and revises land laws with little civil society participation or federal involvement which allows for their manipulation by political interests. The use of land law to redistribute land title and limit native rights is well documented and has majorly shaped the state's timber and plantation industries (Rob A. Cramb, 2007a; FERN, 2006; Mccarthy & Cramb, 2009; Robert Cramb, 2013). As a recent example, in March 2013 the international corruption watchdog Global Witness released a video entitled "Inside Malaysia's Shadow State" where close family relatives of the Chief Minister were unknowingly interviewed and filmed by reporters under the guise of a foreign business investment.

The interviews expose the Chief Minister of allocating forest land through directives of the Ministry of Resource Planning and the Environment for fractions of their commercial value; allowing individuals to turn lands over for multimillion dollar profits; and allowing illegal transactions for evading Malaysian taxes all the while using the service of government lawyers to facilitate these illegal transactions ("Global Witness," 2013). This video went viral, drawing widespread criticism for the Chief Minister. Other investigations expose the Chief Minister and his family as major share owners in hundreds of Malaysian companies (Straumann, 2014).

Peluso and Vandergeest argue that 'the idea of state territorial sovereignty over a category of land cover called *forests* emerged in Southeast Asia in the nineteenth century' and further forests are 'not natural or universal categories of understanding, but constructions' (Peluso & Vandergeest, 2001, p. 762). Through demarcating areas of jurisdiction and by reducing customary practices to circumscribed and individualized sets of Customary Rights, state agencies during the colonial period attempted to totalize control of resources and land, leaving a legacy of legal intervention which continue to evolve, shaping the general view of land, forests and resources (Peluso & Vandergeest, 2001; Vandergeest & Peluso, 2006). This is particularly relevant to the SCORE case as much of the property needed for the dams sits on NCR lands. So starting with Peluso and Vandergeest's concept of territorialization, let us trace the evolution of Sarawak's land law and its role in other resource conflicts.

Sarawak is a largely rural state where social autonomy is highly valued. When the British explorer James Brooke came to Borneo in 1839 he found a sophisticated customary land law, called *adat*, already well-established by indigenous communities across the island. The longhouse, or community living space, was and remains the defining feature of the indigenous village community. While systems differed between Iban, Kenyah, Kayah and other native indigenous groups, every longhouse community in Sarawak, and indeed in Borneo, considered itself as owning an extensive tract of communal land which extended far beyond the areas actually used for swidden or rotational agriculture (Colchester, 1993).

Within these communally held territories, individual families would establish usufructuary rights to the lands that they cleared for gardens. Whatever the detail, the principle was the same: an individual forfeits his usufructuary rights to farming land through absence and the land then reverts to the community. In effect, then, the communally held longhouse territory retained its coherence despite movements of families and individuals between different communities (Colchester, 1993). Detailed explanations of local customary land law or *adat* can be found in (Cooke, 2006; Hong, 1987).

Realizing the importance of native customary tenure to indigenous communities the official policy under Brooke's rule was initially one of non-interference, as manifested in the 1842 Sarawak Land Code which prohibited immigrant races from settling on land already occupied by natives. However as the economic potential of global commodities such as palm oil became clear, the government would need more flexible control over land ownership. Hong presents a highly detailed chronology of the Sarawak Land Code from its inception in 1842 under the Brooke Administration and shows how indigenous people's autonomy narrowed over the years (Hong, 1987).

By 1863 the first official Land Law, known as the Land Regulations, was created and defined all unoccupied lands as property of the government. While natives could continue to practice customary tenure within their Longhouse's domain, they could no longer automatically claim rights to lands outside of that particular domain. This presented a major restriction to the indigenous population whose livelihood revolved around rotating between different areas of land for subsistence agriculture. The law also subsumed all farm lands within a single communal area, diminishing both the individual's rights and the community's rights to ownership of larger territories (Bissonnette, 2011; Colchester, 1993).

This was particularly devastating to the more nomadic groups with an explicit need for mobility. Gradually the code was further modified - first requiring registration and licensing of native lands, then later declaring occupants of state land as licensees of the state. Individuals were eventually required to apply for permits to use state land. These restrictions effectively halted the expansion of native customary lands. Finally, in the revised Land Code of 1958, which holds till today, the Minister of Land Development was given authority to declare by gazette that any native communal reserve cease to exist if needed for state purposes (Hong, 1987).

Stated differently, the state could now exercise compulsory acquisition of native lands through mere notification. This evolution illustrates Corson's advancement of Peluso and Vandergeest's concept. She posits that state territorialization is 'not just a claim to control land and resources, but also the authority to determine who controls those resources. Thus territorialization entails practices of enclosure, not only of rural peasant lands but also the authority to determine who can accumulate from them' (Corson, 2011, p. 704).

In the hydro context we saw this clearly exemplified in the manner of the state's acquisition of lands for Baram Dam. The news of the beginning of construction work for the Baram Dam came in 2012 in the form of a Land Code Direction published in the local newspaper which stated that, in exercise of the powers conferred by the Land Code, all areas delineated therein ‘are required for public purpose, namely the development of a hydroelectric dam and the government has to acquire them’ (“Malaysian Insider,” 2013). The Direction allows claimants two months to submit claims and supporting documents to the Department of Land and Surveying stating that compensation will only be paid to those claimants with proven native customary rights over the said land. However even claiming compensation, as little as it may be, is also a difficult process given the lack of support villages have in demarking community lands. As one Baram villager noted:

> *“There is always logging on village customary rights land. We do not know the extent. We do not have maps of our land to show them. So we do not get any compensation.”*

I note here that this is a clear example of James Scott’s compelling theory of state spaces. According to Scott, the historical basis of freedom in pre-colonial and colonial Southeast Asia was physical mobility – the capacity to be free of the reach of the state (James Scott, 1998; Scott, 1999). The tendency of the state has historically been to narrow this margin of social autonomy, by restricting physical mobility, closing off the ‘forest commons’ and the ‘free-access frontier’ essentially creating what Scott terms ‘state spaces’ and reducing the total ‘non state space’ (James Scott, 1998). In the former the subject population is settled into permanent communities producing an economic surplus easily appropriated by the state. In the latter the population is sparsely settled, typically practicing swidden agriculture and is highly mobile, severely limiting the possibilities of reliable state appropriation (James Scott, 1998).

Indeed, in observing the progression Hong presents there is a clear move from non-interference with native customary rights to limiting their spread and now to a situation where they can actually be extinguished altogether, thus creating Scott’s state spaces. The state’s determination of who can accumulate wealth from resources through the distribution of contracts and licenses as noted in the previous section, it is a form of enclosure as well. The enclosing of lands for hydro development and exclusion of individuals who lay claim to them in Sarawak is a perfect example of state territorialization in operation.

2.5.2.2. The Social and Environmental Impact Assessment Process

Let us briefly look at another use of legal mechanisms to enforce cultural asymmetries in the hydro conflict – namely, the SEIA process. As rates of deforestation climbed across Peninsular and East Malaysia during the 1970s and 1980s, the federal government was prompted by mounting international pressure to play a more significant role in environmental protection. In 1987 the EIA Order was legislated, mandating EIAs for a select category of activities be conducted and published for projects prior to approval (Memon, 2000). Constitutionally, state agriculture and forestry departments refer to federal authority on EIA policy, with the exception of Sabah and Sarawak. As we learned above this legislation does not necessarily have to be enforced in either of these two states, especially where state legislation already exists (FERN, 2006).

In Sarawak the Natural Resources and Environmental Order (NREO) 1994 requires an SEIA for select activities prior to approval and is therefore the default legislation. As a significant point of departure however, NREO makes no reference to the need for public participation, consultation or comment ("NREB," 2015). As a result, little effort is made in distribution of SEIAs and very few people have access to the information contained in them, especially those in remote areas. In fact projects and resettlement plans are often approved with little public awareness at all ("Hornbill Unleashed," 2011). None of the persons that I interviewed, for instance, had ever seen an SEIA for any of the SCORE dams. This system is highly controversial for its lack of transparency – it denies access to knowledge, it makes it difficult for civil society groups to access or comment on EIAs, and where NGOs and community groups are included as stakeholders, they are brought into the project process late and in relatively powerless positions to participate in decision-making (Gellert & Lynch, 2003).

The state government justifies its SEIA process on the argument that existing channels of electoral democracy provide ample opportunities for people to have their say (Memon, 2000). This sharply contrasts international assessment standards and the principles of the United Nations Declaration on the Rights of the Indigenous Peoples (UN-DRIP) which require governments to obtain free, prior and informed consent (FPIC) of affected indigenous peoples before implementing development projects within their territory. As such, there are hundreds of Native Customary Land Rights (NCR) cases now backlogged before the High Court of Sabah and Sarawak where village communities are seeking recognition of ownership to land.

Only recently are landmark rulings being made in favor of communities ("Borneo Project," 2014). New laws such as the Land Surveyors Ordinance 2001 which criminalizes activities such as community mapping make land rights defense in these legal proceedings all the more difficult, compounding the denial of access to information. In other words, the exclusion from access to information and participation in the assessment process disadvantages native groups through knowledge asymmetry.

In summary, we have seen how state autonomy, the lack of federal oversight, and an ethnic asymmetries have together created a situation where state-based actors can use the discretionary authority afforded them to deny and reallocate access to rights, to territorialize spaces and to commodify resources. The transition of free lands to tightly controlled state-spaces and the misuse of legal tools such as the SEIA process further disadvantage indigenous groups and perpetuate major asymmetries in the amount of power different actors are able to exercise over land management. As we saw, these state actor dynamics playing out in the hydro arena strongly parallel those which defined forest conflicts of the logging and palm oil industries, hence my assertion that waterscapes are the new frontier. Let us explore the landscape of non-state actors, counter-claims and means of mobilization.

2.6. Non-State Actors and Mechanisms for Mobilizing Counter-Claims

2.6.1. Legacy of the Indigenous Peoples Protest Movement

The lack of legal avenues to participate in decision-making has forced indigenous communities to pursue other avenues of mobilizing claims to land - namely protest movements. Protest action has a long history in Sarawak with NGOs such as Friends of the Earth and the Malaysia Nature Society staging peaceful protests and mounting blockades in the 1970s and 1980s to prevent the encroachment of logging companies (Cooke, 2002;

Ramakrishna, 2002). These actions were frustrated by legal manipulation and a well-orchestrated government campaign of countering the opposition through discursive displacement. For instance a 1987 amendment to the Sarawak Forest Ordinance made blockading of logging roads illegal and entitled the state to use police power against such activity. Many protest leaders and activists were arrested, jailed, and either had passports revoked or were barred from entering the state stifling their ability to plan and coordinate (Cooke, 1999, 2002).

Furthermore the state-owned media was used to depict a narrative which emphasized the anti-development conservatism of rural indigenous community, narrowing their arguments to conservatism and mystical attachment to land, projecting a modernity-traditionalism duality (Cooke, 2002). The media is heavily controlled by the state, which takes liberty in enforcing the outdated Sedition Act, a colonial legacy of the 1940s. Today the law bans any act, speech or publication that brings contempt against the government with a penalty of imprisonment (Memon, 2000). Amnesty International has highlights the law as a repressive piece of legislation which has historically been used against opposition politicians but which in recent years has been used against journalists, activists and academics. Many civil groups across the country are now calling for its abolition (Pak, 2014). Nevertheless a small number of independent media outlets, such as Radio Free Sarawak and sister organization the Sarawak Report continue to offer alternative and investigative information to the public.

Similar protest and protest-control action has arisen in the hydro conflict. The indigenous face of the mega dam protest movement is called Save Rivers, formed in 2012. Though there was a coalition of concerned NGOs which formed around the Bakun Dam, they pursued legal proceedings over the legality of companies involved in the dam and over the findings of the SEIA. These legal strategies yielded limited results and the relocation of native communities proceeded despite the claims made. With the gazette notice of the State's acquisition of land for Baram Dam in 2012 a number of individuals began coordinating a campaign to educate and inform affected Baram communities, to expose the government and its partner local businesses and to lobby multi-national companies involved with the project. Save Rivers is supported by local community based organizations (CBOs) such as JOAS that lobby for indigenous people's rights in Sarawak. Save Rivers places major focus on education of native communities about the realities of displacement, organizing frequent seminars and trips to the Bakun Dam and its resettlement villages for Baram natives.

Save Rivers efforts have culminated with the Baram and Murum Dam blockades. The Baram Dam blockades have persisted for almost two years, preventing civil work from taking place ("Sarawak Report," 2015) ("Borneo Project," 2012)("International Rivers," 2013). Many international new agencies such as National Geographic and the Times have published on and follow the progress of the blockades (Pei Ling, 2013). Together with the international NGO community Save Rivers has successfully lobbied Hydro Tasmania (an Australian dam operation and consultancy firm) to pull out of its engineering and management service contact with SEB ("Environmental News Service," 2012). Rio Tinto Alcan (a global mining company) has also pulled out of its aluminum smelter venture, which was the flagship industrial project expected to purchase Bakun's hydropower ("Hornbill Unleashed," 2012). The conflict has garnered so much attention that the former Prime Minister of Malaysia recently made an open statement calling on the Sarawak Chief Minister to re-think the SCORE plan (Davidson, 2015). In this sense, the protest action is proving successful at staving of construction and in raising international awareness, but progress of the social movement is complicated by the complex landscape that is the indigenous voice.

2.6.2. Complexities of the Non-State Actor Landscape

2.6.2.1. Diversity in Indigenous Representations and Desires

It is important to note that the indigenous voice is not homogenous. Even in the Baram basin among the very villages that will be displaced, I found that the indigenous stance is not uniformly 'anti-dam'. In fact I found that even single longhouses can be divided. There were many different interpretations of the dam and many ideas of what 'development' for Baram looks like. As Huber and Joshi remind us, 'development is not necessarily perceived by its intended beneficiaries as an anti-democratic, capitalist and imperial agenda. Their concerns are often far more contextual and contingent and grounded within the more immediate and mundane contexts of their everyday lives' (Robins, 1998, p. 1679). This is all the more reason why the nuances of cultural politics should be carefully considered in negotiation and the identification of stakeholders. I will present a few of the different arguments I recorded, which compound upon each other creating a complex indigenous landscape.

In my interviews it was clear that some longhouses see a benefit in being financially compensated for displacement and are in fact eager to be resettled. These longhouses often expressed seeing other longhouses as backward or being against progress. One villager stated:

> *"There is not much potential for conserving forest in Sarawak. There is almost no protected forest left and what is there has been worked over by loggers already. But the rivers, they can bring us new money."*

This heterogeneity is observed by an SEIA consultant who claims that:

> *"The surveys do not show numbers that are very anti-dam. The problem is with groups such as Save Rivers who are not willing to cooperate. If they would communicate instead of taking a stance not to be part of the process at all they would be more successful."*

This notion of protesters using resistance as a sort of counter hegemonic operation of anti-politics was raised by academic perspectives. One legal researcher at a Sarawak university explains that:

> *"The activists misrepresent the intentions of the government for their purposes too. They are unwilling to negotiate. It is their strategy."*

Other villagers though opposed to the dam do not want to take part in resistance action due to the potential legal consequences, while others are not able to participate in the protests because of the headmen who represent them. The village headman and his or her council is normally elected by the village community. However even at this level of governance state actors can still have influence through the local district offices. One Baram headman explains:

> *"Often times if the District Officer does not like the village's choice of a headman he will find some way to have him fail a test like a medical exam or declare him unfit for headman. Then someone else will be selected by the Officer himself."*

Another Baram headman states:

> *"I know they are plotting to charge me, but I have to fight for my people. The Dam will completely change our way of life. We have been here for more than one hundred years. I met with all our other headmen in the Baram and asked how many of them are for the Dam. Everyone said no. But then SEB representation came into the room. Suddenly people are afraid to say how they truly feel. One reason is because their position can be taken away from them by the government. But I don't mind, let them take it from me. This is what I have to do."*

This state actor involvement creates tension between village leaders, who then have varying interests to be gained from individual developments. Thus the sphere of local scale village-level politics to navigate adds to the complexity of relation dynamics.

2.6.2.2. Civil Society and the Plight of the Environmental NGO in Sarawak

The heterogeneity is compounded by urban civil society in Sarawak, which is just as riddled with class interests and ethnic division as the state sector (Cooke, 2002, p. 166). According to the environmental NGOs community, it is a huge challenge to engage urban civil society, partly because of their limited number and constrained capacity. This compounds the difficulty in securing political representation, and thus the overall ability to effectively advance counter claims. First is the sheer number of almost insurmountable legal barriers involved in establishing NGOs, lobbying groups or trustees in Sarawak (Lai, 2002). This makes it difficult for civil society groups to establish themselves legitimate stakeholders in the SEIA process, dysfunctional as it is. An NGO representative from Sabah describes how legal barriers close spaces of participation:

> *"This is the plight of the NGO. It took us ten years to get certified in Sabah. But there isn't even a legal process for NGO registration in Sarawak. International NGOs have to work sort of off the books, or under the title of something like a Trustee or so. Their staff cannot get work permits for Sarawak."*

Secondly, while NGOs should be able to focus on the specific issues that affect their specific member demographic, there is instead tremendous pressure on the few environmental NGOs that exist and operate in Sarawak to be broad enough to represent the interests of many different demographic stakeholders. With limited man power and financial resource available, this quickly becomes a difficult task. In discussing how to use their limited resources, one urban civil society member suggests that:

"Groups like Save Rivers unite communities about one issue. JOAS is a network for media representation. But Sarawak needs a group that brings villages together across issues."

Thirdly, not only are there few environmental NGOs operating in Sarawak, but the ones that exist are poorly connected and produce very little data for the public. This is in part due to the lack of information from and cooperation extended by relevant government agencies. A very few major NGOs such as the World Wildlife Fund (WWF) maintain offices in Sarawak, but even they do not engage in environmental conflicts within the state. One WWF researcher acknowledged:

"We are aware that we are being quiet in Sarawak. But it is the only option if we want to get any real work done under the radar. We don't really get involved."

Wetlands International (WI) is another major multi-national NGO that use to operate in Sarawak because of its ecologically sensitive peat swamps. Even WI found working in Sarawak so difficult they have since abandoned their local Sarawak office and work only in other Malaysian states. One representative explains:

"There are very few environmental NGOs operating in Sarawak because of the legal restrictions. So many questions remain unanswered. How much peat land still remains in Sarawak? What is its condition? How much carbon is it storing? No research is being conducted in these areas. Not even Wetlands International does primary data collection in Sarawak so data is severely limited. If these dams were anywhere else in Malaysia, many NGOs would get involved in the debate and necessary data collection. We would have to, we would be forced by our members. But Sarawak is a difficult, almost hostile place to work in as an environmental NGO."

This climate has contributed to the severe lack of information feeding public discussion on hydro development. Not only is SEIA information inaccessible, but independent study into the downstream or upstream ecological impacts of dams, a gap often filled by environmental NGOs, is now also lacking. According to other NGO respondents, NGO work is made even more difficult by the intentional stigmatization of NGOs by the state. One respondent suggests that government agencies and local district offices have encouraged village communities to distrust NGO interference, stating:

"Research has come to be a bad word in the state, as has the term NGO. It is almost a word in itself, not an acronym. If we go to villages where people do not speak English, they will ask 'NGO?' and if the answer is yes, they will not cooperate."

Conversation with the CBO and NGO representatives also revealed that beyond the struggle to exist and operate, there is the separate difficulty of garnering support from an urban non-indigenous civil society has itself largely resigned to a dispassionate acceptance of the state's authoritarian tendencies. As previously noted, Malaysian society has been largely affected by Bumiputera affirmative action policies of the 1970s which have promoted the growth and expansion of a new Malay middle class, particularly in the professional, technical, administrative and managerial categories.

'These individuals are generally dependent upon and hence supportive of the regime and Malay political predominance. Their political conservatism has left the emergent middle class largely demobilized and loath to be too involved in activities that might challenge the smooth implantation of development plans' (Weiss & Hassan, 2002, p. 6). Urban civil society thus seems removed from the plight of the rural villager and where vocal about the SCORE agenda, it develops arguments from the position of economic rational more than land rights. One academic finds this rural-urban divide as a defining characteristic of the SCORE conflict:

> *"I am not sure how much this debate is being heard in Kuching. This is an indigenous people's fight."*

In lieu of an active local civil society, most support for indigenous activist groups has thus come from ties with international environmental and human rights NGOs without bases in Sarawak, such as International Rivers, the Bruno Manser Fund, the Borneo Project or Friends of the Earth, some of which have been part of the larger international anti-dam movement since the 1980s (Bicker, Ellen, & Parkes, 2003). These NGOs are important as they are able to launch powerful opposition campaigns on the grounds of ecological damages that reach the international community and they place heavy pressure on multi-national companies involved in the projects through lobbying action and declarations (Nüsser, 2003). As discussed in Section 2.2 above, though not their only objective, these groups help bring the ecological upstream and downstream impacts of the dams into the conversation.

This real-time progression of the international conversation on SCORE has been interesting to watch over the past few years. Through adoption of terms such as 'species diversity' and 'habitat loss' into their language, local social movements are creating their own means of advancing counter claims in lieu of legal or political avenues. So that engaging and collaborating with environmental NGOs creates a hybrid approach to cultural and territorial defense. By shaping cultural conflicts in terms of the global conservation debate, marginal indigenous social movements become centers of international attention. Bakker notices as similar discursive shift happening in the Mekong (Bakker, 1999).

This shift is not necessarily a negative thing, as Escobar notes, but it is important to consider that indigenous groups and local communities have agency beyond their roles as stewards of nature, and care should be taken that their social movements do not become refunctionalized to serve western styles of development or conservation (Escobar, 1998). This is particularly relevant for Borneo, which is one of the most important soil carbon stores and sources of biodiversity on the planet. A global commons of sorts, does the international community itself becomes a legitimate stakeholder in the conflict, represented by international NGOs that enter the local conversation?

2.6.2.3. Emerging Proponents of Alternative Energy Solutions

In summing up the complex landscape of non-state actors and actions, I would like to focus for a moment on a final group of actors, not often acknowledged in the literature but who are contributing opinions on alternative means of energy production to the SCORE discourse. Though a smaller voice in the debate, proponents of renewable energy that propose energy efficiency and alternative, feasible strategies for electricity supply are very important for the discussion of energy planning and also represent a new source of local knowledge production.As one Energy Commission respondent simply questions:

> *"Why pursue extra capacity before energy intensification? There are many gains from efficiency that should be tackled before extra capacity."*

The renewable energy sector in Malaysia is small but growing steadily thanks to recent legislation and implementation of incentive policies. The federal Renewable Energy Policy and Action Plan 2009 aims to increase the renewable energy contribution to the national power generation mix. It sets a target of 4 GW of installed renewable energy capacity by 2030, raising the total installed capacity to 17% from less than 1% today. This target covers five individual types of renewable energy: biogas, biomass, municipal solid waste, small hydro and solar photovoltaic (PV).

The Sustainable Energy Development Authority (SEDA) Act 2011 provides for the establishment of an authority to implement these national policy objectives. The main mechanism first established was the Small Renewable Energy Program, which incentivized small local alternative power producers to generate electricity for sale (Sustainable Energy Development Authority Malaysia, 2011). This program has since been replaced by the Feed in Tariff (FiT) scheme which allows electricity produced from a local renewable energy source to be sold to authorized power utility companies at a fixed premium price. The goal is to offer cost-based compensation to renewable energy producers through price certainty and long term contracts. There are now 750 MW of renewable energy either planner or operational across Malaysia.

The renewable energy technology wave is slowly spilling into Sarawak, but progress is slow. Sarawak is the only state that has not adopted the FiT policy and cannot be mandated to since it is not under the federal Energy Commission's authority. Since SEB offers few other incentive schemes operations here are still comparatively expensive. One project developer explains other hurdles:

> *"Though there are incentives for alternative technologies, there are hoops that render them inefficient in promoting appropriate technology. Applying for and receiving tax exemptions or allowances is a very slow process. It discourages project developers. It also does not help with upfront costs so they are still likely to buy cheaper, less efficient technologies anyway."*

Another project developer explains that beyond the lack of incentives there are logistical barriers that need to be addressed to create an energy industry out of a resource such as palm oil mill wastes:

> *"The technology is ready but transportation of the waste is a problem if generation is no co-located with the mills. But the mills are sometimes far away from transmission. So which is less expensive? Also millers are reluctant to enter into fixed supply contracts for waste to power stations because of the seasonal fluctuations. They have problems*

securing their own supply of fruit. They are happy to guarantee a cost but cannot guarantee supply so it is difficult for power generators to be secure."

Nevertheless small renewable energy operators such as Kina Biopower and Seguntor in Sabah demonstrate the feasibility of biomass waste power production while other developers focus on micro-hydro and photovoltaic systems. New project developers are slowly entering this space, helping to address the lack of local capacity and skilled labor for the emerging industry. Tonibung for instance, is a local renewable energy project developer that installs micro-hydro and solar systems in rural communities across Sabah, Sarawak and Kalimantan Borneo ("Tonibung," 2014a). Tonibung has recently also established CREATE, a renewable energy training center in Sabah. The center opened in 2014 and receives community members from across Malaysia and offers work space, a technical curriculum and modules, leadership training, certification and facilities for product testing ("Tonibung," 2014b). To date CREATE has graduated two cohorts of local energy technicians and the program continues to grow.

2.6.2.4. Rural Energy Technology as a Mobilization Strategy

One of the most prominent voices in spreading awareness of dam impacts is the community of Long Lawen, a village in which half of the residents rejected relocation plans during the inundation of the Bakun Dam in 1998 and moved to higher terrain within its ancestral land claim while the other half were resettled at Sungai Asap. The only means of transportation into or out of Long Lawen now involves a two hour drive to the Bakun Dam from the nearest town and then an hour long motor-boat ride from the Bakun Dam dock to a far edge of its reservoir where the village sits. Nevertheless, Long Lawen collaborated with Tonibung to install a 15 kW micro-hydro turbine power system that has been operating for over twelve years and which supplies electricity to the long houses in their new space. According to the village headman, their decision to remain behind has not affected their self-sufficiency and they have fared much better than communities that were resettled:

> *"Our families cultivate rice, rubber and pepper for trading as well as hunt and fish in the 40% of their territory which was not flooded. We have cheap electricity from our hydro turbine. Because conditions in Long Asap are so poor many families have returned to Long Lawen. We accept them once they agree to live in Long Lawen, not just own land here again."*

Long Lawen, its story of resistance and its micro-hydro success have gained much popularity since the Bakun Dam was constructed. I bring up this story because to me it illustrates the role that locally appropriate solutions can play in social movements. In Sarawak the micro-grid and more specifically micro-hydro technology, has come to take on social symbolism for the indigenous environmental movement that lobbies to save the Baram River. The mega-dams have never translated into electricity access for affected or upland river communities. Rather, the micro-hydro system is an explicit representation of alternative use of the very same river resource to satisfy local needs.

A powerful movement has grown around the spread of micro-hydro systems from village to village in East Malaysia because of this stark juxtaposition (Schnitzer et al., 2014). Tonibung alone has now installed more than two dozen micro-hydro systems in villages across East Malaysia. This is a sterling example of a growing grassroots operation that supports an emerging rural industry based on locally designed energy technology, simultaneously fostering an indigenous breed of environmental consciousness and energy progressiveness. As a locally trained Tonibung technician reflects:

> *"Installing micro-hydro systems is more than an end in itself. It is a means to community empowerment."*

I thus find that, in addition to resistance and protest action which lobby *against* a certain type of development, indigenous groups are also mobilizing their claims to land and autonomy through *pro* development demonstrations of energy self-sufficiency, affirming Baviskar's argument for the validity and importance of different cultural experiences of resource use (Baviskar, 2003). Indigenous villages are arguing against large-scale hydro development by implementing even more innovative systems of small-scale hydro development, ironically contradicting the common notion of peasant resistance to *modernization*. Thus the adoption of rural energy technology is in itself a new, creative mechanism for mobilization of indigenous counter claims in Sarawak.

2.6. Discussion: Implications for Redistributive Efforts in Sarawak

In this chapter I have demonstrated the role of cultural differences and cultural politics in the construction and use of discursive and material mechanisms for the mobilization of claims around SCORE. This is in attempt to encourage discussion on the political ecology and economics of hydro development through using Sarawak as a case study. In this analysis we have explored how state actors use social identities to access power, use land laws to territorialize spaces and use the SEIA process to close access to knowledge and participation. We have also seen the creation of new protest movements, the introduction of new language into the conflict's common discourse, and adoption of technology, as mechanisms that have, in resourceful fashion become central to the indigenous movement, as diversified as it is. We find this pattern of interaction between actors, or this 'conflict constellation' (Nüsser, 2003), as a reiteration of conflicts past (and ongoing), proving waterscapes to be a new frontier in the local resource commodification and territorialization conflict.

For this reason many civil society representatives and people from affected communities I interviewed argued that land rights above all else must be the basis of meaningful change. Because whether the conflict of the day is over dams, oil palm, timber logging, mining, the proposed industrial parks, or another resource, precedence of state claims over indigenous claims is at the root. The pool of particular actors may vary, the amount of international attention may fluctuate, the environmental impacts may become more complicated, the language of the discourse may evolve, but the basic issue of access to land rights continues to sit at the source of environmental conflict in Sarawak. If we see SCORE and each individual hydro-electric power plant proposed as part of this larger sphere, the issue of energy supply quickly becomes secondary to the elementary issue of rights and inclusion.

Escobar offers an elegant framework to solution-oriented discussion. As he theorizes, modernity and development have universally been both defined and built through unfair distribution and unequal exchange on three levels – economic, ecological and cultural. Redistributive efforts on each front are required to restore balance and equality (Escobar, 1998). Movements for economic justice, environmental sustainability and cultural difference are thus inherently interconnected and individually indispensable. I find that evident policy implications for Sarawak follow from this reasoning.

First is the need to limit cultural dominance in the state's key institutions, especially those that create and implement development policy and local institutions that control access to rights. I would argue that for Sarawak addressing cultural dominance would encompass extensive legal reformation beginning with reform of the state land code and its definitions of Native Customary Rights; the establishment of anti-corruption legislation that limits political interference and promotes merit based employment and business contracting; and legislation that institutes regulatory bodies for local industries that are independent, transparent and accountable to the courts. For the dams more immediately, this would also mean openness on the part of RECODA, SEB, Sarawak Hidro Bhd and the respective government ministries in the process of approving projects, negotiating power purchase agreements and in the issuance contracts.

Second is a need to create spaces for, and to support diverse visions of, rights and what the exercise of rights means. As we have seen, even within one river basin ideas of resource, subsistence, autonomy, identity, economy and development differ widely. Acknowledging and empowering non-dominant bio-cultural experiences of nature is a move towards peace with justice. Beyond legal and economic reform I believe that this would involve strategic intervention from Sarawak's education system. As we have seen, relationships of dominance become socially indoctrinated and manifest themselves not only in obvious forms of injustice or confrontation, but also in everyday relationships and interactions. Restoring confidence and freedom in identity is a long term process of re-learning.

Corson's reframing of primitive accumulation as an ongoing process that entails the enclosure of ideas and claims of authority from non-state actors (Corson, 2011) also reminds us to take a critical look at the role of the conservation movement itself. Enclosure through restructuring resource use can have the same impact on peasants as enclosure through physical fencing. So solutions to environmental conflict that involve community management of forests, payment for ecological service or such initiatives should be approached thoughtfully and through participatory decision-making processes.

Finally, while inclusivity is critical, a legitimate community of people who have rights to participate cannot be a foregone assumption in negotiation processes (Baviskar, 2003). Creation of such a community will involve conscientious attention to the diverse and more nuanced expressions of agency (political, ecological and cultural) are important in identification of stakeholders for public participation and involvement. For the SCORE dams for instance, adherence to even federal requirements for the SEIA process at minimum could affect the local discourse. Furthermore, as numerous representatives that I interviewed noted, the local community of NGOs and concerned civil society could be far more coordinated, even within the currently limited legal space they are afforded. A more organized civil society that acknowledges its own diversity would support a broader representation in decision-making processes.

While these are long-term policy goals that speak to environmental conflict beyond SCORE and while involve massive shifts in political will, it is important to acknowledge the smaller shifts that occur along the way. At the time of writing, the Baram blockades have just celebrated their second anniversary, with much media attention, making this the longest standing dam blockade in Sarawak's history. Furthermore, the new Chief Minister has publicly declared a moratorium on the Baram dam. Meanwhile many innovations in micro-grid technology, design and economics are being made by project developers working in Borneo and throughout Southeast Asia. In fact small-scale grid solutions have arguably been the fastest growing sector of the global energy system over the past few years. It remains to be seen whether the dam will be built and how the government proceeds with subsequent hydro projects currently in the pipeline. The exercise of deconstructing SCORE that I have presented in this chapter allows us a broader and more nuanced perspective on energy resource conflict through which to explore the building of integrated energy planning tools for developing countries, as we will see in the chapters that follow.

CHAPTER THREE
Energy Planning and Development in Malaysian Borneo: Assessing the Benefits of Distributed Technologies versus Large Scale Energy Mega-projects

3.1. Introduction: Mega Projects and Long Term Energy Planning

Energy megaprojects have become a defining feature of the modern energy transition. Whether driven by growing demand stemming from urbanization and industrialization - or by energy security concerns over foreign dependence and price volatility - large, centralized, national and transnational energy projects are now common centerpieces of energy strategy in many developing countries (Sovacool & Cooper, 2013). Development of large infrastructure is generally characterized by the involvement of a wide spectrum of actors. These projects can be conceptualized as socio-technological systems - embedded in the surrounding socio-economic environment and co-evolving with socio-political institutions. There is, understandably, inherent inertia against departing from the established, centralized patterns of control (Goldthau, 2014). This can be a barrier to addressing the multi-dimensional nature of energy access needs.

A critical aspect of energy infrastructure is scale. Because of considerations such as population density, connectivity, rurality or the delocalized nature of industry, scale becomes a key element in determining how to plan and manage infrastructure. Likewise, though the mantra of energy security is often used to justify large-scale energy projects, electricity demand is often overstated and the projects themselves often serve to exacerbate existing social tensions and conflicts, intensifying various manifestations of insecurity (Simpson, 2007). Balancing the need for large infrastructure with locally appropriate solutions thus presents a very real governance challenge.

While there is widespread agreement on the need for a combined approach, most national energy or electrification strategies contain very few details on the integration of decentralized systems and little information on the potential for distributed solutions is available for public discourse (Tenenbaum, Greacen, Siyambalapitiya, & Knuckles, 2014). We see this story playing out across Asia, Latin America and Africa where the mega-dam has become a resurgent solution for energy service. A renaissance of World Bank funding for large hydropower projects after a decade long lending hiatus during the 1990s along with infusions of new capital from middle-income countries is driving investment in these large-scale national energy projects.

The Three Gorges Dam of China was completed in 2006 (Jackson & Sleigh, 2000; Nakayama & Shankman, 2013) while the Nam Theun Dam (completed in 2010) and the Xayaburi Dam (under construction) in Laos are the first of a series of dams being built in the transboundary Lower Mekong Basin (Goh, 2007; Molle, Foran, & Flock, P, 2014). Construction on the Grand Inga Dam in the Democratic Republic of Congo begins this year (Green, Sovacool, & Hancock, 2015), while the Belo Monte Dam in northern Brazil is expected to be completed by 2019 (Tundisi, Goldemberg, Matsumura-Tundisi, & Saraiva, 2014). Tension is growing between civil communities and policy makers as decisions affecting land rights, resource use, industry, and social and ecological health are being made with little discussion of necessity, risk and alternatives.

Our research aims to address this gap and contribute to the literature on management of energy transitions. We present an adaptation of a long term energy planning and analysis tool and demonstrate its use in comparing transition pathways using contemporary mega-dam development in Borneo, East Malaysia as a case study (Sovacool & Bulan, 2012a).

The island of Borneo has abundant natural resources, immense global ecological importance, a largely rural population and an agrarian economy on the cusp of major industrial transformation. It is a relevant case study to explore the role of decentralized energy systems as well as the direct and indirect costs of supplying energy service. We create a capacity expansion model, which incorporates existing energy infrastructure stocks, resource constraints and system operability constraints to determine technically feasible options for clean electricity supply that satisfy future demand. We use this model to explore the economic, technical and land-use trade-offs of various future energy system configurations under different assumptions of demand growth and different policy scenarios. Our findings are applicable to other developing countries where assessment of large-scale energy infrastructure is critical to public policy discourse.

The remainder of this chapter is organized as follows: Section 2 presents our case study. Section 3 describes the methodology, software simulation tool used, demand growth forecasting, data collection and policy scenario development. Section 4 summarizes the results and our model limitations. Section 5 presents our conclusions and a discussion of the implication for other developing countries.

3.2. Background: The Sarawak Corridor of Renewable Energy

In 2006, the Federal Government of Malaysia embarked on a number of initiatives to promote balanced regional development and accelerate growth in designated geographic areas through the Ninth Malaysia Plan ("Tenth Malaysia Plan," 2014). The Plan describes a philosophy of development focused on decentralizing economic growth away from the federal capital through the establishment of *economic corridors* in different states[5]. The Sarawak Corridor of Renewable Energy (SCORE) is a corridor in central Sarawak, an East Malaysian state on the island of Borneo. SCORE differs fundamentally from the other Malaysian economic corridor projects in its predominant emphasis on hydropower ("RECODA," 2015).

Sarawak, located along the northern coast of the island of Borneo (Figure 1), is the poorest and most rural state in Malaysia. An increased focus on cheap electricity to attract manufacturing and industry is the state's approach to achieving high income economy status. The current peak annual energy demand in Sarawak is 1250 MW, met by a mix of diesel, coal and natural gas generation either operated or purchased by the state utility company. Over the long term SCORE involves building out 20 GW of hydroelectric capacity in Sarawak through a series of 50 dams.

[5] The five prescribed corridors are: Iskandar Malaysia in Johor; The Northern Corridor Economic Region (NCER) covering the states of Kedah, Pulau Pinang, Peris and Perak's four northern districts; The East Coast Economic Region (ECER) covering the states of Kelantan, Pahang, Terengganu and Johor's Mersing district; The Sarawak Corridor for Renewable Energy (SCORE) and The Sabah Development Corridor (SDC).

At least 12 large hydroelectric dams and two coal power plants, together constituting 9380 MW of capacity, are scheduled to be built before 2030 (Sovacool & Bulan, 2012a)(Harris & Lang, 2014). Six dams are scheduled to be completed by 2020 with three major dams already under different stages of development (Figure 1). In 2012 the 2400 MW Bakun dam became operational (Oh et al., 2011). At 205 meters high it is Asia's largest dam outside China. The dam's reservoir submerged 700 km^2 of land and displaced about 10,000 people. The 944 MW Murum dam was completed in 2013 and is currently being filled. Access roads for the 1200 MW Baram dam have been cleared but preparatory construction work has been stalled since 2013 due to road blockades by local community protesters (Lee et al., 2014).

With this hydropower backbone the SCORE plan involves attracting investment to promote a number of priority industries in hubs across the state. These include heavy industry such as glass, steel and aluminum as well as resource based industry such as livestock, aquaculture, tourism and palm oil. The SCORE plan will also involve doubling land area under palm oil plantation concession to 2 million hectares by 2020 (Sovacool & Bulan, 2012a). The state anticipates these projects will attract over 334 billion Malaysian Ringgit (RM) (US$100 billion) in investment – 80% as private funding for the hydropower projects and industrial development, 20% as government funding for basic infrastructure and human capital. Though two of the dams have already been built returns are yet to realize. The cost of the Bakun Dam has escalated over many years of delay to RM7.3 billion (US$2.3 billion) – more than double initial price estimates. Construction has been funded primarily through the Malaysia Employees Provident Fund and the Malaysia Pension Fund (Oh et al., 2011).

Sarawak has a population of 2.47 million, more than half of which are indigenous groups living in rural village communities (State Planning Unit, 2011b). Many of these communities are being impacted or displaced by the SCORE dam construction, causing civil unrest. In addition to the displacement of roughly 30-50,000 indigenous people, the 12 dams would result in an estimated 2425 km^2 of direct forest cover loss (Bruno Manser Fonds, 2012). The three initial dams discussed above will flood an expected 1357 km^2 alone. Indigenous groups protest the rationale for the dams given low local energy demand, the quality of social and environmental impact assessment and the history of past failed resettlement schemes. They claim indigenous rights are being violated in the decision to build on native customary lands (Sovacool & Bulan, 2011a).

These indigenous groups are supported by a larger international NGO community concerned for human rights and the ecological impacts that the dams present. In particular, Borneo has been identified as one of Earth's 34 biodiversity hotspots and a major evolutionary hotpot for a diverse range of flora and fauna. Borneo's forests house the highest level of plant and mammal species richness in Southeast Asia (de Bruyn et al., 2014; Struebig, Wilting, et al., 2015). Civil society groups argue that efforts to conserve Borneo's forests are critical as their size and quality are deteriorating rapidly (Mittermeier et al., 2005; Pei Ling, 2013). Our study adapts a commercial energy modeling platform to create a framework for discussing the cost and benefits of various transition pathways in this context.

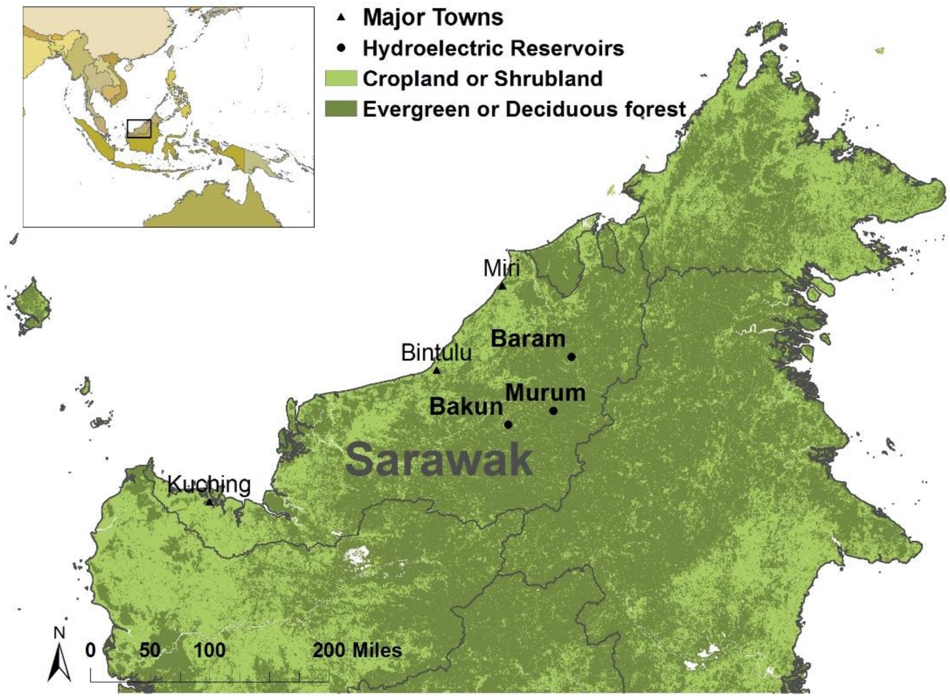

Figure 1 Location of Sarawak, its major towns and the three SCORE dams completed or under construction

3.3. Methodology and Data Inputs

3.3.1. Energy Modeling Tools

PLEXOS is a commercial linear mixed integer power sector model developed and commercialized by Energy Exemplar (Energy Exemplar, 2013). It is used by academia, industry and planning agencies in many countries. We selected a commercial software package to make our modeling directly accessible to state planning agencies. We also use PLEXOS because of its flexible framework which is very adaptable to client needs and data constraints. We use PLEXOS first to map available primary energy resources, existing generation and potential generation options and then to analyze optimal system configuration under various constraints and assumptions of demand growth and implemented policy.

PLEXOS allows for expansion planning for any number of years ahead using mixed integer programming which minimizes NPV of total cost of expansion and production. The transmission module includes optimal power flow (OPF) with losses, thermal limits, forced outages and maintenance, pricing and variable load participation factors at different nodes, thereby accounting for congestion, security and marginal losses. The thermal generation module uses unit commitment, heat rate functions, fuel constraints, fuel price escalation, emissions constraints and taxes, generator 'must run' and other operating constraints, dynamic bidding, a Monte Carlo Simulation of forces outages and optimized maintenance (Foley, Ó Gallachóir, Hur, Baldick, & McKeogh, 2010). We do not simulated forced outages as will be explained in Section 4.3.

The Capacity Expansion problem is solved through a mixed integer linear program (the LT Plan) which finds the optimal combination of generation new builds, retirements and transmission upgrades that minimizes the net present value (NPV) of the total system costs subject to energy balance, feasible energy dispatch, feasible builds and integrality over a long-term planning horizon. The LT Plan can be run in chronological mode or non-chronological mode using Load Duration Curves (LDC).

We decided to use a yearly LDC with twelve blocks per curve where the slicing is done using a quadratic formula that creates a bias toward placing blocks at the top (peak) and bottom (off-peak) of the curve, with less blocks in the middle. This method allows for greater emphasis on the system's ability to meet demand in the extremes. While in chronological mode the LT Plan would capture the dynamic effects of intermittent generation and load uncertainty on generator cycling (co-optimizing), it requires high resolution load data not available at the time of this study. Rather, in non-chronological mode, an algorithm uses the given LDC to estimate how often each class of unit will run based on marginal operating cost and will select units for investment by optimizing capital and operating costs compared to the expectation of hours operated (Blair, Dobos, & Gilman, 2013).

The LT Plan can also be run in deterministic or stochastic modes. In stochastic mode it can be used to find the single optimal set of build decisions in the face of uncertainties in any input e.g. load, fuel prices, hydro inflows or wind generation using probability distributions that govern the data. Deterministic models observe the outcome of discrete inputs. We decided to run a series of deterministic scenarios because we are less concerned with the likelihood of different outcomes and more concerned with the feasibility of various expected scenarios. We apply a standard discount rate of 8% to all cash flow analysis to represent the opportunity cost of capital investment (Lind et al., 2013). Limitations of the LT Plan design are discussed in Section 4.3. Details on PLEXOS modeling can be found in (Energy Exemplar, 2013). Our Model XML and data CSV files can be found at:
www.rael.berkeley.edu/sustainableislands.

In the following section we describe the physical and economic information regarding energy resources that were locally available at the time of study to populate and parameterize the model.

3.3.2. Electricity Demand Forecasts

The Sarawak Electricity Supply Corporation (SESCO) is responsible for the generation, transmission and distribution of electricity in the state. The parent holding company is Sarawak Energy Berhad (SEB), wholly owned by the Sarawak State Government. SEB owns a number of other generation subsidiaries (Sarawak Energy, 2010) and in 2012 the total generating capacity of SEB stood at roughly 2,550 MW: 555MW from SESCO, 795 MW from other subsidiaries and 1,200 MW from the Bakun Hydroelectric Dam's (four of its eight generators are currently operational) (Energy Commission, 2012a). This represents more than a 100% reserve margin compared to an average of 30% across other Malaysian states.

Current maximum energy demand in Sarawak is 1250 MW. Demand is shared among the industrial (51%), commercial (26%) and residential (21%) sectors (Energy Commission, 2012a). According to the National Energy Report growth rates for electricity sales and maximum demand in Sarawak average 8.6% and 7.0% respectively from 2000 to 2012 (Figure 2) (Energy Commission, 2012a), (Energy Commission, 2012b). The National Planning and Implementation Committee for Electricity Supply and Tariff (JPPPET) performs long term load forecasting based on current economic trends and the latest electricity demand performance (Energy Commission, 2013). For Peninsula Malaysia JPPET forecasted an electricity sales growth rate of 4.0% per annum for the 2012 – 2015 period, followed by a decline to 3.6% in 2016-2020 and to 1.9% from 2021 – 2030 with similar rates for Total Generation and Peak Demand.

The SCORE plan revolves around a targeted nine-fold increase in energy output between 2010 and 2020, or from 5,921GWh to 54,947GWh, which represents a 16% growth rate. In terms of installed capacity this translates to an expansion from 1,300MW in 2010 to between 7,000MW and 8,500MW in 2020 (Sarawak Energy, 2010).

In our model we forecast demand to 2030 under four different assumptions in order to observe the effect of demand growth on optimal system configuration (Figure 2). We model both the SCORE growth assumption and a conservative historic growth assumption. We then model two intermediate growth rates – 7% per annum and a more ambitious 10% per annum. We describe the demand growth assumptions here:

1. The 'Business as Usual (BAU)' projection: We apply the JPPPET projections to historic SEB data to obtain a BAU demand forecast for Sarawak (Figure 2). Though conservative, this growth assumption is still high projection given that energy demand in Sarawak has historically grown at a slower rate than Peninsula Malaysia;

2. The 'Seven Percent Growth' Projection: We assume that energy demand from 2012 increases at a 7% growth per annum for both total annual energy (GWh) and maximum demand (MW). This rate is higher than the average projected for Peninsula Malaysia yet is plausible given the primary energy demand growth rates across the region (International Energy Agency, 2013) (Figure 2);

3. The 'Ten Percent Growth' Projection: We assume that energy demand from 2012 increases at 10% growth per annum for both total annual energy (GWh) and maximum demand (MW);

4. The 'SCORE' Projection: We model SEB's assumptions for demand growth (and required generation capacity) as anticipated in SEB documentation. Though sustaining such a level of growth is unprecedented, we model SEB's assumption for completeness.

To represent load PLEXOS takes a "base" year's profile of demand (i.e. period-by-period demand) and a forecast of both total energy (GWh) and maximum demand (MW) over the forecasting horizon. PLEXOS then applies a linear growth algorithm to create a forecast profile or time series (Energy Exemplar, 2013). The Energy Commission provides daily and hourly grid system reports for each state utility company in Sabah and Peninsula Malaysia, which show relatively little diurnal or weekly variation in demand. Sarawak specific monthly averaged maximum demand and electricity sales data for 2003-2004 was obtained from the Energy Commission (Energy Commission, 2005) and was compared with monthly averaged trends in Sabah and Peninsula Malaysia to create the base year of data for Sarawak (Figure 3).

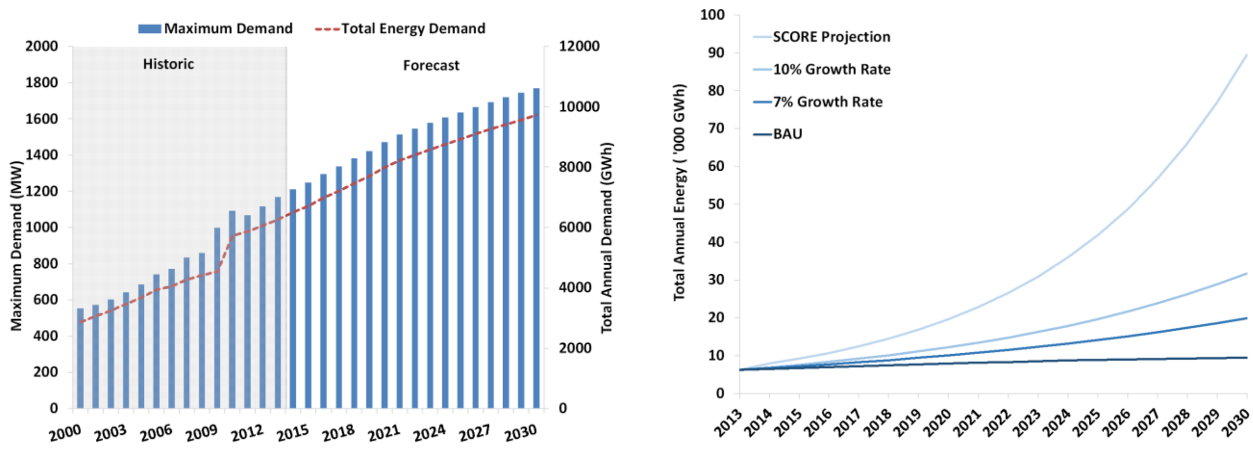

Figure 2 (a) State Growth Forecast (BAU Assumption); (b) Long Term Load Demand under Four Different Growth Assumptions

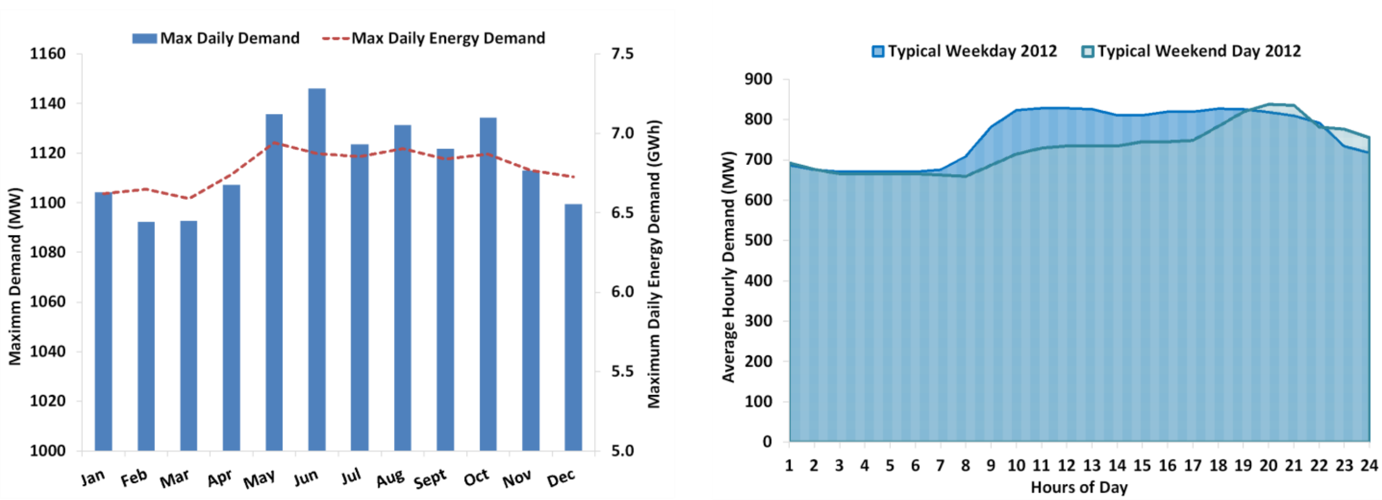

Figure 3 (a) Monthly Averaged; (b) Hourly Averaged Demand in Sarawak

3.3.3. Energy Resources Available in Sarawak

Together the SEB generation portfolio is comprised of large scale coal, diesel, gas and hydro capacity along with about 50 MW of off grid diesel generation in rural communities. Together, fossil fuels (natural gas, coal and diesel) represented roughly 92% of both installed capacity and annual generation in the state of Sarawak until 2012. With the start of Bakun Dam operations, hydropower is now 64% of installed capacity, while natural gas, coal and diesel are 16%, 16% and 4%, respectively (Sarawak Energy, 2010). In this section we discuss the scope of various energy resources in Sarawak and highlight our data sources for resource quality, fuel prices and technology costs.

3.3.4. Fossil Fuel Resources

Malaysia's oil reserves are the third largest in the Asia-Pacific region after China and India. Malaysia held proven oil reserves of 4 billion barrels as of January 2011 and total oil production in 2011 was an estimated 630,000 barrels per day (bbl/d). Nearly all of Malaysia's oil comes from fields offshore Peninsula Malaysia ("Energy Commission," 2011). This oil was the main source of electricity in Malaysia until the energy crisis in the 1970s, which prompted investment in other resources. Oil share in the national energy mix fell from a high of 87.9% in 1980 to a low of 2.2% in 2005. Natural gas and to a lesser extent, coal, have become more dominant fuel sources for the country over the past 20 years ("Malaysia Brief," 2013). Malaysia held 83 trillion cubic feet (Tcf) of proven natural gas reserves as of January 2011, and was the fourth largest natural gas reserves holder in the Asia-Pacific region. Gross natural gas production has risen steadily, reaching 2.7 Tcf in 2010. Most natural gas reserves are in the eastern territories, predominantly offshore Sarawak.

Malaysia's domestic coal industry is much smaller than its domestic oil and gas industry. Most of the nation's reserves are located in Sabah and Sarawak where together there are 1,938 million metric tonnes (tonnes) of reserve. Production of coal has increased gradually from 1990 while consumption and imports have increased dramatically ("Malaysia Brief," 2013). There are government plans to extract more coal resources from Sarawak and as discussed two large coal power plants are part of the SCORE proposal. There was a government proposal to build a 300 MW coal power plant in Sabah, but this was rejected in 2010 by the state government on environmental grounds. Information on the individual fossil fuel generators currently operational in Sarawak including capacity and output are taken from Energy Commission annual performance reports (Energy Commission, 2005, 2006, 2008, 2009, 2012a, 2012b) and SEB annual reports (Sarawak Energy, 2010). Current and future forecasted fossil fuel prices are taken from the EIA Energy Outlook (U.S. Energy Information Administration, 2013).

3.3.5. Hydroelectric Data and Resource

Until 2012 there were over 3,000 MW of hydropower capacity in Malaysia, representing 11.4% of total installed capacity (Energy Commission, 2012b). The largest of these was the 600MW Pergau Dam in Peninsular Malaysia. The 2.4 GW Bakun Dam is the most recent large scale hydropower plant built in the country. Sarawak has one of the country's densest river networks and abundant rainfall. The northeast monsoon, usually between November and February, brings the heaviest rain, while the southwest monsoon from June to October is milder. The average rainfall per year is between 3,300 mm and 4,600 mm, depending on locality. According to the state government, which has surveyed a number of potential large hydro sites in Sarawak, there is at least 20,000 MW of potential capacity in the state (Tate & Sarawak Electricity Supply Corporation, 1999).

The capacity, expected reservoir size and status of dams taken from the Bruno Manser Fund (BMF) Geoportal Database can be seen in Table 2 ("Sarawak Geoportal," 2015). We model Bakun, Baram and Murum - the three dams either built or currently under construction - using data on the specific dam dimensions directly from ("SIWRM," 2008) (**Error! Not a valid bookmark self-reference.**). We obtain historic monthly average maximum and minimum stage data for respective river basins (Department of Irrigation and Drainage Sarawak, 2011). This data was used to estimate monthly peak and minimum energy outputs for their respective dams as inputs for the annual hydro resource profile (Staub, Among, & Gastaldo, 2000).

Much uncertainty exists over the cost of dam construction in Sarawak (Oh et al., 2011). Sovacool and Bulan (Sovacool & Bulan, 2011c) estimate capital costs for all of the prospective dams, reporting US $4,643 million for Bakun based on direct interviews. This corresponds to US$ 1935/kW and corresponds with other cited ranges for Bakun (Oh et al., 2011; Sovacool & Bulan, 2012a). A recent Oxford study by Ansar et al. (Ansar et al., 2014) analyzes a sample of 245 large dams built between 1934 and 2007. The researchers find that three of every four dams suffer from cost overruns and for one of every two dams costs exceed benefits. The study finds actual costs are on average double their estimated costs and suggests a cost uplift of 99% to reduce risk of overrun to 20%. We apply this uplift to the Sovacool and Bulan cost estimates and obtain an average capital cost value of US $3870/kW, very similar to the NREL 2012 estimate for hydro power plant capital cost of US $3500/kW (Black and Veatch, 2012). We apply this capital cost value to all major dams and use NREL values for all other cost estimates (Fixed O&M Cost, VO&M Cost). We also include the standard US $0.1/kWh water levy as a Variable O&M cost for dam operation (Oh et al., 2011).

In Malaysia, and Sarawak more specifically, many small hydro projects have been designed and implemented by different non-governmental agencies including UNIMAS, PACOS and Green Empowerment. These projects are particularly useful given the disbursed and largely inaccessible nature of rural settlements in Sarawak. Local reconnaissance studies find that there are a number of sites suitable for low head large flow small hydro run of river schemes near to existing settlements. Researchers have identified at least twenty sites in Sarawak alone with head above 50m suitable for small hydro development (Hussein & Raman, 2010). According to surveys done by SEB there are over 4400 kW of small hydro that can be developed in districts across Sarawak ("Sarawak Energy," 2013a).

Table 1 SCORE Hydroelectric Dam and Reservoir Dimensions (data from Sarawak Integrated Water Resources Management Master Plan)

Dimension	Units	Murum	Batang Ai	Bakun
Capacity	MW	944	108	2,400
Crest Length	m	473	810	814
Dam Height	m	141	85	206
Catchment Area	km^2	2,750	1,200	14,750
Resevoir Gross Storage	km^3	12	3	44
Dead Storage	km^3	7	2	25
Full Supply Level	m	540	108	228
Min Operating Level	m	515	98	195
Reservoir Area at Full Supply Level	km2	245	85	695
Reservoir Area at Min Operation Level	km2	234	77	594

Table 2 Hydroelectric Power Plants planned and being developed under SCORE (data from BMF)

Dam	Status	Reservoir Area (km^2)	Water Level (m)	Affected Settlements	Output (MW)	Start of Construction	Date Operational	Estimated Cost (Million USD)
Bakun	Built	700	255	31	2400	1994	2011	4,644
Baleh	Planned	527.3	241	1	1300	2019		2,424
Baram	Planned	412.5	200	36	1200	2014		1,515
Batang Ai	Built	76.9	125	59	108	1981	1985	387
Belaga	Planned	37.5	170	0	260	2015		242
Belepeh	Planned	71.8	570	5	114	After 2022		49
Lawas	Planned	12.4	225	1	87	After 2022		95
Limbang	Planned	41.3	230	11	245	After 2022		439
Linau	Planned	52	450	3	297	After 2022		264
Murum	Under Construction	241.7	560	10	944	2008		1,061
Pelagus	Planned	150.8	60	78	410	2015		424

3.3.6. Biomass Resources

Sarawak is a largely agricultural economy generating large volumes of agricultural waste from the palm oil industry on a monthly basis. Malaysia produces roughly 19 million tonnes of crude palm oil annually (Malaysia Palm Oil Board, 2013). As land for cultivation becomes scarce on peninsular Malaysia, cultivation in Sarawak has drastically scaled up in recent years. Sarawak alone now represents 45% of national production with an average of 8.5 million tonnes annually (Figure 4). In 2010, there were over 919,000 hectares of oil palm plantation in the state. The Sarawak Department of State Land Development has stated that it plans to double plantation area to two million hectares by 2020, making Sarawak the biggest crude palm oil producing state in Malaysia.

There are a number of palm oil refineries near major load areas including Miri, Bintulu and Sibu that allow palm oil waste to energy to be a feasible option for energy production. According to SEB there are 41 palm oil processing plants across Sarawak (Figure 5) ("Sarawak

Energy," 2013b). Plants vary in size and processing capacity with the average across Malaysia being 600 tonnes fresh fruit bunches (FFBs) processed per day. Individual palm oil mills are thus able to act as small power producers (SPPs), selling electricity to retail customers or to the national utility's main grid.

While a certain volume of dry biomass waste, mostly empty fruit bunches (EFBs), is usually retained on plantation land as fertilizer, a large volume remains which can be directly combusted, or gasified for use in a steam turbine. All palm oil mills also produce a large volume of Palm Oil Mill Effluent (POME), which is usually treated in settling ponds and discharged to water bodies. This POME can be anaerobically digested producing biogas as a by-product. Thus there are a number of ways that palm oil waste can be converted to electricity. In this paper we focus on EFB biogasification and POME biogas recovery. For detailed descriptions of biomass waste to energy conversion techniques see (Sumathi, Chai, & Mohamed, 2008; Shuit, Tan, Lee, & Kamaruddin, 2009; Lam & Lee, 2011; Chiew, Iwata, & Shimada, 2011; Sulaiman, Abdullah, Gerhauser, & Shariff, 2011; Umar, Jennings, & Urmee, 2013; Chin, Poh, Tey, Chan, & Chin, 2013).

Given the size of the palm oil industry, both in Sarawak and Malaysia more generally, the government of Malaysia initiated the Biomass Power Generation and Cogeneration in Palm Oil Industry Project (BIOGEN) in 2002 with support from the UNDP to strengthen local capacity and help promote the palm oil waste to energy sector (UNDP, 2007b). According to the Malaysia Energy Commission, by 2012 there were 64 MW of licensed power generation coming from palm oil mills registered as SPPs between Peninsula Malaysia and Sabah. There are eight of these registered mill projects in total, using EFB and POME as fuel, and ranging from 0.5 MW to 15 MW installed capacity.

There are also 13 licensed agricultural waste co-generators with a total of 35 MW installed capacity on the grid. Predominantly palm oil mills, a small number of these operators are also rice and paper mills using other types of biomass such as rice paddy husk, wood dust and wood chips. There is also a large number of licensed self-generators. These are mills that use agricultural waste to generate electricity for on-site mill consumption only and do not sell electricity to the grid. These generators are generally less than 5 MW each and together totaled 475 MW across Malaysia in 2012 (Energy Commission, 2012a).

There is therefore significant precedent for electricity generation from palm oil wastes. A growing body of literature finds the economics of oil palm waste to be feasible in Malaysia and Sarawak (Sumathi et al., 2008; Shuit et al., 2009; Sulaiman et al., 2011; Shafie, Mahlia, Masjuki, & Ahmad-Yazid, 2012; Hosseini & Wahid, 2013; Umar et al., 2013; Chin et al., 2013). In fact the government's National Biomass Strategy estimates that by 2020 Malaysia's palm oil industry will be generating about 100 million dry tonnes of solid biomass waste (Agensi Inovasi Malaysia, 2011). According to the strategy, the biomass waste to energy industry could result in some 66,000 jobs nationwide and a number of existing local projects POME biogasification plants may sustain Investor Rate of Returns (IRR) of 7-17% and higher (FELDA, 2009; Malaysia Energy Center, 2004).

Though an emerging sector, there are a number of challenges to scaling up the palm oil waste to energy sector which we discuss in Section 5. The Malaysian Palm Oil Board keeps monthly records of state-wide production which we have used to estimate dry and wet biomass waste production into the future ("MPOB," 2015). SEB publishes residue ratios (volume of EFB and POME produced per tonne of FFB processed at a mill). SEB makes projections based for current and future potential power output from biomass waste resources as seen below and we use these published assumptions on productive residue ratio, energy content, conversion efficiency and waste price ("Sarawak Energy," 2013b).

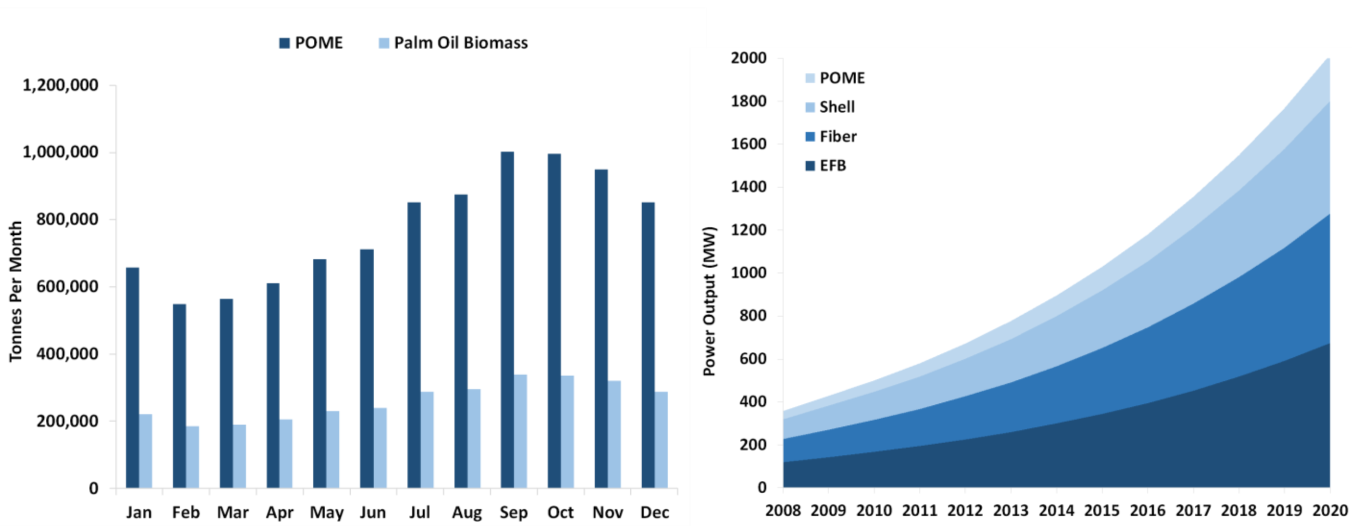

Figure 4 (a) Estimates of Palm Oil Waste Availability based on Monthly FFB processing; (b) Palm Oil Waste Power potential based on Future Expansion (data from SEB)

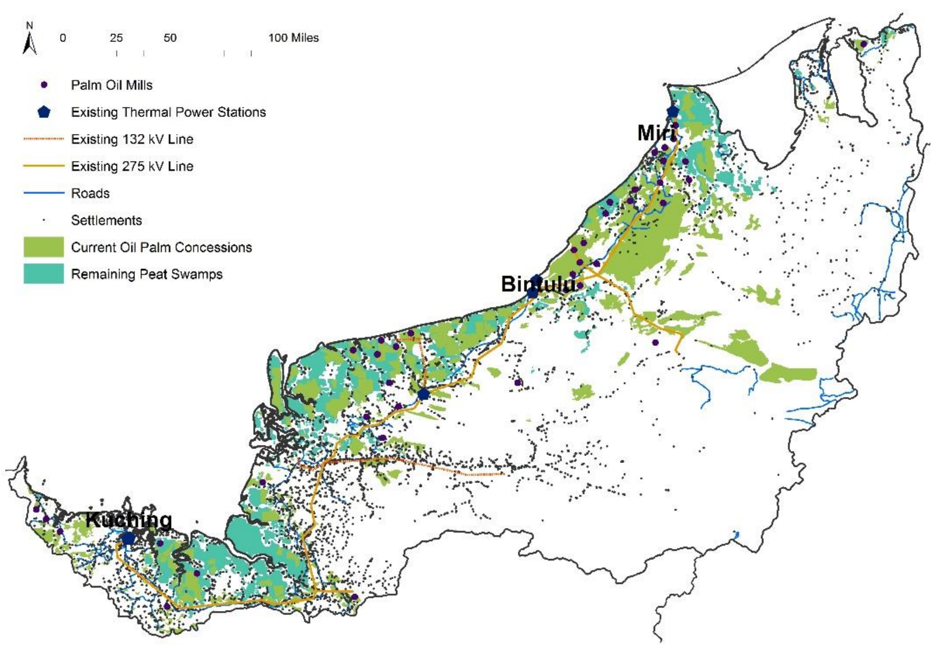

Figure 5 Map of Sarawak showing Current Oil Palm Plantations and remaining Peat Swamp lands

3.3.7. Solar and Wind Resources

Malaysia lies entirely in the equatorial region. The tropical environment has been characterized by constantly high temperature, abundant sunshine and solar radiation but also by heavy rainfall, and high relative humidity, so that it is in fact rare to have an entirely clear day even in periods of severe drought ("Sarawak Energy," 2013c). We use the NASA Surface meteorology and Solar Energy Global Data Set (Release 5) which provides 10-year monthly and annual average Global Horizontal Irradiance and monthly and averaged Wind Speed at 50m above earth surface data both at one degree resolution ("SWERA," 2014).

The minimum monthly average for insolation in Sarawak is found in the month of January at 3.26 kWh/m^2/day, and maximum monthly value in April at 6.91 kWh/m^2/day with the annual average being 5.00 kWh/m^2/day (Figure 7). Monthly averages are consistently lower in the west, near the capital Kuching and are higher in the east (Figure 6) (Jakhrani, Othman, Rigit, & Samo, 2013). Though a good quality resource, according to the Malaysia Energy Commission, there are only 10 MW of photovoltaic capacity installed in Peninsula Malaysia through a number of small distributed SPPs ranging from 0.5 MW to 5 MW in size (Energy Commission, 2012a). Thus there is significant opportunity to develop the sector.

The wind resource however, is relatively poor. The minimum monthly averaged wind speed is 1.51 m/s in April and the maximum is 5.27 m/s in August, with an annual average of 2.6 m/s. Wind speeds are strongest at the coast and weaken moving in toward the forested highlands of the interior (Figure 6, Figure 7).

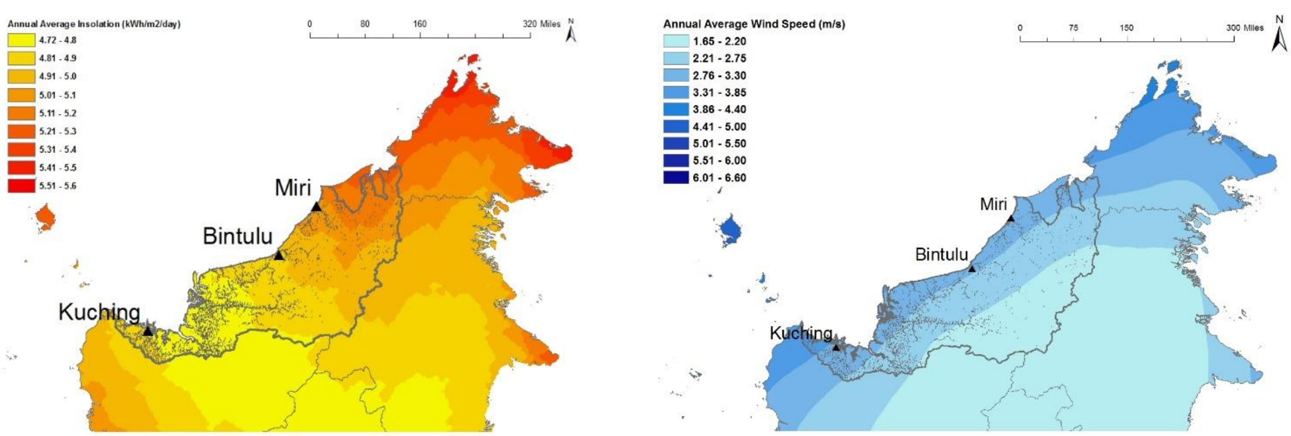

Figure 6 (a) Annual Average Insolation (data from NASA); (b) Annual Average Winds Speed for Sarawak (data from NASA)

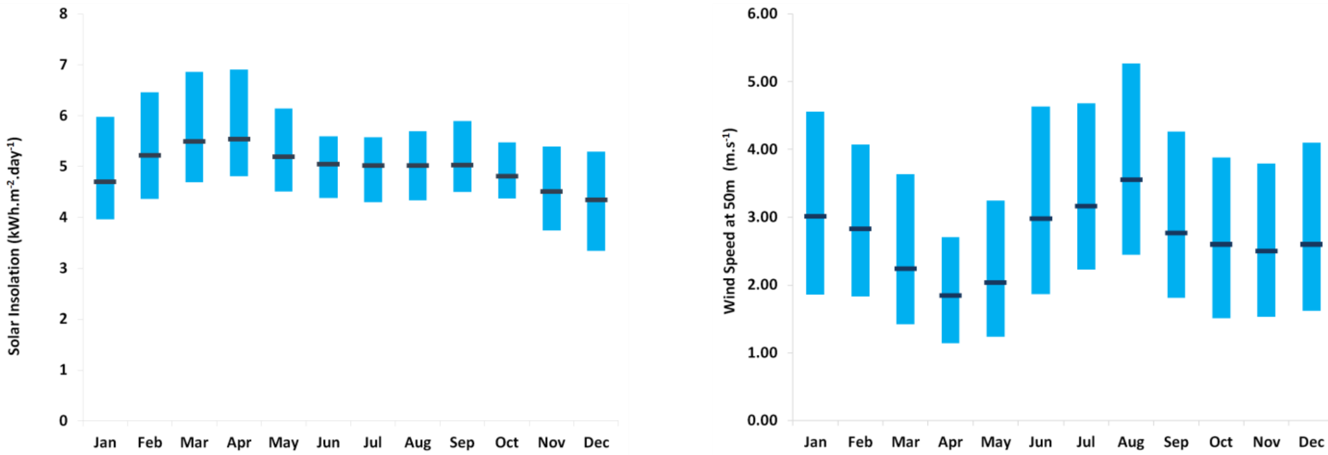

Figure 7 (a) Maximum, Minimum and Monthly Averaged Solar Insolation for Sarawak (data from NASA); (b) Maximum, Minimum and Monthly Averaged Onshore Wind Speed (data from NASA)

3.3.8. Generator Build, Fixed and Variable Costs

In 2012 SEB's cost of producing electricity was US $0.078/kWh, a steep increase from US $0.060/kWh in 2008. However SEB purchases electricity at US $0.036/kWh from independent power producers. Overall cost to the utility was thus US $0.044/kWh in 2012. The average selling price for domestic customers is US $0.097/kWh while commercial customers pay US $0.068/kWh and industrial consumers pay US $0.077/kWh (Energy Commission, 2012a).

For each generation technology we take overnight build cost, variable cost and fixed O&M cost from NREL (Table 4) (Black and Veatch, 2012). Hydropower cost estimates are previously described in Section 3.3.2. POME methane capture costs are taken from (Chin et al., 2013) as the technology is not included in NREL's study. We also consider the effect of the Malaysia Feed-in Tariff (FiT) program currently being rolled out in accordance with Renewable Energy Act 2011 and Sustainable Energy Development Authority Act 2011 (Chua, Oh, & Goh, 2011; Muhammad-Sukki et al., 2014; Wong, Ngadi, Abdullah, & Inuwa, 2015). The FiT system obliges utility companies to purchase electricity from certified renewable energy producers and sets the FiT rate. The maximum installed capacity for eligible installations is 30MW. The rates vary according to technology type and are degressive, decreasing annually according to prescribed rates (Table 3) (KeTTHA, 2011).

Table 3 Feed-in-Tariff Rates prescribed by SEDA (data from Ministry of Energy, Green Technology and Water)

	Biogas	Biomass	Solar	RoR
Max FiT Rate RM/kWh	0.31	0.31	0.88	0.23
Max FiT Rate US/kWh	0.094	0.094	0.267	0.094
Annual Degression Rate (%)	0.005	0.005	0.080	0.000
2014	0.093	0.093	0.245	0.094
2015	0.093	0.093	0.226	0.094
2016	0.093	0.093	0.208	0.094
2017	0.092	0.092	0.191	0.094
2018	0.092	0.092	0.176	0.094
2019	0.091	0.091	0.162	0.094
2020	0.091	0.091	0.149	0.094
2021	0.090	0.090	0.137	0.094
2022	0.090	0.090	0.126	0.094
2023	0.089	0.089	0.116	0.094
2024	0.089	0.089	0.107	0.094
2025	0.088	0.088	0.098	0.094
2026	0.088	0.088	0.090	0.094
2027	0.088	0.088	0.083	0.094
2028	0.087	0.087	0.076	0.094
2029	0.087	0.087	0.070	0.094
2030	0.086	0.086	0.065	0.094

3.4. Integration of Indirect Impacts

We attempt to include indirect costs of major environmental impacts in the assessment of technology mixes. In this section we describe the data and assumptions used in estimating green-house gas (GHG) emission factors and direct loss of land attributed to different technologies.

3.4.1. Emission Factors

Generator-specific emission rates for conventional generation in Sarawak was obtained from CDM studies on Sarawak's commercial grid (GreenTech Malaysia, 2011, 2013). These studies report rates that are similar to average US generation emission rates from NREL reports (Black and Veatch, 2012) (Figure 8). We use the NREL emissions rates and heat rates for analysis purposes (Table 4). For Palm Oil biomass technologies we take heat rates from SEB ("Sarawak Energy," 2013b). Emission rates for EFB biomass gasification plants are averaged across local CDM biomass project reports (Kina Biopower, 2012)(Seguntor Bioenergy, 2012). An emission rate for POME methane capture plants is taken from (Harsono, Grundmann, & Soebronto, 2014). We choose US $10/tonne $CO_{2\text{-eq}}$ as the emission cost and increase this cost to US $25/tonne $CO_{2\text{-eq}}$ during sensitivity analysis. These carbon price points are taken from EIA outlook scenarios (U.S. Energy Information Administration, 2013).

Estimating emissions from hydroelectric generation is still an evolving field. There is however broad consensus among the scientific community that methane is the main GHG species of concern for freshwater reservoirs (International Hydropower Association, 2009, International Hydropower Association, 2010). Major emission pathways for fresh water storage reservoirs include diffusion of dissolved gases at the air-water surface, methane emission from organic matter decomposition, and downstream dam emissions from degassing at turbine and spillway discharge points (Demarty & Bastien, 2011). Especially given the global warming potential of methane, reliable estimation methods are necessary, however the rate of emission is highly variable, being related to age, location biome, morphometric features and chemical status (Barros et al., 2011). Preliminary emissions estimates for dam reservoirs in Southeast Asia are still emerging (Chanudet et al., 2011).

As net GHG emissions cannot be measured directly, their value is estimated by assessing total (gross) emissions in the affected area and comparing the values for pre- and post-impoundment conditions based on reservoir age, mean annual air temperature, mean annual runoff and mean annual precipitation (International Hydropower Association, 2010, p. 3). For our purposes we employ the International Hydropower Association (IHA) GHG Measurement guidelines and GHG Risk Assessment tool which estimates gross GHG diffusive fluxes of methane and carbon dioxide from a fresh water reservoir based on limited and available field data (International Hydropower Association, 2009).

The tool requires values for the following parameters: reservoir age, mean annual air temperature, mean annual runoff and mean annual precipitation. For a description of the IHA model see (International Hydropower Association, 2009, p. Annex 2). The results from the IHA Risk Assessment Tool are the predicted annual gross carbon dioxide and methane fluxes and their associated 67% confidence intervals over a 100 year period (Figure 8). Across the SCORE reservoirs average initial emission rate is predicted to be 72.92 $lbCO_{2\text{-}eq}$/MWh while the average long term emission rate is 52.84 $lbCO_{2\text{-}eq}$/MWh.

A number of studies are currently furthering our understanding of the contribution of methane emissions. Deshmukh et al. in (Deshmukh et al., 2014) study the Nam Theun 2 Dam in Laos and find that methane ebullition may contribute 60-80% of total emissions from the surface of a dam reservoir, suggesting that ebullition may actually be a major methane pathway for young tropical reservoirs though little considered in current estimations. Yang et al. in (Yang et al., 2014) collate the recent progress in estimating dam emissions across the tropics. Taking these higher estimates into consideration we observe the effect of high estimates for dam emissions on our model through sensitivity analysis.

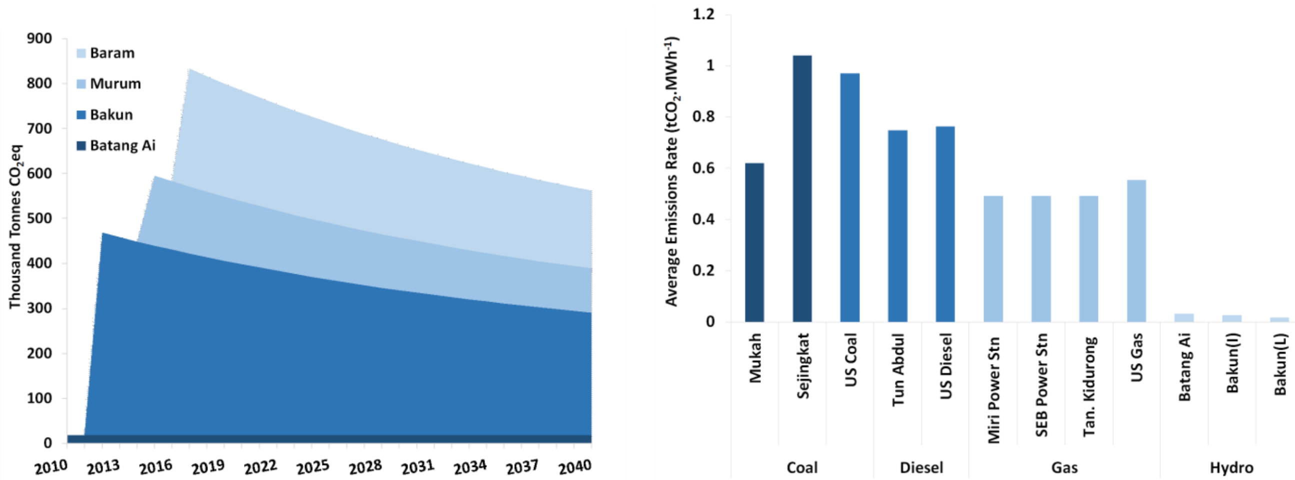

Figure 8 (a) Results from IHA GHG Assessment Tool for SCORE Dams; (b) Average Emissions Rate from various technologies

3.4.2. The Value of Forest Lands and Services

The Bornean economy is highly dependent on its natural capital despite the fact that resource rents are rarely collected and the cost of negative impacts commonly externalized. Recent literature highlights the importance of valuing the benefits that ecosystems provide though there is much debate surrounding the cost values attributed to such services (Fisher, Edwards, Giam, & Wilcove, 2011; Porras, I., Barton, D.N., Miranda, M. and Chacon-Cascante, A., 2013; Tobias & Mendelsohn, 1991). Alongside the environmental services that forest land provides - including carbon storage, protection of watersheds, provision of non-timber forest products and ecotourism - there is also a growing awareness of the role of biological diversity in the providing distinct ecosystem goods and services (Gillison & Liswanti, 2004; Norris, 2012; Swift, Izac, & van Noordwijk, 2004; Tomich, Thomas, & van Noordwijk, 2004).

This field of study is particularly relevant for Borneo, identified as a global biodiversity and evolutionary hotspot. Borneo's forests house the highest level of plant and mammal species richness in Southeast Asia (de Bruyn et al., 2014; Struebig, Wilting, et al., 2015). Accelerated efforts to conserve Borneo's forests are therefore critical in the face of unabated commercial logging and agricultural expansion as the size and quality of remaining forests deteriorates rapidly (Mittermeier et al., 2005; Pei Ling, 2013). Emerging literature establishes the importance of protecting both primary and degraded or logged forests for conservation and preserving ecosystem service value (Edwards et al., 2011; Fisher et al., 2011). (Edwards et al., 2011) compare the species-richness of once and twice logged forests in the neighboring state of Sabah, Malaysia and find degradation to have little impact on bird diversity.

Generation technologies affect ecosystem service provision in different ways. While high land intensity technologies have a large impact through direct land clearing, other technologies have more diffuse impacts on water quality or air quality, which indirectly affect services (Ingram & Hong, 2011; McDonald, Fargione, Kiesecker, Miller, & Powell, 2009). A full discussion of the impacts on biodiversity and ecosystem service from generation technologies is beyond the scope of this chapter. We estimate the area of forest land that would be directly affected by land clearing for technology development. We then incorporate the cost of direct forest land loss using land value estimates taken from the 2012 WWF Heart of Borneo (HoB) Study (van Paddenburg, Bassi, & Cosslett, 2012).

The HoB study used a non-linear macroeconomic system dynamics model to show that shifting toward a green economy can promote faster long term economic growth for Borneo, as land use trends are tightly coupled with social and economic drivers. The authors provide estimates for the value of different ecosystem services from forested areas in Borneo (van Paddenburg et al., 2012). They find the estimated forest land value (including primary, secondary, swamp and mangrove forests) to be US$900 ha^{-1} $year^{-1}$ over the past decade and project a doubling by 2030. This is based on estimates of the weighted average potential profit from different land uses. By combining this with land intensity for generation types from literature (ha/kW) (McDonald et al., 2009) we apply an annual Forestland Value charge ($/kW-$year^{-1}$) to our least cost optimization to account for direct land loss (see Table 4).

3.5. Results and Discussion

3.5.1. Scenarios

As discussed we analyze four different demand forecasts: (i) BAU, (ii) 7% growth, (iii) 10% growth, and (iv) SCORE Projection (see Section 3.2 for an explanation of demand forecast). We also design policy scenarios to observe the effect of policy instruments relative to the mega-dam strategy. The scenarios modeled are:

1. The 'Reference' scenario, where we commit the generators that are currently on the SEB grid including the Bakun Dam. We do not commit (i.e. force) any other mega-dam projects;

2. The 'SCORE' scenario where the Bakun dam and the two dams currently under impoundment or construction (Murum and Baram) are built along with 7GW of other hydroelectric power;

3. The 'Feed-in-Tariff' scenario where the SEDA approved FiT rates in effect across Peninsular Malaysia and Sabah are applied to their respective renewable technologies in Sarawak;

4. The '20% 2020 RPS' where a 20% generation-based Renewable Portfolio Standard is implemented.

In all scenarios other than the SCORE scenario, generators are committed according to the standard optimization function for least cost. In SCORE the Bakun, Baram and Murum dams must run after their completion. We are interested in system cost, system reliability and environmental impact through emissions and land loss (Figure 10). We address each of these criteria incrementally. We optimize for least cost, then impose a reliability constraint into the linear program and then include emissions costs and PES costs. We observe the impact of these costs across policy scenarios and through further sensitivity analysis.

Table 4 Power Plant Parameters used for Optimization Modeling (data from NREL and the HoB)

Power Plant Type	Heat Rate (Btu/kWh)	Emissions Production Rate (lb/MWh)	Build Cost ($/kW)	FO&M Cost ($/kW-year)	VO&M Cost ($/MWh)	2015 Forestland Value Charge ($/kW-year)
Coal	9370	2291	2890	23.0	3.7	6.8
New Coal	9370	2291	2890	23.0	3.7	0
Gas	6705	1080	1230	6.3	3.6	10.7
New Gas	6705	1080	1230	6.3	3.6	0
Diesel	10991	1647	917	6.8	3.6	7.8
HEP Batang Ai	0	72	3870	15.0	10	21.9
HEP Bakun	0	36	3870	15.0	10	21.9
HEP Baram	0	92	3870	15.0	10	21.9
HEP Murum	0	44	3870	15.0	10	21.9
HEP Other	0	69	3870	15.0	10	21.9
Oil Palm Biomass	10625	500	3830	95.0	15	375
POME Plant	9480	200	3030	120.0	15	375
Run Of River	0	0	1300	10.0	10	0
Solar PV	0	0	2357	48.0	0	9.5
Wind	0	0	2213	39.6	0	22.1

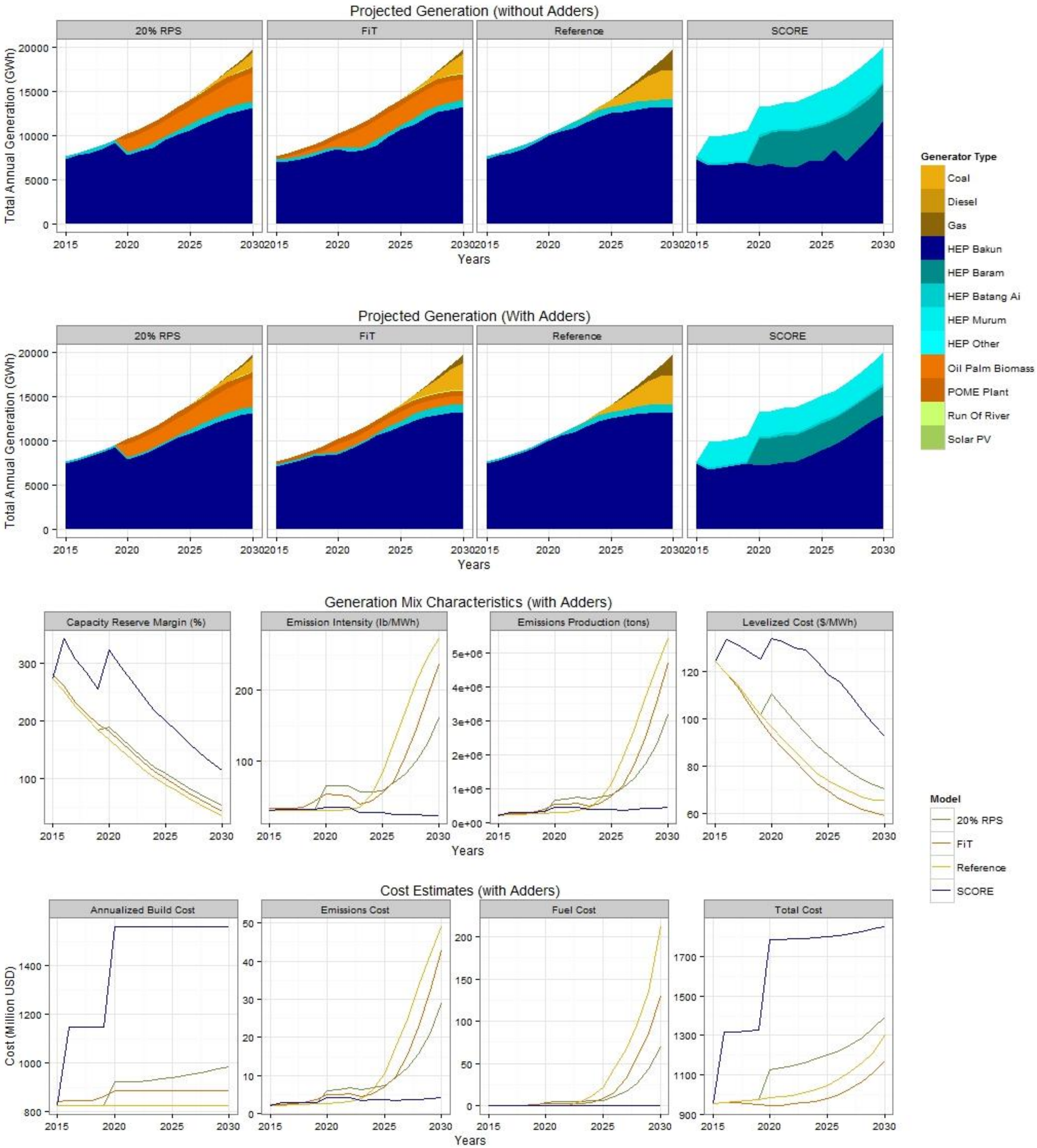

Figure 9 Generation Profile, Cost Components and Generation Characteristics of Scenarios under 7% Demand Growth

3.5.2. 2030 Energy Scenarios

We find that Sarawak's current installed capacity including Bakun already exceeds expected demand in 2030 under the BAU growth assumption. So there is no additional build out and no investment differences across policy scenarios under the BAU growth forecast. We focus here on the 7% and 10% growth forecasts, which are highly ambitious yet plausible. All results for the 7%, 10% and SCORE growth forecasts are found in the Supporting Information (SI). See Appendix B for all PLEXOS results across these four scenarios.

Demand Forecasts	Scenarios	Priorities	Sensitivity Analysis
BAU Growth	20% 2020 RPS	Least Cost	Emission Pricing Scheme
7% Growth per annum	Feed-in Tariff	Minimum Reserve Margin	Emission Production Rates
10% Growth per annum	Reference	GHG Emissions Cost	Technology Build Costs
SCORE Forecast	SCORE	Forestland Value Adder	Land Limits

Figure 10 Levels of Variability in Analysis

3.5.3. Examining Scenarios Under 7% Demand Growth

The model results show that there are a number of alternative capacity expansion choices that meet future demand at this growth rate. Under a 7% growth forecast energy demand grows to a peak demand of 2730 MW in 2030 (20,000 GWh/year in 2030). In the Reference case under 7% growth we see that current generation capacity – comprised of the two existing dams (Batang Ai and Bakun) and recently installed combined gas and coal-fired generators - are sufficient to meet future demand. In the SCORE scenario where the Bakun, Murum and Baram dams are built and committed, we see that these three dams meet future demand with a large excess of undispatched energy as noted by the Capacity Reserve Margin (Figure 9). The other cases show that local resources including solar PV, biomass gasification and POME conversion can all contribute to future demand as well. Both the FiT Scenario and the 20% 2020 RPS Scenarios call for the build out over 450 MW of biomass waste capacity.

We consider the additional cost of environmental impacts including GHG emissions and direct loss of forest land. We apply the emissions factors discussed in Section 3.5.1 and assume that a carbon price of \$10/tonne $CO_{2\text{-eq}}$ is applied in 2015. A charge based on Forestland Value is applied as a fixed charge per kW-year as described in Section 3.5.2. We find that inclusion of the carbon adder changes the optimal configurations selected while the land value adder has little significant impact on the choices made. Emissions cause total annual cost in 2030 to be 4% greater for the SCORE scenario while increasing the total cost by a much larger margin for other scenarios. The FLV adder causes no observable change in any cost property for any scenario. Inclusion of the environmental cost adders also causes fuel switching: the 20% 2020 RPS scenario again build out 490 MW of biomass gasification and POME biogas capacity while the FiT scenario switches to 596 MW of Solar PV.

When both environmental adders are included the SCORE scenario has a higher total cost and a higher levelized cost than all other scenarios. While it has a low fuel cost and emissions cost, the high annual build cost and associated fixed costs are high. This is because the system is over-built. Building three dams causes the Capacity Reserve Margin to rise to over 300%

and the reserve margin stays well above 100% in 2030, much higher than the 15% minimum constraint imposed. The SCORE scenario has 6 GW installed capacity by 2030, almost 33% greater than any of the other scenarios which each have roughly 4 GW installed. Nevertheless, the SCORE scenario has one of the lowest emissions production and emission intensity rates. The overall total cost per year is quite similar across the other scenarios, though the various cost components differ. We find the Reference and FiT scenarios have the lowest total cost and levelized costs across the fifteen year time horizon.

3.5.4. Examining Scenarios Under 10% Demand Growth

Under a more aggressive 10% growth forecast, energy demand peaks at 3635 MW in 2030 (30,000 GWh/year). The resultant energy matrix varies more than under the 7% growth scenario as a significant amount of new capacity is required to satisfy the higher demand growth. Unlike in the 7% growth scenarios, we find additional natural gas capacity is built in every scenario other than SCORE, where again the three dams and existing coal and gas are already sufficient installed capacity. In the 20% RPS and FiT scenarios non-conventional sources, including biomass gasification and POME biogas capacity are called upon. In both of these scenarios all potential Run of River hydro and significant amounts of PV (50MW and 100MW respectively) are also chosen. In each of the four scenarios total capacity is built to over 5 GW and by 2030 the Capacity Reserve Margin of each scenario is between 20-30%.

The inclusion of the carbon adder has a greater impact at this growth rate, increasing the cost of the SCORE Scenario by 11% and the total cost of other scenarios by as much as 23%. However the emissions intensity, total emissions production and emissions cost of the Reference scenario meets that of SCORE by 2030. The FLV adder is again largely insignificant. When both environmental adders are included under 10% growth we find the overall total cost under different scenarios is quite similar. As some amount of natural gas and coal is required in each scenario, the fuel cost, the emissions intensity, production and cost are more similar here than under the 7% growth assumption. The SCORE scenario is marginally more expensive than others while the FiT scenario is again the least expensive by a significant margin. While build cost for SCORE is still higher, the fuel, fixed O&M and emissions costs for the other scenarios increase due to the additional capacity requirements. See Appendix B.

It should be noted that these levelized cost values are much higher than the 2012 reported SEB average generation cost of $0.047/kWh (Energy Commission, 2012a). Likewise the emissions rates are much lower than reported through CDM (see Section 3.5.1 above) where total 2011 emissions were 5.48 million tonnes with an intensity of 1898 lb/MWh. The shift in primary generation from gas and coal to hydropower significantly lowers the emissions of the entire system. Mega-dams represents 76% and 64% of total generation for the Reference scenario under 7% growth and 10% growth respectively.

Note here that we ran a fifth scenario, called the 'Low Conventional Fuel Price' scenario where we assumed lower gas, diesel and coal prices in the future according to the EIA's Low Fossil Fuel Cost projections (U.S. Energy Information Administration, 2013). However the resultant matrices under this scenario were identical to their respective Reference scenarios, showing fossil fuel cost to have limited impact on selections. As such we do not include this scenario in the results description.

3.5.5. Sensitivity Analysis

We describe here the impact of various sensitivity analysis tests on the generation matrix and cost results obtained by running the models with different discrete parameters. We describe results for the impact of sensitivity on the 7% growth scenarios while the results of all other Sensitivity Analysis runs can be found in Appendix B.

Sensitivity to Carbon Pricing ($25/tonne $CO_{2\text{-}eq}$): When we apply a higher carbon price there is little change to the generators selected except that new coal switches to gas, and gas takes up a larger share of the matrix in each scenario. With regard to emissions production however, the effect of the change in pricing is significant. While SCORE total emissions do not change, the FiT, 20% RPS and Reference scenario emissions all decrease by more than 30% by 2030. This decrease likely comes from switching coal to gas. Despite reducing emissions production, the emissions cost and thus the total annual system cost in these scenarios still increases over the horizon (by about 10% each). Thus the Carbon Pricing Scheme would have impact on the proportion of conventional fuels selected.

Sensitivity to Hydro emission factor: When we double the hydropower dam emissions factor there is minimal effect on the generators selected in the 7% growth scenarios. However it does double the total emissions produced every year of the time horizon under the SCORE scenario. It also significantly impacts emissions for the other scenarios, though to a lesser extent. High hydro emissions cause the total cost of both the Reference and SCORE scenarios to double while increasing total cost under FiT and 20% RPS by more than 75% each. We find that because emissions cost accounts for such a large proportion of the total annual system cost, the dam emissions factor is very essential to future energy planning if the cost of GHG emissions are to be internalized. This is one of the parameters with most uncertainty.

Low Renewable energy Technology (RET) Prices: We test the impact of reducing the RET build costs (Biomass: $1500/kW; POME: $2000/kW, Solar PV: $1100/kW and Wind: $2210/kW). This changed the resulting generation matrix in the FiT scenario, which called on as much Palm Oil Biomass generation and PV generation as possible, with no conventional generation chosen. Subsequently, the total emissions did not change for any of the scenarios other than FiT, where total emissions in 2030 were almost 60% lower than normal, due to the switch away from fossil fuel sources. The total cost also did not change for scenarios other than the FiT, where the total annual system cost declined every year and was almost 30% of the original by 2030.

Biomass limited by palm oil moratorium: While the SCORE development plan includes doubling palm oil plantation acreage to 2 million hectares by 2020 ("RECODA," 2015), there is significant opposition to this plan amidst international environmental pressure to place moratoriums on palm oil expansion into high-carbon forest areas. In 2011 for instance, Indonesia decreed a 2 year moratorium on the issuance of forest licenses for logging and palm oil, though the transparency of enforcement has been brought into question (Sloan, 2014). Using palm oil waste for electricity potential may present a perverse incentive to intensify palm oil production or increase forest land conversion.

We therefore also tested a scenario where the total Palm Oil Biomass waste available for biomass gasification and POME capture is limited by a moratorium that caps the total area of land cleared for plantations to one million hectares. In effect this means no future palm oil expansion. Such a moratorium would involve strict zero deforestation sourcing regulations and enforcement mechanisms. These policy tools exist in practice today though with varying degrees of success (Lambin et al., 2014). We find that this policy effectively halves the total amount of generation potential from either biomass source. The impact is only felt on the 20% RPS and FiT scenarios where biomass waste capacity is then replaced by larger capacities of solar PV.

3.5.6. Limitations

A number of limitations impact our modeling approach. As described in Section 3.1, we chose to use a deterministic optimization for the LT capacity expansion plan which uses expected values for variable inputs. Stochastic programs have greater capability in handling uncertainty as they assume that the probability distributions governing data are known. The differences and trade-offs between these two modeling approaches are well described in the literature (Wallace & Fleten, 2003). Given that our aim is to generally observe the feasibility of alternative generation technologies, we opt for deterministic optimization as it greatly reduces the number of constraints observed and simplifies the model. However future studies that employ a stochastic approach would be very useful in yielding specific policy and strategy suggestions for Sarawak's electric utility operation.

Another inherent impact of this decision is that, without stochasticity we do not observe the impacts of random outages on the system. Thus our metric for system adequacy is the satisfaction of a zero unmet load constraint. Observation of higher resolution metrics for system reliability, such as Loss of Load Probability (LOLP) or Loss of Load Expectation (LOLE), will be possible in future studies where the stochastic approach is used. These metrics will be useful for operation decisions and management.

In our LT plan we also opted to use a non-chronological LDC method rather than a chronological method. There is a spectrum of general methods for integrating non-dispatchable technologies into capacity expansion modelling. Trade-offs between fine and coarse spatial and temporal resolution requirements make different choices applicable for particular applications (Blair et al., 2013). Given the data limitations we use a LDC method for aggregating time blocks combined with least cost dispatch and augmented with reliability constraints. This method does not include start-up costs, ramping constraints, minimum turndown or other system considerations, and so is an approximation of unit commitment.

As we have shown, this first order approximation is nevertheless very useful for estimating the impact that various investments may have, including fuel savings, emissions reductions and shifts in generation mix to different types of capacity (e.g. between base, intermediate and peak-load capacity). PLEXOS is a detailed operational program that can be expanded to include production cost modeling and chronological optimization. Future work will involve expanding our model to take advantage of these capacities as utility data becomes available.

We have noted the limitations of data availability in our case study. For instance, our demand forecast is based on hourly data for neighboring states from the Energy Commission since Sarawak generation data is not publicly available. Where local data for costs and emission factors were not obtained, values from well accepted authorities such as the EIA and the IEA were used which adds an element of uncertainty to results. As mentioned we do not include the impact of specific generator ramp rates, start up and shut down costs or minimum down and up time due to lack of data. However as data or credible estimates become available these can be easily added to the model in future revisions to increase the number of operation variables considered.

The lack of data on river flow rates for the respective rivers impounded by the SCORE dams was also a significant factor limiting our ability to model hydro-thermal interactions at high temporal resolution. We provided the model with seasonal maximum and minimum output constraints in lieu of extensive stream flow data and intend to revise the model as data from Bakun's operation becomes available from the relevant utilities. This will be an important improvement as hydropower may have a future role to play in balancing variable generation.

Finally, we faced a number of limitations in attempting to incorporate indirect environmental impacts into the economic cost framework. The $/kW-year^{-1} Forest Land Value applied is understandably not a direct metric for either biodiversity or ecosystem service value. Services such as flood risk mitigation and watershed function or biodiversity services are not included in this land value. Without further economic valuation studies, it is difficult to include the impacts of other indirect land use impacts such as air or water pollution in the model.

The HoB study mentioned earlier (van Paddenburg et al., 2012) is the most recent attempt to quantify the localized economic value of natural capital and discuss avenues for its incorporation into mainstream decision making. HoB uses a non-linear macroeconomic system dynamics model to show that land use trends in Borneo are tightly coupled with social and economic drivers and estimates the net present value of natural capital stocks under different development scenarios (green economy vs BAU). Further ecological economic studies that disaggregate ecosystem services and assess value are critical for the conversation on development pathways.

3.6. Discussion and Conclusions

Our application of a capacity expansion methodology has implication for many other regions where the need for assessment of alternatives to large-scale energy infrastructure may exist. The Lower Mekong River Basin for instance, is currently undergoing massive hydropower development. The transboundary basin passes through Myanmar, Lao, Thailand, Cambodia and Vietnam. It is home to a large rural population of more than 40 million people and is the site of one of the biggest inland fisheries in the world, making infrastructural development in the basin both an important food security concern for these countries and a major biodiversity priority more globally (Ziv, Baran, Nam, Rodríguez-Iturbe, & Levin, 2012).

Similar large-scale energy infrastructure projects are under way across Africa and Latin America commonly rationalized through the discourse of national energy security (Green et al., 2015; Simpson, 2007). Such projects are often characterized by information shortage, a lack of rigorous analysis on the assumptions of demand, and narrow definitions of cost that impede broader evaluation of risk and tradeoff. Here we demonstrate a simple and effective framework for assessing critical assumptions embedded in energy-infrastructure development strategy while also providing directionality for appropriate solutions.

The method we present explores potential paths of least cost capacity expansion over a fifteen year period in Malaysian Borneo where cost includes indirect environmental costs of greenhouse gas emission and direct land loss. We also observe the effects of different possible policy and market conditions including low fuel costs, high and low RET build costs and the implementation of renewable energy incentive schemes. We find that the Bakun Dam itself can provide more than 10,000 GWh per annum. Under a 7% electricity demand growth assumption, this represents half of expected demand by 2030. Even under the more aggressive 10% growth assumption, Bakun alone will satisfy a third of demand in 2030. Completion of the two additional dams currently under construction (Murum and Baram) would oversupply 2030 demand under 7% growth, leading to a large excess capacity, and would require a marginal amount of additional generation under 10% growth.

These results highlight the gross overestimation of generation capacity required to satisfy high expectations of growth. Similar study could be very useful for public conversation in other energy megaproject debates across the developing world. The modular design of PLEXOS allows for consideration of cascading hydropower systems, where multiple dams are built within the same river system, as well as the exploration of hydro-thermal interactions. These capabilities would be very useful in contexts like the Mekong Basin hydro developments which include a series of main-stem and tributary dams (Ziv et al., 2012).

We also find that distributed solar and biomass waste technologies can contribute significant capacity to the state's energy portfolio. These findings are consistent with other studies that find solar and biomass waste to be effective solutions for Borneo given their large resource potential (Agensi Inovasi Malaysia, 2011; Shuit et al., 2009; Sulaiman et al., 2011; Sumathi et al., 2008). In our model these technologies become cost effective only under incentive schemes such as an RPS or FiT. This supports the case for incentivizing and formally incorporating SPPs into energy infrastructure development plans.

In fact, small renewable energy power production was a large part of Malaysian energy policy in the early 2000s and was the cornerstone of the country's Firth Fuel Diversification Plan and featured prominently in the Eight Malaysia Plan (Sovacool & Drupady, 2013). The Small Renewable Energy Program (SREP) was established in 2001 to tap into waste fuels from the palm oil industry and to stimulate local innovation and capacity through grid-connected SPPs of less than 10 MW. The SREP's 500 MW goal was scaled back to 350 MW of renewable energy technology installed by 2010, and has yet to be met. The SREP was revised on multiple occasions to increase tariffs offered to SPPs but this did not accelerate participation in the program. In 2011 SREP was suspended and has been replaced by the SEDA FiT mechanism.

Independent studies cite high risk premiums for financing and bureaucracy of the application process as reasons for the slow growth of the Malaysian renewable energy sector (Sovacool & Drupady, 2011; Chua et al., 2011; Hashim & Ho, 2011; Maulud & Saidi, 2012; Sovacool & Drupady, 2013). Along with investment transaction costs, technical integration issues and poor policy design, a lack of local capacity is frequently cited as one of the largest barriers to renewable energy development in Malaysia (Verbruggen et al., 2010).

Nevertheless, regional and local successes with PV and biomass waste technologies (such as Kina BioPower and TSH Bioenergy Sdn Bhd in Sabah) demonstrate the potential for deployment. This challenge thus presents an opportunity for diversification of the labor market. This is in line with the Tenth Malaysia Plan which calls for increased technical and vocational training for the labor workforce ("Tenth Malaysia Plan," 2014). Beyond knowledge capacity, integration of decentralized energy solutions involves more detailed discussion on regulation, financing, incentives, purchase agreements and payment structures, permitting, licensing, quality of service standards and more. While this discussion is outside the scope of this chapter, resources such as (Tenenbaum et al., 2014) detail best-policy practice for integration of SPPs.

Our study is the first instance of a commercial energy model being applied to SCORE, and one of the first instances of PLEXOS being used in Southeast Asia in the academic literature. Our study represents an important contribution to the public conversation by demonstrating a framework for integrated analysis despite data constraints. Many further studies on socio-cultural and ecological impacts are urgently needed. However, using Sarawak as our case study, we demonstrate the potential for effective energy analyses in the information-scarce contexts where many large-scale energy projects are now emerging. Future work will involve data collection to simulate hydropower operation at higher resolution and observe its interactions with variable generation.

CHAPTER FOUR
Estimating biodiversity impacts without field surveys: A case study in northern Borneo

4.1. Introduction

The increasing rate of global land use change has generated significant interest in understanding how land conversion affects human communities and natural ecosystems. Along with direct ecosystem services such as carbon storage and watershed quality, there is a growing awareness of the potential importance of biodiversity in the provision of ecosystem goods and services (Mace, Norris, & Fitter, 2012; Myers et al., 1997).

Although natural processes, planning and management activities, and ecosystem service provision often occur at landscape scales, there is relatively little empirical data on biodiversity at this scale, leading to a significant gap in the information available to policymakers who are tasked with balancing tradeoffs between global environmental concerns and national development objectives (Jetz, McPherson, & Guralnick, 2012; Rands et al., 2010; Tomich, Noordwijk, & Thomas, 2004; Tomich, Thomas, et al., 2004). In many cases, for example, little information is available on the potential biodiversity losses associated with planned development projects, leaving the impacts of these projects uncertain and largely hidden from the public. This issue is particularly acute in low income nations where much land use change is occurring and where financial and logistical challenges combine to limit empirical data collection.

In the absence of direct empirical data, two broad classes of approaches, top-down and bottom-up, can be used to bridge this information gap and provide landscape-scale information on potential biodiversity impacts. The first approach relies on large-scale maps of species occurrences, generated via expert assessment, atlas data, or species distribution models, across a region containing the site of habitat loss. Such maps can be used directly to estimate the number and identity of species whose ranges overlap with the site of habitat loss (Finer, Jenkins, Pimm, Keane, & Ross, 2008; Kitzes, 2012) or as an input into algorithms that support managers and policy makers in evaluating the biodiversity loss associated with different planning scenarios (Ball, Possingham, & Watts, M, 2009; Sarkar et al., 2006). These maps, however, are only available for well-studied taxa, such as birds and mammals, and do not generally provide information on the impacts of habitat loss on species populations.

In contrast, the bottom-up approach relies on the availability of high quality small-scale data, such as complete censuses of all of the species in a small plot that is "upscaled" using statistical or theoretical scaling relationships. For example, the species-area relationship (SAR), which can be used to estimate changes in species richness with changes in area (Rosenzweig, 1995), is frequently used for estimating potential diversity and extinction rates in un-censused areas (May, Lawton, & Stork, 1995).

These applications of the SAR, however, are less straightforward than commonly assumed, as complexities such as the appropriate functional form of the relationship, habitat geometry, complex patterns of habitat loss, and species overlap between multiple patches must be carefully considered (Ney-Nifle & Mangel, 2000; Seabloom, Dobson, & Stoms, 2002; Tjørve, 2003; Sizling, Kunin, Sizlingová, Reif, & Storch, 2011; Harte & Kitzes, 2011; He &

Hubbell, 2013). Additionally, the most widely used equation for the SAR, a power law, has come under increasing criticism from several empirical and theoretical angles (Dengler, 2009; Harte, Smith, & Storch, 2009; McGlinn, Xiao, & White, 2013). More recently developed and better tested scaling theories have not yet been integrated into applied ecology.

In this chapter I present on research that I conducted with Dr. Justin Kitzes, specialist in ecological modeling. We use a combination of top-down and bottom-up methods to estimate the biodiversity impacts associated with habitat loss due to three large hydroelectric dams in the state of Sarawak in northern Borneo. Our approach goes beyond simple species counts to estimate three distinct measures of biodiversity impact for each dam and all three dams together: the number of affected species, number of local extinctions, and number of lost individual organisms. The number of lost individuals is important both directly as a measure of decreased species abundances as well as indirectly as a proxy for the number of lost demographic or genetically distinct populations within species (Ehrlich & Daily, 1993; J. Hughes, Daily, & Ehrlich, 1997).

These estimates are completed for four taxonomic groups: mammals, birds, trees, and arthropods. Top-down methods are applied to the relatively well-studied mammals and birds and bottom-up methods to trees and arthropods. While the predictions from these indirect methods are necessarily uncertain, this approach provides the best available means of estimating biodiversity impact when field surveys prior to habitat loss are not available. Dr. Kitzes was responsible for the bottom-up estimations of impact to trees and arthropods using macroecological scaling laws.

4.2. Methods

4.2.1. Study site

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 (International Energy Agency, 2013; OECD, 2013). The "mega-dam" in particular has returned to public planning policy as a solution to increasing energy demand in the region, with many new dams currently under construction across Laos, Thailand and Cambodia (Goh, 2007). This trend extends to Malaysia, one of the fastest growing economies in Southeast Asia, where part of the federal government near-term economic growth strategy (the Tenth Malaysia Plan) involves building at least twelve mega-dams in the state of Sarawak to attract energy-intensive industry and stimulate local production (Choy, 2004, 2005; Sovacool & Bulan, 2011a).

The state of Sarawak, located along the northern coast of the island of Borneo, is the poorest and most rural state in Malaysia. This area 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, with three major dams already under different stages of development (Sovacool & Bulan, 2012a). In 2012, the 2400 MW Bakun dam became operational, and as of 2014, the reservoir for the 944 MW Murum dam is being filled.

Access roads for the 1200 MW Baram dam have been cleared, although preparatory construction work has remained stalled since 2013 due to road blockades and protests from local NGOs (Lee et al., 2014). In addition to displacing 30,000–50,000 indigenous people, the development of the twelve mega-dams would result in at least 2,425 km^2 of direct forest cover loss (Bruno Manser Fonds, 2012). The three initial dams discussed above, whose reservoirs will together flood an expected total area of 1,354 km^2 (700 km^2 for Baram, 242 km^2 for Murum, 413 km^2 for Bakun), are the focus of our analysis.

The island of Borneo, part of the Sundaland biodiversity hotspot Myers2000, is notable both for its high levels of biodiversity and highly threatened natural ecosystems (Brooks et al., 2006; Koh et al., 2013; Sodhi et al., 2010). Borneo's forests house the highest level of plant and mammal species richness in Southeast Asia (Bellard et al., 2014), including 581 species of birds and 240 species of mammals, and the island is considered a major evolutionary hotspot (de Bruyn et al., 2014). Extensive development has led to significant land cover change on the island, with 389,566 km^2, approximately 53% of the total area of the island, remaining under forest cover (Gaveau et al., 2014).

4.2.2. Birds and mammals

For birds and mammals, global range maps were first used to determine the species that were potentially found in the three reservoir areas prior to inundation. Species extinctions were then estimated conservatively as the number of species whose entire range was lost due to reservoir inundation (we show below that the relatively small areas of the three reservoirs are expected to lead to no extinctions for these taxa). Finally, published population densities and allometric scaling relationships were used to estimate the number of individual organisms in each taxa that were likely lost due to reservoir inundation.

4.2.2.1. Species affected

To estimate the number of species affected by dam construction, global range maps for birds were requested from Birdlife International (Birdlife International, 2011) and global range maps for mammals were obtained from the IUCN (IUCN, 2014). For both birds and mammals, species ranges were filtered to include only those with Presence code 1 or 2 (Extant and Probably Extant), Origin code 1 (Native), and Seasonal code 1 (Resident). These range maps were clipped with polygons representing the expected reservoir inundation areas for the three dams, obtained from the Sarawak Geoportal published by BMF ("Sarawak Geoportal," 2015), and the species found within each dam area identified and counted.

4.2.2.2. Extinctions

The number of determined extinctions due to reservoir inundation was calculated conservatively as the number of species whose ranges are completely overlapped by the reservoir areas. As a fractional loss of range, however, may still contribute to extinction risk for individual species e.g.(Kitzes & Harte, 2014; Thomas et al., 2004), these fractions were also examined for all affected bird and mammals species.

4.2.2.3. Individuals lost

For birds, a central estimate of the total number of lost individuals across all species was estimated by multiplying reservoir areas for each dam by an estimated typical bird density of 2,500 individuals per km^2 (Gaston & Blackburn, 2000) for tropical forest. For mammals, the number of individuals lost for each species was estimated by multiplying the area of a species' range intersecting the reservoir area for each species by an observed or estimated population density for that species. Where available, observed densities were drawn from the PanTHERIA database (Jones et al., 2009). Where observed density was not recorded in PanTHERIA but adult body size data were available, population density was estimated from a log-log linear regression of body size on observed population density for those species with both density and body size data in the PanTHERIA data set. The regression can be seen in the Supplementary material that accompanies our published article (Kitzes & Shirley, 2015).

We note that while specific individuals present in the reservoir area during inundation may be able to migrate to avoid immediate death, the long-term abundance of both groups is presumed to be proportional to resource availability and hence habitat area. Any migrating individuals are thus not expected to permanently increase population densities surrounding the reservoirs.

4.2.3. Trees and arthropods

For trees and arthropods, range maps and atlas data are not commonly available for individual species. Our estimates of impacts for these groups are thus based on macroecological scaling laws and census data from comparable landscapes outside of the dam region.

Two macroecological scaling laws are used below: the species-area relationship (SAR), which gives the expected number of species found in a habitat patch as a function of area, and the endemics-area relationship (EAR), which gives the expected number of species within a large reference region that are found only within a smaller habitat patch of a certain area (i.e., the number of species that are locally endemic, with respect to the larger region, to the small patch). Of the many functional forms for these metrics have been proposed for these metrics, we here generate our central estimates of biodiversity impact based on particularly successful maximum entropy theory of ecology (Harte, 2011; Harte, Zillio, Conlisk, & Smith, 2008).

To predict the shapes of the SAR and EAR, this theory requires as input small-scale data from a fully censused plot, in which the total number of species, *S*, and the total number of individuals across all species, *N*, are known. As these data are not available from within the reservoir areas themselves, the best available data from comparable habitats, as described below, are used in our analysis. We note that this requirement is not unique to the maximum entropy theory, as all existing theories that estimate a number of affected species and extinctions require knowledge of *S* at some scale, and all theories that estimate the number of individuals affected require knowledge of *N* at some scale.

4.2.3.1. Census data

For trees, many complete censuses of forest plots are available throughout the world through the Center for Tropical Forest Science network ("Smithsonian Institute," 2015)(Losos & Jr, 2004). The closest censused plot to the dam region is the Lambir Hills Forest Dynamics Plot, a 52 ha mixed diterocarp forest plot in northern Borneo, which contains 1,174 species and 366,121 individual trees >1 cm DBH (Condit et al., 2000). This plot, however, is noted for its unusually high species richness due to an abrupt soil gradient that occurs within the plot, and as such the richness observed here may be larger than the expected richness at this area across the entire forested region of northern Borneo. A 50 ha plot of lowland diterocarp forest at the Pasoh Forest Reserve in Peninsular Malaysia, for comparison, contains 818 species across 320,382 individuals (Condit et al., 2000). For subsequent analysis, we take the Lambir plot to represent an upper estimate of richness and the Pasoh plot to represent a lower estimate, with the average of these two predictions at larger scales used as the central estimate.

Globally, there are very few equivalently complete censuses of arthropods (Forister et al., 2015; Novotny et al., 2006). For the bottom-up methods used in this analysis, an arthropod census must be taxonomically broad, based on indiscriminate sampling methods designed to sample arthropods with different habitat preferences, and be drawn from a complete and clearly defined contiguous area. Of the arthropod censuses conducted in Borneo ((Beck, Kitching, & Linsenmair, 2006; Beck & Ruedliner, 2014; Dial, Ellwood, Turner, & Foster, 2006; Kitching, Li, & Stork, 2001; Stork, 1991) and references therein), we are not aware of any that meet these three criteria.

The most comprehensive census of which we are aware that meets these criteria is a recent survey of lowland tropical forest in the San Lorenzo forest, Panama (Basset et al., 2007, 2012). Although there are many abiotic, structural, and taxonomic differences between this Panamanian forest and the study area of northern Borneo, we believe that this very comprehensive data set is less prone to bias in biodiversity estimation than more limited studies conducted in South Asia. To the extent that the tropical forests of Borneo are richer in tree species, for example, than similar forests in Central America, the arthropod impacts given here may be low-end estimates.

(Basset et al., 2007) sampled a total of twelve plots, each 0.04 ha in area, using a variety of census methods, not all of which were applied at all plots. For subsequent estimates, we use data from eight of these plots, excluding data from four that display undercounting of relatively abundance insect orders (Harte & Kitzes, 2015). Calculations were completed using data from all eight plots, with minimum, maximum, and mean predictions based on individual plots representing our lower, upper, and central estimated species richness at large scales.

4.2.3.2. Species affected

The number of species affected by reservoir inundation was estimated using a species-area relationship (SAR). The SAR, which describes how the number of species present changes with area, has been widely used to estimate changes in species richness due to habitat loss. To estimate the species affected by reservoir inundation, the SAR is used to upscale measured richness from the observed small-scale cenuses to predicted expected richness, prior to inundation, in an area the size of each reservoir.

The most commonly applied form of the species area relationship is a power law $S=cA^{z}$, where c is a fitted intercept, A is habitat area, and z is a constant slope often taken to be near 0.25. Given a species richness S at some small-scale A, this equation can be used to estimate richness at a larger scale as $S'=S(A'/A)^{z}$. While this power law SAR has a long history of application in ecology and conservation, ecosystems show substantial variation around the slope (Drakare, Lennon, & Hillebrand, 2006; Rosenzweig, 1995). More importantly, it was recently recognized that empirical SARs show systematic decreases in log-log slope with the mean number of individuals per species at any spatial scale (Harte et al., 2009). This pattern suggests that traditional SAR applications that use a log-log slope of 0.25 to upscale small-scale census data will almost certainly overestimate large-scale species richness.

The number of species affected by reservoir inundation was estimated using the SAR predicted by the maximum entropy theory of ecology of (Harte et al., 2008) which closely fits the empirical pattern of decreasing SAR slope at large scales (Harte et al., 2009). The iterative variant of this curve (Harte & Kitzes, 2011; McGlinn et al., 2013) which has successfully upscaled tree richness and has been applied to upscaling arthropod richness was used here. This SAR is recursively calculated at successively larger doublings of area by solving the coupled equations:

$$S(2A) = S(A)x + N(2A)x\left(\frac{1-x}{x-x^{N(2A)+1}}\right)\left(1-\frac{x^{N(2A)}}{N(2A)+1}\right) \qquad (1)$$

and

$$S(2A) = N(2A)x^{N(2A)}(-\phi(x,1,N(2A)+1)) - ln(1-x)\left(\frac{x-1}{x(x^{N(2A)}-1)}\right) \qquad (2)$$

for $S(2A)$, where $S(A)$ and $N(A)$ are the known number of species and individuals at area A and $S(2A)$ and $N(2A)$ are the number of species and individuals at twice area A. The parameter x is an unknown constant, and $\Phi(n)$ is the Lerch phi function. For values of A' falling between exact doublings of area, S' (the number of species in A') can be interpolated linearly on a log-log scale. A Python function to perform these calculations is included as Supplementary Material in our published paper (Kitzes & Shirley, 2015), and pre-calculated results for a range of parameters are included in Table S1.

An important shortcoming of the SAR is that it applies only to a single contiguous habitat area and thus cannot directly estimate the total number of species found across all three reservoir areas combined. This additional calculation requires information on the overlap in species composition between the reservoirs. Knowledge of the overlap of species between pairs of areas, known as commonality, turnover, or beta diversity, is insufficient, as the number of species in common to all three reservoirs must also be known to complete this calculation exactly. As more areas are included in a system, knowledge of increasingly higher order correlations is required (Hui & McGeoch, 2014).

In the absence of information on overlap, the total number of species affected across the three reservoirs can still be bounded (Kinzig & Harte, 2000). A low estimate presumes that the species lists across reservoirs are completely nested, such that the number of species affected by the reservoir with the highest low-end estimate of richness is equal to the total number of species affected across all three reservoirs. There are two logical approaches to generating a high estimate. First, the high estimate can be generated as the upper estimate of the number of species that would be affected by a single patch with an area equal to the combined areas of the three reservoirs.

Second, the high estimate can be generated by presuming that the species affected by each reservoir are unique, such that the total is the sum of the upper estimates of the number of species affected by the three reservoirs. In general, the lower limit is applicable when species ranges are large while the upper limit is applicable when ranges are small and endemism is high. To avoid potential overestimation, we report results from the first method for our high estimates of affected species, although results from the second method can be calculated easily by summing the individual dam results in Table 5.

4.2.3.3. Extinctions

The number of extinctions associated with the inundation of the three reservoirs can be estimated through a second application of the SAR in concert with an endemics-area relationship (EAR), which estimates the expected number of species within a large region that are found only in habitat patch of a certain area (Harte & Kinzig, 1997). In contrast to the case of birds and mammals, where global range maps allow for the measurement of global extinctions, the EAR can be used only to estimate extinctions with reference to a surrounding reference bioregion. For this analysis, the reference region is considered to be the remaining tropical forest on the island of Borneo, and our extinction estimates for trees and arthropods thus refer to extirpations of forest-dwelling species from the island. To the extent that tree and arthropod species found on Borneo are found only on the island and not elsewhere, these local extinctions will also correspond to global extinctions.

The endemics-area relationship (EAR), which gives the expected number of species found only within a small plot of area A within a large landscape of area A', can be used to estimate local extinction rates as a function of area. In any real landscape, the EAR and SAR have a necessary complementary relationship. Within a large region A', the measured number of endemics in a patch A plus the measured number of species in the complementary area $A'-A$ must sum to S', the total number of species in A' (Axelsen, Roll, Stone, & Solow, 2013; Harte & Kinzig, 1997).

There has been a recent debate over the correct use of theory-based SAR and EAR models to estimate extinction that stems from the recognition that models will not satisfy the above identity unless the geometries of lost versus remaining habitat are properly accounted for when parameterizing the two models (Axelsen et al., 2013; He & Hubbell, 2011). In general, both SAR and EAR models have been developed and tested using data from relatively regular habitat areas, and thus the EAR, applied to lost habitat, is recommended when lost habitat is contiguous and leaves a "hole" in the original landscape, while the SAR, applied to the remaining habitat, is recommended when habitat is lost at the edges of a landscape, leaving a relatively regular area of habitat remaining (Harte & Kinzig, 1997).

In the case of reservoir inundation, the habitat that is lost is small relative to the area of the surrounding region, generating a small "hole" nested within a larger landscape. The appropriate method for extinction estimation is thus to apply the EAR to the lost area. The maximum entropy theory described above also predicts a complementary EAR (Harte, 2011), which, when the area lost is small relative to the large region, can be approximated by the linear relationship:

$$E = -\frac{S^*}{ln(1-p))}\left(\frac{A'}{A^*}\right) \quad (3)$$

where S^* is the number of species in the larger region, A^* is the area of the region, and A' is the reservoir area. The parameter p is calculated by solving the implicit equation:

$$\frac{N^*}{S^*} = -\frac{1}{ln(1-p)}\frac{p}{1-p} \quad (4)$$

where N^* is the number of individuals in the larger region. This EAR equation is applied to estimate the number of locally endemic species, and hence the number of local extinctions, in each of the three reservoir areas. As the value of S^* is unknown, it is estimated as the central estimate of the SAR procedure described above with A'=389,566 km^2, the remaining forested area of Borneo. The value of N^* is similarly unknown, and is estimated by linearly scaling the measured number of individuals in the small plots N, to the area A^* (see also below). If A were not small relative to A', a numerical evaluation of the exact EAR equation would be needed in place of the above approximation (Harte, 2011).

As in the case of the SAR, the EAR alone is not sufficient to estimate the total number of local extinctions across all three reservoirs, as this metric does not consider overlap in species lists between reservoir areas (Kinzig & Harte, 2000). A low bound on the total number of local extinctions is the sum of the lower EAR estimates from the three areas, as this gives the count of species locally endemic to one of the three reservoirs. This sum ignores, however, species that are locally endemic to two or more of the reservoir areas, which would not be lost if a single reservoir was flooded but will be lost when the set of three reservoirs are created. Similar to the SAR, an upper bound on local extinctions can be estimated as the upper result from applying the EAR to a hypothetical single plot with area equal to the sum of the three reservoir areas. As Eq. (3) predicts a linear EAR, this upper bound is equal to the sum of the upper estimates for the three reservoirs.

4.2.3.4. Individuals lost

To calculate the number of individual trees or arthropods lost due to reservoir inundation, the density of individuals in small plots is scaled linearly to the reservoir areas as $N'=N(A'/A)$, where N' is the number of individuals at the reservoir area A'. This calculation presumes that the measured density in the small plot is representative of the density of all individuals, across species, in the larger region. As there are no issues of overlap associated with estimates of lost individuals, lower and upper estimates for the three reservoirs together are calculated as the sum of the lower and upper estimates for all reservoirs, respectively.

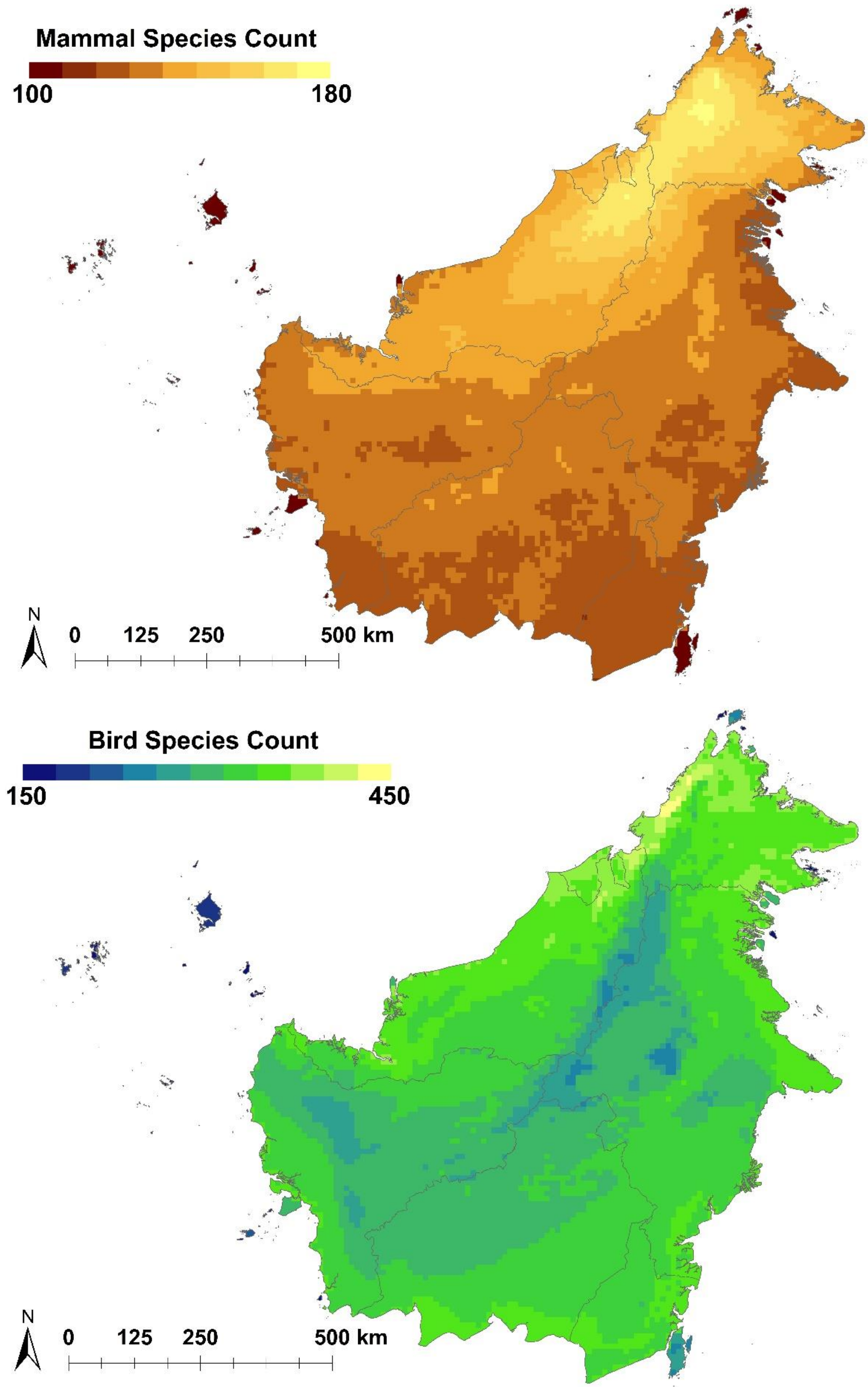

Figure 11 Species Count Results for (a) Mammals and (b) Birds within Borneo

Table 5 Species Affected and Individuals Lost by each hydroelectric plant

			Number of Species Affected		Total Number Individuals Lost (Millions)	
Dam	Status	Reservoir Area (km^2)	Birds	Mammals	Birds	Mammals
Bakun	Operational in 2011	701	302	142	1.75	55.09
Murum	Being inundated	242	312	147	0.61	19.55
Baram	Under Construction	414	318	162	1.04	35.52
Total		1357	331	164	3.39	110.16

Table 6 Break Down of all Species Affected by IUCN Classification

Code	Definition	Birds	Mammals
EX	Extinct (EX)	0	0
EW	Extinct in the Wild (EW)	0	0
CR	Critically Endangered (CR)	0	1
EN	Endangered (EN)	2	6
VU	Vulnerable (VU)	14	24
NT	Near Threatened (NT)	75	14
LC	Least Concern (LC)	240	103
DD	Data Deficient (DD)	0	16

Table 7 Global Biodiversity Impact Statistics

Statistic	Birds	Mammals
Total Number of Species Globally	10424	5513
Total Number of Species in Borneo	580	239
Number of Species Affected	331	164
Percentage Global Species Affected	3.2%	3.0%
Percentage Bornean Species Affected	57.1%	68.6%
Maximum Percentage Global Range Affected	4.7%	1.8%

4.3. Results

Top-down global range maps show that the reservoir areas overlap habitat for a total of 331 species of birds and 164 species of mammals (Table 5, Figure 11, Appendix). For both taxa, there is substantial overlap in the species affected by individual dams, with the Baram dam alone affecting 318 out of 331 bird species and 162 out of 164 mammal species (Figure 11).

With regard to extinctions, no species of bird or mammal had its entire range contained within the reservoir inundation areas. Additionally, no species of bird or mammal was found to have more than 5% of its total range located within the reservoir inundation areas, which can be presumed to represent a negligible contribution to expected species extinctions. For comparison, the IUCN Red List v3.1 requires a species to experience a minimum population reduction of 30% to be listed as Vulnerable, the least at-risk status of the three threatened categories. See Appendix C Table 1 for fraction of global range lost by species.

Using observed and estimated population density data, the three dams together are estimated to cause the loss of 3.4 million individual birds and 110 million individual mammals (Table 5). For qualitative comparison, this is more individual birds than were counted across the North American Breeding Bird Survey in 2012 (Sauer et al., 2014) and more individual mammals than the standing inventory of cattle in the United States in 2013("FAO," 2015). As the reservoir areas will remain inundated indefinitely, these figures amount to an indefinite decrease in the abundance of these taxa on the island of Borneo.

Of the 331 bird species affected by the dams, two are categorized as endangered by the IUCN (*Ciconia stormi*, Storm's stork, and *Polyplectron schleiermacheri*, the Bornean peacock-pheasant) 14 are considered vulnerable. One mammal species found in the dam region is classified as critically endangered (*Manis javanica*, the Sunda Pangolin), six species are considered endangered, and 24 are vulnerable (Table 6). These endangered mammals are the endemic Bornean Bay Cat (*Catopuma badia*), the Sunda Otter Civet (*Cynogale bennettii*), the Grey Gibbon (*Hylobates muelleri*), the Hairy nosed Otter (*Lutra sumatrana*), the Flat-headed Cat (*Prionailurus planiceps*), and the Smokey Flying Squirrel (*Pteromyscus pulverulentus*).

Bottom-up estimates based on the species-area relationship suggest that the three dam areas will affect 2,100 to 3,300 species of trees and 17,700 to 31,800 species of arthropods. As there are approximately 3,000 known species of trees that inhabit Borneo Whitmore1987, these results suggest that the dams will cause decreases in abundance for at least two-thirds of the tree species on Borneo. Results for number of species affected, extinctions and individuals lost for trees and arthropods can be found in Appendix C Table 2.

The combination of species-area and endemics-area relationships suggest that, similar to birds and mammals, there are likely to be few extinctions of tree or arthropod species due to dam inundation. Approximately one extinction is expected for tree species, and arthropod extinctions are estimated from 4-7 species for all three dams combined. Based on population density data from intensive census plots, an estimated 870-950 million individual trees and 34-73 billion individual arthropods will be lost due to reservoir inundation.

4.4. Discussion

This analysis demonstrates that the Bakun, Murum, and Baram dams impose a potentially significant impact on the biodiversity of Borneo. While the results show that few or no species extinctions are expected for birds, mammals, trees, and arthropods, many species in all four taxa are expected to experience population loss due to habitat loss. Although the reservoir areas of these dams represent only 0.2% of the total land area of Borneo, the 331 species of birds affected by the dams represent 57% of the 581 species of birds found on the island of Borneo, and the 164 species of affected mammals represent 68% of the 240 species on the island. The lower estimate of 2,100 affected tree species similarly represents approximately two-thirds of the estimated 3,000 species of trees on the island (Whitmore, 1987). The extent of these population losses range from the millions to the billions of individual organisms, depending on the taxa.

There are several important sources of uncertainty in our analysis, the majority of which suggest that the results above are likely a low-end estimate of the true biodiversity impacts of the dams. First, the application of the SAR and EAR do not account for the steeply sloping topography of the reservoir areas. Sloped areas such as these are likely to contain a greater diversity of abiotic conditions, which would lead to steeper slopes for the SAR and EAR and hence higher numbers of affected species and extinctions than predicted above. More affected species and extinctions may also be expected if this topography leads to stronger than expected dispersal limitation, especially for taxa such as arthropods that may have relatively small ranges, which can lead to higher than predicted endemism.

Second, all three estimated biodiversity impacts are based on range maps or scaling laws that reflect current counts of the numbers of species in each taxa. The existence of undiscovered species of birds and mammals within the island of Borneo or the inaccurate lumping of morphospecies in the tree and arthropod census plots, for example, would cause an underestimation of all three measures of biodiversity impact. Related to diversity measurement, we note again that the arthropod small-plot data used in this study are drawn from a Panamanian forest survey due to a lack of comprehensive census data in Borneo, and that the impacts presented here may be underestimates to the extent that, similar to trees, the richness of arthropods in Borneo per unit area is higher than in central America.

Third, the estimates of species-level extinctions do not reflect potential extinctions of subspecies or local populations, both of which may be critical to species' long-term viability (Ceballos & Ehrlich, 2002; Ehrlich & Daily, 1993). As the geographic ranges of subspecies and populations will be, by definition, smaller than species ranges, the expected number of extinctions at this level will be higher than the number of species extinctions predicted here. Our measure of the number of lost individuals within taxonomic groups is thus an important complement to extinction analyses, as it has been suggested that the loss of genetically or demographically distinct populations may scale linearly with area and hence the loss of individuals (J. Hughes et al., 1997).

Fourth, the estimates of the number of lost individuals relies on expected population density estimates derived from global data sets, in the case of mammals and birds, or small-plot censuses, in the case of trees and arthropods. In both cases, the reservoir-scale estimates of individuals lost can be interpreted as the best estimate of the statistical expectation of decreases in abundance, given the available data. Thus, while variability in these densities across space will lead to additional uncertainty around the predicted decreases in abundance, we do not expect that the central estimates themselves will be biased due to spatial variation in abundance.

Fifth, the estimates of the number of bird and mammal species affected by the dams, and the associated number of affected mammal individuals, may be an overestimate, as species ranges contain "holes" across spatial scales that are not reflected at the level of the global IUCN range maps. These holes may be due to small scale habitat variation or to transient population dynamics that leave a portion of the available range uninhabited at any given time. The number of affected species in these taxa should thus be understood as the number with the potential to use the habitat inundated by the reservoir areas, not necessarily the number that were inhabiting the area at the moment of inundation.

Finally, this analysis does not account for the many impacts of these three dams on biodiversity that are not directly related to habitat loss from reservoir inundation. A full accounting of the dam impacts would need additionally to include the roads and other infrastructure related to dam construction and operation, downstream changes to the river and flooding regime and their effect on habitat, impacts on river species, and indirect costs stemming from displaced communities, economic activity outside the dam region, and greenhouse gas emissions from the reservoirs.

Although outside of the scope of this analysis, we note that climate change and habitat loss are likely to have synergistic impacts on biodiversity in the future. Borneo is projected to experience annual maximum temperature increases above the global average and increased precipitation variability under a 2^0 C temperature increase (World Wildlife Fund, 2012). Changes in mean temperature and precipitation may reduce local species abundance, alter synchronizing between trophic levels, cause geographic range effects, phonological changes and/or changes in disturbance regimes.

These can all interact with habitat loss and the combined effect may be greater than the effects of each threat individually (Mantyka-pringle, Martin, & Rhodes, 2012), (Brook et al., 2008). One recent study finds that as many as 49% of mammalian species in Borneo will lose more than a third of their habitat by 2080 when climate and deforestation impacts are considered together, a two fold increase over historical trends (Struebig, Wilting, et al., 2015). With suitable ecological conditions predicted to shift upslope for many of these species, the importance of preserving upland forest areas, such as those inundated by the three reservoirs examined in this analysis, is therefore increasingly significant.

Although the biodiversity of Borneo has undisputed global and local significance, neither the economic value of its functional ecosystem services nor the economic value of its intrinsic worth to humans have been well documented. As one example, the HoB Initiative is a transboundary governmental collaboration among Brunei, Indonesia and Malaysia established in 2007 to protect over 23 million hectares of high land forest in central Borneo (van Paddenburg et al., 2012). The HoB takes first steps toward harmonizing government development plans by quantifying the value of forest natural capital and discussing avenues to integrate this economic value into mainstream decision making. Even this large initiative, however, uses an economic value of biodiversity per hectare based on general ranges found in the literature (van Paddenburg et al., 2012, p. 82), highlighting the need for improved site-specific biodiversity estimates and valuation.

The approach presented here provides a simple and scalable method for assessing landscape-scale diversity in a manner that can be relevant for policy and management. In participatory management schemes or multi-criteria decision analysis approaches that explicitly consider tradeoffs amongst criteria other than economic cost, for example, methods that allow for the rapid assessment of biodiversity outcomes under alternative scenarios are critical to informed decision making.

In the case of the Sarawak hydroelectric dams, a state and national level debate on the suitability of the dams continues to unfold, involving affected village communities, subsistence farming populations, commercial plantation interests, timber interests, land-rights advocacy groups, conservationists, utility companies, forest management authorities, state development planners and other stakeholders (Sovacool & Bulan, 2011a, 2012a). Regardless of the weight or priority that different stakeholders give to biodiversity, the ability to collectively consider the risks posed to species and populations in quantitative terms will allow for more informed opinions and discussion of tradeoffs.

In the absence of field surveys prior to the construction of three hydroelectric dams in northern Borneo, this analysis has provided a quantitative means of retrospectively assessing the biodiversity impacts of these projects. While few species-level extinctions are expected, the results show that a significant fraction of the resident species of Borneo are likely to suffer reduced populations due to habitat loss following reservoir inundation. More broadly, the methods presented here provide a readily applicable tool for rapidly estimating biodiversity impacts under alternative development scenarios when little empirical data are available. Given the rapidity of land conversion and biodiversity loss in many regions of the world, model-driven approaches such as these will be critical for illuminating the otherwise hidden biodiversity costs associated with global land use change.

CHAPTER FIVE
Using Spatial Analysis tools to Assess Potential for Distributed Energy Resources in Data Constrained Contexts

5.1. Introduction: Tool for supporting optimal resource allocation

Broadly defined, land use suitability analysis aims at identifying the most appropriate spatial patterns for future land use according to the specific requirements or predictors of some activity and the preferences of relevant stakeholders (Malczewski, 2004). This process of balancing objectives and function becomes critical in landscapes of global importance with multiple local stakeholders. With different functions and values derived from such landscapes, determining socially, ecologically and economically desirable land use allocations is challenging. Landscape level suitability study is often limited by the paucity of data and poor methods for forecasting and monitoring the impacts of land use change (Gillison & Liswanti, 2004), representing a significant gap in information available policymakers tasked with balancing tradeoffs between global environmental concerns and national development objectives (Rands et al., 2010; Tomich, Noordwijk, et al., 2004).

The Sarawak mega-dam conflict has indeed prompted a small but growing academic literature which provides qualitative appraisal of energy infrastructure with respect to economic benefits, technical efficiency and social challenges (Choy, 2005; Oh et al., 2011; Sovacool & Bulan, 2011a, 2011b, 2012a). However there is little literature to date – quantitative or qualitative - on land use trade-offs, impacts on ecosystem services or contributions to rural livelihoods. Borneo's forests are large stores of natural capital, from extractable forest products to the numerous direct and indirect ecosystem services they provide. Furthermore, Sarawak is a largely rural state, with 50% of the population living in rural communities (Borhanazad, Mekhilef, Saidur, & Boroumandjazi, 2013). A planning process with does not incorporate land use values and rural community needs may lead to locally and globally inefficient resource policies (Law et al., 2014).

Recent advances in multi-criteria decision analysis and the availability of high resolution global spatial data sets together provide new ways of explicitly exploring local land use change, impacts and opportunities. In this study we quantify the spatial distribution of energy resources at the local landscape level in Sarawak in order to understand the trade-offs associated with productive land uses and stakeholder interests. We determine the potential future supply of energy resource under various socio-physical constraints and then evaluate the performance of two broad energy infrastructure development scenarios. We also use a hybrid optimization model to analysis the trade-offs between various local small-scale energy technologies in satisfying rural energy needs.

5.2. Methods

Current literature explores environmental health and function using high-resolution satellite imagery. Recent data sets now provide more accurate assessments of logging road expansions, forest loss, forest cover change, carbon storage and biodiversity loss - which were either undocumented or poorly measured by conventional satellite approaches (Bryan et al., 2013; de Bruyn et al., 2014; Dong et al., 2014; Hansen et al., 2013). A number of studies mapping socio-cultural ecosystem service specifically in Borneo have recently been conducted (Abram et al., 2014; Law et al., 2014) which find inefficiencies, trade-offs and unintended outcomes for existing land use plans. These studies tend to focus on the potential supply of provisioning services (timber, plantations and agriculture) (Law et al., 2014). Given the recent large scale energy infrastructure developments in Borneo, studies that also explore the potential for electricity supply from various alternative energy resource scenarios is necessary. The aim of this study is to demonstrate methods in accounting for multiple stakeholder interests in developing land use policy.

In this chapter we demonstrate spatial and optimization support tools to better guide and focus the overall energy assessment process on stakeholder interests, rural energy needs and appropriate energy solutions. We use state government mega-dam development plans in Sarawak, East Malaysia, as a case study. We first use global data sets to map geographic and social variables for Sarawak. We describe species richness and identify hotspots of critically endangered species presence, as a metric for biodiversity importance. Using publicly available energy resource datasets we then perform a suitability study of hydro, solar and biomass resources with respect to the social and ecological constraints already identified as well as other technical factors. We map the resulting spatial distribution of these potential resources and compare the tradeoffs that exist under two different planning scenarios – the 'Business as Usual' (BAU) scenario where the mega-hydro dam plans are implemented and a 'Distributed Resources' scenario where distributed resources are exploited to meet future demand. Data sources are referenced in their corresponding sections and described in detail in Table 8.

Secondly, we conduct a non-spatial study in the Baram Basin that explores the role of distributed energy resources in also satisfying rural energy demand. We use a hybrid optimization model to analyze the trade-offs between various local small-scale energy technologies in meeting village demand. Together the studies demonstrate the incorporation of rural energy access needs and socio-ecological criteria into land use planning frameworks. The aim of these support tools are to (i) create an understanding of the present environmental and social hotspots; (ii) provide an outlook on potential future distribution of land use change for energy technology through simple scenario-driven land conversion modeling and (iii) provide spatial guidance in earmarking environmentally and socially sound areas for energy development. This can add value as an early entry point for integrated planning but should not be considered a replacement for more detailed integrated spatial planning frameworks.

5.2.1. Environmental, Social and Geographic Variables

We first collect spatial data sets on key social and ecological features in Sarawak: population density, settlements, Native Customary Rights (NCR) land dispute areas, road and river networks, forest cover, palm oil concessions, existing electricity infrastructure including transmission and existing power plants, planned hydro-electric reservoirs and topography. We describe our mapping of the biodiversity resource in the section below. See Table 8 for a complete listing of all data sources.

Stretched along the northern coastline of Borneo, Sarawak comprises 124,450 km^2 and is the largest state of Malaysia. It consists of a combination of broad categories of land use and land cover. Along the coastal region are large extents of swamp and wetland environments. Separating it from Indonesian states to the south are the mountainous central highlands now covered by a few remaining stands of primary tropical forest and predominantly by secondary tropical forests under timber and palm oil concession. Out of these highlands springs a complex and predominant river network. The low foothills in between the coast and the mountain range are the most populated regions of the state (Figure 12). The population is divided between urban communities that live near its major cities and rural communities that extend into the highland areas. In 2000 the two million population was 52% rural and 48% urban (State Planning Unit, 2011b). The rural population is declining approximately 1% per annum and population density data (Figure 12) alludes to the general highlands to coast migration pattern.

The local Sarawak economy is based on extractive industry including mining, plantation agriculture and timber logging. In the late 1970s, some 75% of Sarawak was under forest cover, however by 2000 more than 50% of forest area had been logged. A significant amount of logging has taken place since then and is expected to continue. In 2011 alone, four new saw mill licenses were issued (Figure 12). Over the past twelve years the state produced an average of 11.5 million cubic meters of logs per year (the major species planted is acacia mangium, batai and eucalyptus). There are currently a total of 17,500 km^2 currently under timber concession with almost half of that awarded to one company - the Samling Group. It is difficult to estimate the size of the Sarawak timber industry as much of the timber extraction and export is illegal and undocumented.

Oil palm has become the state's third largest foreign exchange earner after petroleum and LNG. There are more than 10,600 km^2 under palm oil concession. Much of the land under palm oil concession was peat swamp forest (Figure 12). Both timber and palm oil concessions encroach on indigenous lands presenting a major socio-economic impact of the industry. Many indigenous groups do not have formal acknowledgement of village lands or boundaries and they are taken over as state lands without consultation or compensation. There are hundreds of Native Customary Land Rights (NCR) cases backlogged before the High Court of Sabah and Sarawak where village communities are seeking recognition of ownership to land.

There are currently a total of 3 km^2 currently under legal dispute. Only recently are landmark rulings being made in favor of communities ("Borneo Project," 2014). According to the State Department there are an estimated 15,000 km^2 of native customary rights (NCR) land without titles, which is currently 'under-utilized' and where the government has identified several large tracts of land for plantation projects. The distribution of palm oil concessions and NCR lands can be seen in Figure 12. On average, these industries have together resulted in the loss of on average 0.65% of forest area per year since 2000.

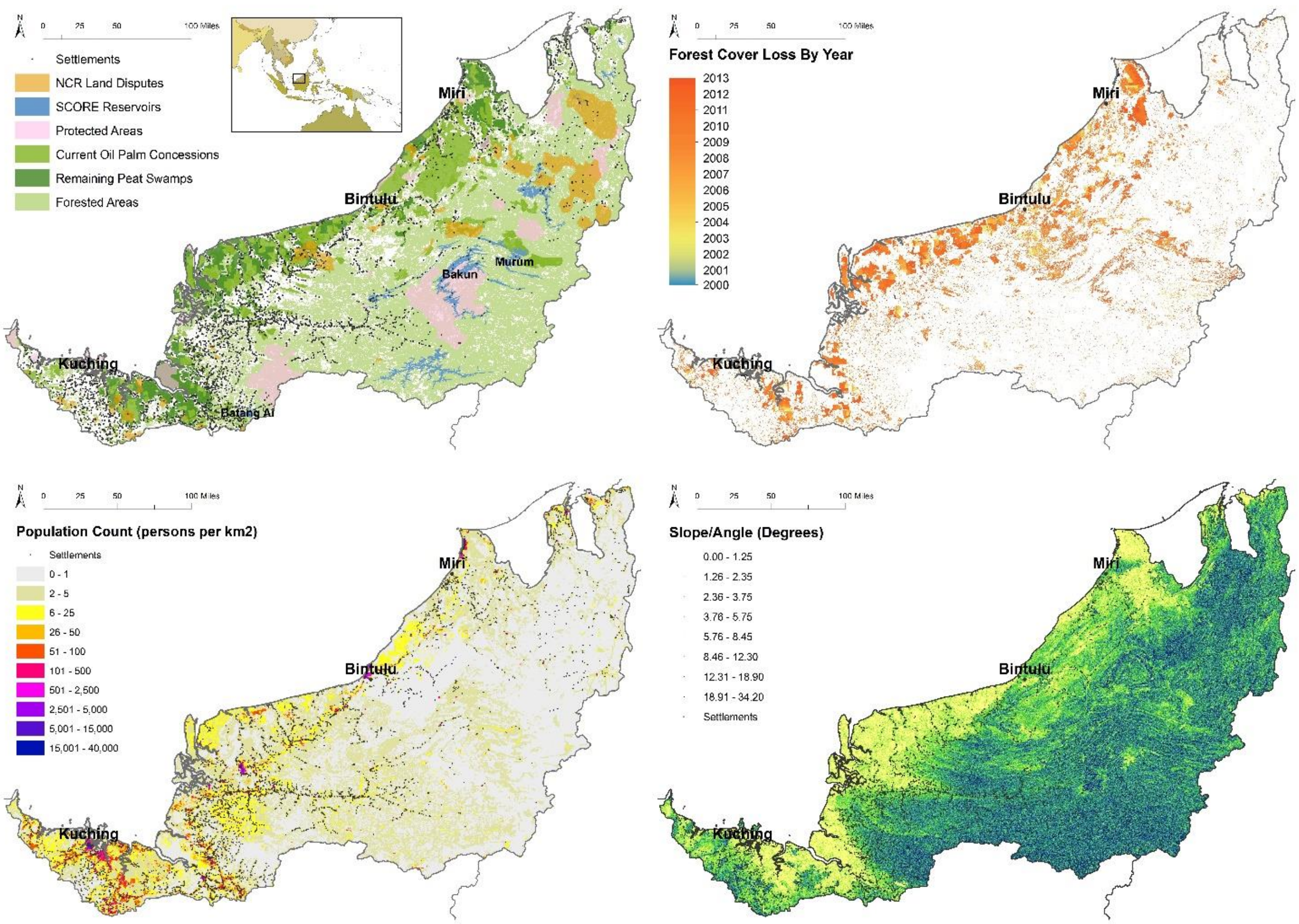

Figure 12 From Top Left (a) Map of Sarawak showing features of social importance; (b) Incremental Forest Loss in Sarawak by Year from 2000 to 2013; (c) Population density in Sarawak estimated for 2015; (d) Relief of Sarawak showing land gradient in degrees.

5.2.2. Biodiversity: Using Spatial Tools to Approximate Ecosystem Service

The island of Borneo, part of the Sundaland biodiversity region has been identified as one of earth's 34 biodiversity hotspots and in particular a major evolutionary hotspot for a diverse range of flora and fauna (de Bruyn et al., 2014). Borneo's forests house the highest level of plant and mammal species richness in Southeast Asia (Bellard et al., 2014; de Bruyn et al., 2014; Koh et al., 2013; Mittermeier et al., 2005; Sodhi et al., 2010; Sodhi, Koh, Brook, & Ng, 2004). The island is home to 581 species of birds and 240 species of mammals, including several threatened and endangered species (IUCN, 2014).

Extensive development has led to significant land cover change on the island, with 389,566 km^2, approximately 53% of the total area of the island, remaining under natural forest cover leading to highly threatened natural ecosystems (Gaveau et al., 2014). There is a growing awareness of the role of biological diversity and associated genetic diversity in the provision of distinct ecosystem goods and services (Gillison & Liswanti, 2004; Norris, 2012; Swift et al., 2004; Tomich, Thomas, et al., 2004).

Accelerated efforts to conserve Borneo's forests are critically required as their size and quality are deteriorating rapidly in the face of unabated commercial logging and agricultural expansion (Mittermeier et al., 2005; Pei Ling, 2013). To date there has been little quantitative analysis of the impact of major land use changes such as reservoir inundation on local Bornean biodiversity. Direct biodiversity impact assessments based on field surveys are often unavailable or incomplete due to time and funding limitations, so indirect methods for estimating impact based on non-local data sources are useful complementary solutions. In this study we use species richness (species count) as a proxy for animal biodiversity and identify hotspots of critically endangered species for inclusion in our suitability analysis. Metrics of species richness are typically employed in ecosystem service assessments (Law et al., 2014). We note that biodiversity hotspots do not necessarily correlate with conservation priority areas which may include other considerations.

In a previous study we estimated the number of affected species, number of local extinctions, and number of lost individual organisms associated with habitat loss due to reservoir inundation from the reservoirs across four major taxonomic groups: birds, mammals, trees, and arthropods (Kitzes & Shirley, 2015). To estimate bird and mammal species richness global range maps for birds were requested from Birdlife International (Birdlife International, 2011) and global range maps for mammals were obtained from the IUCN (IUCN, 2014). For both birds and mammals, species ranges were filtered to include only those with Presence code 1 or 2 (Extant and Probably Extant), Origin code 1 (Native), and Seasonal code 1 (Resident). Using a GIS function to count overlapping species ranges we were able to determine the total number of species per cell ($100m^2$) (Figure 13). Here we explore other spatial representations of biodiversity importance. We further filter for all mammal and bird species with Critically Endangered (CR) and Endangered (EN) with IUCN Red List Status. This allows us to observe both total species richness as well as endangered species richness (or count) distribution. As we filter for endangered species the hotspot priority zones shift across the state (Figure 13).

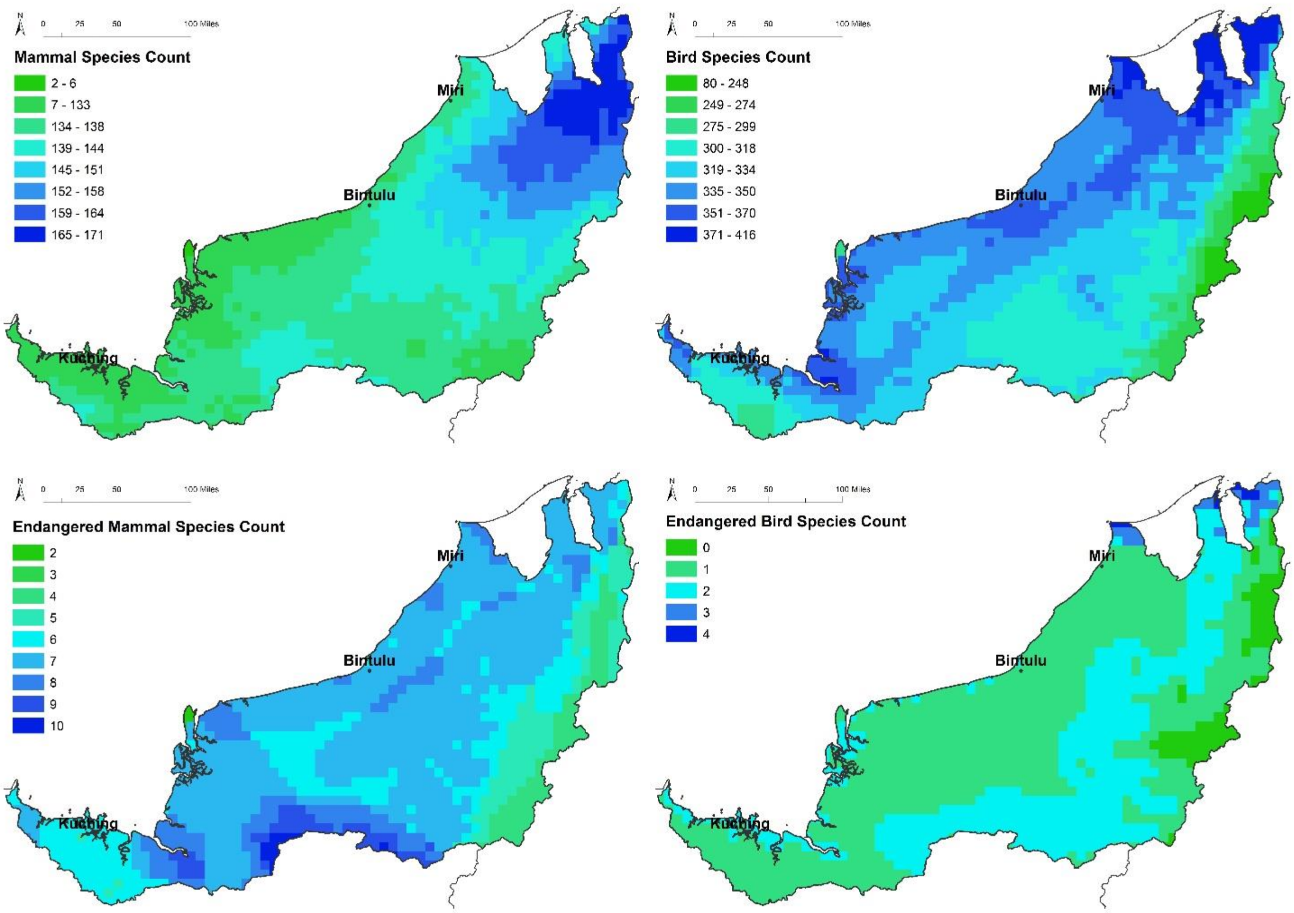

Figure 13 From Top Left (a) Total Mammal Species Count; (b) Total Bird Species Count; (c) Endangered (CR and EN) Mammal Species Count; (d) Endangered (CR and EN) Bird Species Count

5.2.3. Existing Electricity Infrastructure

The Sarawak Electricity Supply Corporation (SESCO), privatized in 2005, is the organization responsible for the generation, transmission and distribution of electricity in the state. The parent holding company is Sarawak Energy Berhad (SEB), wholly owned by the Sarawak State Government. SEB owns a number of other generation subsidiaries in addition to SESCO (Sarawak Energy, 2010)[6]. In 2012 the total generating capacity of SEB stood at roughly 2,550 MW: 600 MW of gas, 480 MW of coal and 163 MW of diesel spread across a handful of power plants and 1,200 MW from the Bakun Hydroelectric Dam's (only four of its eight generators are currently operational) (Energy Commission, 2012a). This represents more than a 100% reserve margin, compared to an average of 30% across other states of Malaysia.

In 2012 this demand was shared among the industrial (51%), commercial (26%) and residential (21%) sectors. According to the National Energy Report and based on the past twelve years in Sarawak (2000 – 2012), averaged growth rates for electricity sales and

[6] Including Sarawak Power Generation Sdn Bhd (SPG), Sejingkat Power Corporation Sdn Bhd (SPC), PPLS Power Generation (PPLS) and Mukah Power Generation Sdn Bhd (MPG).

maximum demand were 8.6% and 7.0% respectively during this period (Energy Commission, 2012a), (Energy Commission, 2012b). SEB owns 1025 km of 275kV and 385 km of 132kV of high voltage (HV) transmission lines (Energy Commission, 2012a). There are plans to extend the 275 kV network and build a new 500kV system that runs through the hill lands to transmit power from the dams.

5.3. Identifying Distributed Energy Resource Opportunities

The identification of social, ecological and geographic variables described above provides important thematic focus for the suitability analysis steps that follow. The data used for this study were separated into constraint and factor variables. The constraint variables are used to identify areas where a renewable energy development could not usually occur. The constraint variables identified include: topography, forest cover, NCR disputed lands, biodiversity and protected areas. We exclude particular areas chosen from these variables to create 'non-constraint' or 'opportunity' layers for energy resources.

The factor variables are then used in a second tier of analysis to assess the suitability of non-constraint areas under different planning scenarios. Factor variables include proximity to existing electricity infrastructure and transmission (Watson & Hudson, 2015). The selection criteria for each constraint and factor variable can be seen in Table 9. The GIS-based land-use suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability and regional planning, however here we focus on land-use suitability as applied to energy planning and selecting areas for energy infrastructure development rather than agriculture and urban planning applications.

5.3.1. Solar Energy Resource Opportunities

Located in the South China Sea, Malaysia lies entirely in an equatorial region between 1^0 and 7^0N Latitude. The state of Sarawak is crescent shaped, spread between 1^0 and 5^0 N Latitude with a predominantly East-West orientation. The weather in Malaysia is characterized by two monsoon seasons. During the Northeast monsoon from November to May cold winds from Central Asia bring heavy rainfall especially to the eastern states of Peninsular Malaysia and western Sarawak. The Southwest monsoon occurs from May to September, bringing warm winds across from Australia and generally signals drier weather (Mekhilef et al., 2012). For Sarawak December to March are the most wet months while June to August have the least rainfall, nevertheless it is rare to have a completely clear day even during drier weather. This seasonal variation contributes to the total solar resource received yet still the annual average insolation across the state is fairly high, at approximately 5 $kWh.m^{-2}.day^{-1}$.

We use NASA Surface meteorology and Solar Energy Global Data Set (Release 5) which provides 10-year monthly and annual average Global Horizontal Irradiance data at one degree resolution ("SWERA," 2014). The minimum monthly average for insolation in Sarawak is found in the month of January at 3.26 kWh/m^2/day, and maximum value in April at 6.91 kWh/m^2/day with the annual average being 5.00 kWh/m^2/day. Monthly averages are consistently lower in the west, near the capital Kuching and higher in the east.

We create an opportunity or non-constraint layer for the solar resource. We use GIS tools to buffer and exclude all areas that are legally recognized protected areas, all areas considered NCR lands, all forested areas and peat swamps, all current palm oil concessions and all remaining land on slopes higher than 5^0 . We then create an opportunities layer, assigning positive values to all areas proportionately to their average solar insolation ($kWh.m^{-2}.day^{-1}$).

Combined, these layers show areas for potential solar development. Here we show solar opportunity results based on annual average insolation and based on three other monthly averages that represent seasonality: June represents the fairly constant insolation received during the Southwest monsoon months, December represents the months at the beginning of the Northeast monsoon (lowest monthly insolation) and April represents the end of the Northeast monsoon (highest annual insolation).

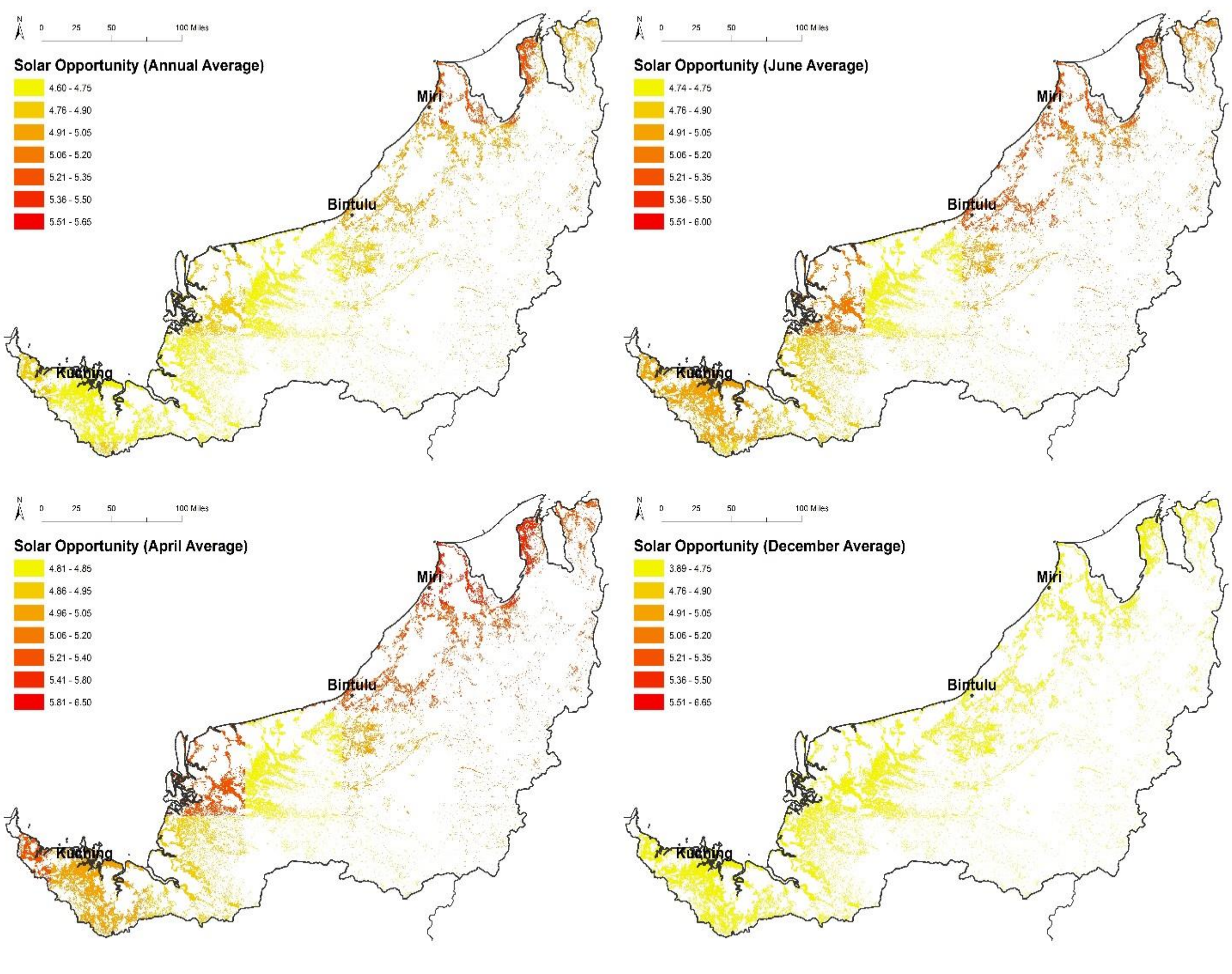

Figure 14 Results of Suitability analysis showing annual average $kWh.m^{-2}.day^{-1}$

5.3.2. Biomass Waste Resource Opportunities

Malaysia produces roughly 19 million tonnes of crude palm oil annually. Sabah and Sarawak are the most important states for oil palm cultivation and production. Together they represent over 75% of total crude palm oil production. Sarawak alone represents 45% of production with an average of 8.5 million tonnes annually. In 2010 there were over 919,000 hectares of oil palm plantation in the state. As land for cultivation becomes scarce on peninsular Malaysia, Sarawak has drastically scaled up oil palm cultivation in recent years. SCORE involves doubling plantation area to two million hectares by 2020, making Sarawak the biggest crude palm oil producing state in Malaysia. According the Malaysia Palm Oil Board, estates were 93% of land under palm oil while small holders comprised the other 7%. Also, 80% of total plantation land is owned or leased by private companies[7].

There are forty-one palm oil refineries across Sarawak and a number of these refineries are near major load areas in Sarawak including Miri, Bintulu and Sibu that allow palm oil waste to energy to be a feasible option for energy production (Agensi Inovasi Malaysia, 2011). In the process of extracting crude oil and palm kernel from fresh fruit bunches (FFB) considerable amounts of residue are generated. These include solid residues such as shells, fibers and empty fruit bunches (EFB), as well as liquid wastes including palm oil mill effluent (POME). For every tonne of FFB processed roughly 0.22 tonnes of wet EFB (60% moisture content) are produced. For every tonne of FFB processed 0.65m^3 of POME are produced (Sulaiman et al., 2011). Thus large volumes of waste are produced daily at the palm oil mills.

Palm oil mills frequently depend on their own biomass for fuel. The dry waste - shells and fibers - are feed into boilers to create steam for electricity generation. As this dry biomass residue is meant for disposal little effort is normally spent on optimizing process steam consumption, or boiler or turbine efficiency. The high moisture content of fresh or wet EFB makes it a poor fuel without drying and its use in boilers is discouraged. EFB can instead be used for mulching or fertilizer though this use is often limited by labor, transportation logistics and concerns over encouraging oil palm pests. Dry palm branches are often left on the land as mulch rather than transporting wet EFB back from the mills. EFB are instead often disposed of or left to rot at the mill site. Thus EFB are another major waste stream sub-optimally used (Chiew et al., 2011; Sulaiman et al., 2011).

Finally, POME is the effluent from the final stages of palm oil production in the mill. The large volumes of POME produced actually represent a major environmental concern due to its polluting characteristics (extremely high levels of COD, BOD, oil and grease). POME is normally treated using the open settling pond system without methane capture and then discharged directly to rivers. The palm oil industry is in fact cited as producing the largest pollution load for rivers throughout the country (Sulaiman et al., 2011). With its high protein, carbohydrate and lipid organic content POME has great potential for biogas production through anaerobic digestion which can then be used in a gas turbine for power generation.
Every m^3 of POME can generate 25m^3 of biogas comprised of carbon dioxide and methane (Chin et al., 2013; Lam & Lee, 2011; Sulaiman et al., 2011). In addition to the benefit of

[7] The major planters include Rimbunan Hijau Group, Ta Ann Holdings Bhd, Samling Group, Lembaga Tabung Haji and Boustead Group while the new investors are conglomerates like Sime Darby Bhd and IOI Corp Bhd.

electricity generation, biogas recovery in this manner also results in final effluent with significantly reduced BOD and COD levels discharged to watercourses (Sulaiman et al., 2011). However studies find that less than 30% of palm oil mills in Malaysia have some sort of recycling activity for EFB or POME (Chiew et al., 2011). Thus palm oil wastes represent a readily available resource in need of a revolutionized and efficient means of utilization.

Because of the rate of palm oil waste production in the state a large body of research on waste to energy potential via different technologies has emerged in Malaysia. A number of studies find the economics of oil palm waste to energy conversion to be feasible in Malaysia and Sarawak particularly (Sumathi et al., 2008; Shuit et al., 2009; Sulaiman et al., 2011; Shafie et al., 2012; Hosseini & Wahid, 2013; Umar et al., 2013; Chin et al., 2013; "Bursa Malaysia," 2015). Common energy conversion technologies explored for EFBs include ethanol production, methane recovery, compression and briquette production, and cogeneration or combined heat and power production. The predominant technology explored for POME utilization is closed tank anaerobic digestion for biogas recovery.

Given the size of the resource, biomass waste energy technologies featured heavily in the Malaysian government's fuel diversification policy of 2001. The Small Renewable Energy Power Program was established through this policy to support the development of this sector. Additional support came from the UNDP and the global Environment Facility (GEF). There are now a number of mills in Peninsula Malaysia where POME biogas recovery systems and EFB gasification systems have been installed. There are more than 23 MW of installed capacity using palm oil waste fuels with sizes ranging from 1.5MW to 13MW depending on mill capacity. In fact the government's National Biomass Strategy 2020 estimates that by 2020 Malaysia's palm oil industry will be generating about 100 million dry tonnes of solid biomass waste (Agensi Inovasi Malaysia, 2011). According to the strategy, the biomass waste to energy industry could result in some 66,000 jobs nationwide and a small number of existing local projects POME biogasification plants can sustain Investor Rate of Returns (IRR) of 7-17% and higher (FELDA, 2009; Malaysia Energy Center, 2004).

There are still many barriers to the successful integration of the biomass waste energy sector into the larger distributed and utility scale power sector. Many of the existing combined heat and power plants mentioned above are not operational. Issues cited include difficulty drying and preparing EFB fuel for the power plants due to its bulky nature and high moisture content, problems maintaining a consistent supply of EFB throughout the year, and the incentive for transporters to create and control informal markets that inflate the cost and complexity of procuring EFB wastes. Policy will be required to control the local biomass waste supply and create a sustainable distributed energy sector for these waste resources. In our study we estimate the size of this resource through correlation with total land area under palm oil plantation and standard yield rates. We assume only areas under current concession can contribute to biomass waste and use SEB official yield and residue ratios ("Sarawak Energy," 2013b). We obtain data on country wide plantation areas and apply constraint variables as described above for the solar resource. That is, we exclude areas that overlap with protected areas, remaining forest and swamp, NCR lands as socio-ecological constraints. The resulting opportunity layer is seen in Figure 14 below.

Table 8 Features Used in Energy Resource Suitability Analysis

Feature	Description	DataSet	Source
Administrative Data	Boundaries, Roads,	Diva GIS	www.diva-gis.org/gdata
Land Cover	Annual Forest Cover Loss/Gain at 30m res	Global Forest Change 2000 - 2013 (UMaryland)	www.earthenginepartners.appspot.com/science-2013-global-forest
Topography (Relief)	Elevation at 80m res	CGIAR Consortium for Spatial Information (SRTM)	srtm.csi.cgiar.org/SELECTION/listImages.asp
Population Density	2012 Population Count at 1km res	Landscan Global Population Database (ORNL)	web.ornl.gov/sci/landscan/
NCR Land Disputes	Lands being disputed in Native Court	Sarawak Geoportal (BMF)	www.bmfmaps.ch/EN/composer/#maps/1002
Protected Areas	All National and International Classified Protected Areas/Reserves	World Protected Areas Database	www.protectedplanet.net/
Mammal Species Range Data	Mammalian Species Ranges	IUCN Red List	www.iucnredlist.org/technical-documents/spatial-data
Bird Species Range Data	Avian Species Ranges	Bird Life International	www.birdlife.org
Hydroelectric Reservoir Areas	Reservoir Estimates km2	Sarawak Geoportal (BMF)	www.bmfmaps.ch/EN/composer/#maps/1001
Solar Resource	22 year Monthly and Annual Average	NASA Surface Meteorology and	eosweb.larc.nasa.gov/sse/
Wind Resource	10 year Monthly and Annual Average Wind	NASA Surface Meteorology and	eosweb.larc.nasa.gov/sse/RETScreen/
Palm Oil Concessions	Area under Concession km2	Sarawak Geoportal (BMF)	www.bmfmaps.ch/EN/composer/#maps/1002
Electricity Infrastructure	Existing power plants, existing and planned transmission	Sarawak Energy Berhad (SEB)	http://www.sarawakenergy.com.my/

Table 9 Variables used to create suitability layers for energy resources

Variable	Constraint Criteria	
	Solar Resource	Biomass Waste Resource
Constraint Variables		
Protected Areas	All Protected Areas buffered	All Protected Areas buffered
Land Under Native Customary Right (NCR) Dispute	All known NCR lands buffered	All known NCR lands buffered
Forested and Peat Swamp Areas	All remaining forested and peat swamp areas buffered	All remaining forested and peat swamp areas buffered
Current Palm Oil Concessions	Land currently under Oil Palm Cultivation is buffered	No further Palm Oil expansion allowed
Gradient	5 degree maximum threshold	Not constrained
Factor Variables		
Transmission	Within 50 miles (80 km) of High Voltage transmission	Within 50 miles (80 km) of High Voltage transmission

5.3.3. Comparing Future Scenarios for Commercial Energy Demand

Thus far we have used a number of GIS tools to create a multi-layered representation of Sarawak. Each layer contains a different type of information. By combining these layers with energy resource data (solar radiation and plantation areas) according to our selection criteria we defined the suitable available land areas for certain energy technologies. We now use these opportunity layers to estimate the geographic potential of solar and biomass resources with respect to factor variables. Such an approach can help identify the most suitable areas for different energy technologies within a case study area. This in turn can help policy makers to develop policy incentives for resources of the highest potential and can help energy planners to appropriately consider energy options in master plan design. Our study is meant to serve as a starting point for such refined analyses.

The theoretical potential of a resource describes the amount of resource available without considering any conversion efficiencies and losses. This is effectively the maximum amount of energy physically available from a given source. The geographic potential takes into account areas which are suitable and usable for a specific technology's deployment as defined by our factor variables and the selection criteria chosen (IRENA, 2014). We demonstrate here a method that uses our opportunity layers to explore potential scenarios for meeting energy demand in 2030 and assess suitability in terms of impacts on criteria of concern. Any number of scenarios can be modeled using our data and framework however here we describe two scenarios: a 'Distributed Resources' scenario and the business as usual 'SCORE' scenario. In the Distributed scenario existing dams and transmission are complemented by the resulting solar and biomass resources. In the SCORE scenario all planned dams and transmission are built, no solar or biomass resource is developed.

We use the opportunity layers created above, determine their geographically feasible cells, and calculate total potential available under each scenario. For solar resource we select cells that are within 50km of existing HV transmission and that receive significant annual insolation, which we define as monthly averaged insolation above 5 $kWh.m^{-2}.day^{-1}$ more than nine months of the year (Hott, Santini, & Brownson, 2012). We apply the same proximity to transmission criteria for palm oil mill sites. However we find all mills are less than 30 km from existing transmission, so for biomass resources we include all concession areas included in the opportunity layer above. We note here that our assessment of biomass waste resource is not exhaustive. There are other agricultural waste supply chains and other forms of waste to energy conversion. We focus here on EFB and POME waste conversion technologies as these options are highly location and area dependent and can be well analyzed using spatial data on plantation areas.

We calculate the total potential for each resource in the Distributed scenario using the formulae in Table 10 below. Given uncertainty of land availability, we conservatively assume 3% of selected solar area can be used for PV. This results in 1GW PV potential. We assume all EFB is used for gasification and all POME for biogas recovery. This results in 450 MW of biomass waste energy potential. Under assumption that energy demand from 2012 increases at a 7% growth per annum for both total annual energy and maximum demand (higher than the average projected for Peninsula Malaysia) demand grows to a peak demand of 2730 MW in 2030 (20,000 GWh/year in 2030).

Together solar and biomass could represent an additional 1.5 GW of capacity in addition to the 3444 MW that Batang Ai, Bakun and Murum represent. Combined with existing thermal generation the total capacity of the system would be 5687 MW, compared to the SCORE scenario, where expected total capacity by 2030 is 16GW. Our biodiversity analysis shows that the reservoir areas of Bakun, Murum and Baram overlap habitat for a total of 331 species of birds and 164 species of mammals. For both taxa, there is substantial overlap in the species affected by individual dams, with the Baram dam alone affecting 318 out of 331 bird species and 162 out of 164 mammal species. As solar and biomass are constrained to non-forested areas the impact on biodiversity is significantly reduced in the Distributed scenario.

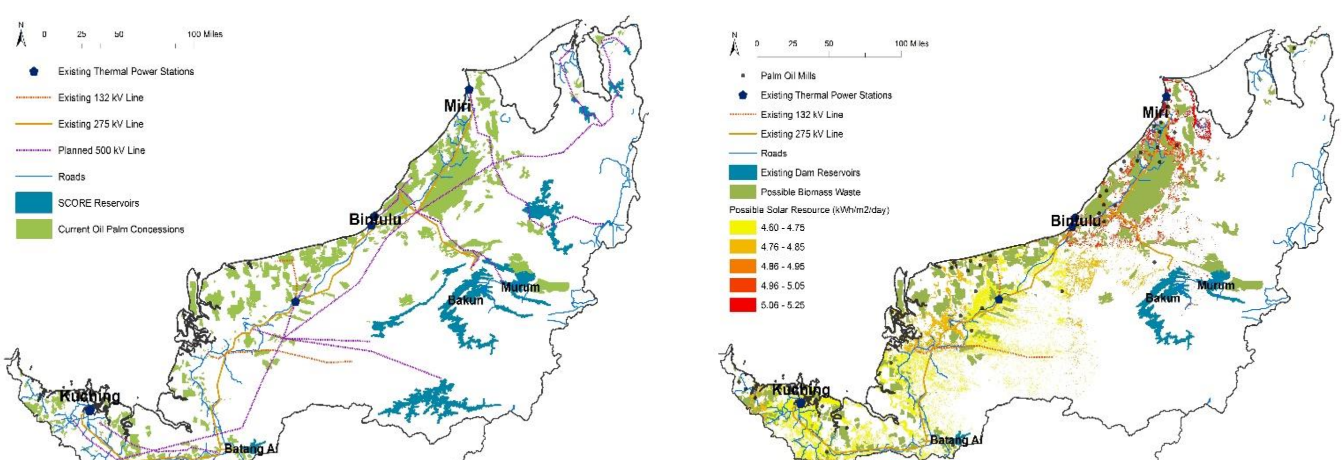

Figure 15 Results for Scenarios (a) BAU - SCORE Scenario which assumes building of all hydroelectric reservoirs and new transmission; (b) Distributed - assumes only existing transmission, already built dams and shows potential alternative resources

Table 10 Summary of Methods for Estimating Potential from Selected Opportunity Cells

Resource	Estimated Potential	Variables
Solar PV	$P_{solar} = \sum_{n=1}^{n} \frac{A \times I \times \eta}{S \times 1000}$ where : $A =$ area (m^2) $I =$ annual average insolation $(kWh.m^{-2}.day^{-1})$ $\eta =$ assumed efficiency $S =$ daily sunshine hours $n =$ cell where $I \geq 5.00\ kWh.m^{-2}.day^{-1}$ for ≥ 9 months per year	η = 15% S = 12 hours
Biomass EFB Gasification	$P_{biomass,EFB} = \sum_{n=1}^{n} \frac{(100 \times A) \times Y \times r_{EFB} \times \frac{E}{3600} \times \eta \times 1000}{C \times 8760}$ where : $A =$ area (km^2) $Y =$ yield (tons/ha) $r =$ wet FFB residue ratio (ton EFB/ton FFB) $E =$ primary energy content of EFB (MJ/kg) $\eta =$ assumed plant efficiency $C =$ capacity factor $n =$ opportunity cell	Y = 20 r = 0.22 E = 6 η = 32% C = 75%
Biomass POME Biogas	$P_{biomass,POME} = \sum_{n=1}^{n} \frac{(100 \times A) \times Y \times r_{POME} \times B \times \frac{E}{3600} \times \eta \times 1000}{C \times 8760}$ where : $A =$ area (km^2) $Y =$ yield (tons/ha) $r =$ wet FFB residue ratio $(m^3$ POME/tonFFB$)$ $B =$ biogas production $(m^3$ biogas$/m^3$ POME$)$ $E =$ biogas heating value (MJ/m^3) $\eta =$ assumed plant efficiency $C =$ capacity factor $n =$ opportunity cell	Y = 20 r = 0.65 E = 22 B = 25 η = 32% C = 75%

5.4. Distributed Energy Resources for Rural Energy Supply

5.4.1. Assessing Rural Energy Demand

While energy infrastructure can contribute to economic development goals, they differ in potential to contribute to local livelihoods. In discussion of distributed energy scenarios and trade-offs it is important to consider the importance of rural energy access especially in a state where the total rural population is so significant. Scale and localized needs are important considerations in energy planning. 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 energy future discussions, however little quantitative data on demand and potential exists. We conduct a case study in the Baram Basin - the next basin to be flooded for a hydroelectric reservoir - which explores the potential of renewable energy as a bottom-up solution to satisfy the energy needs of these impacted communities.

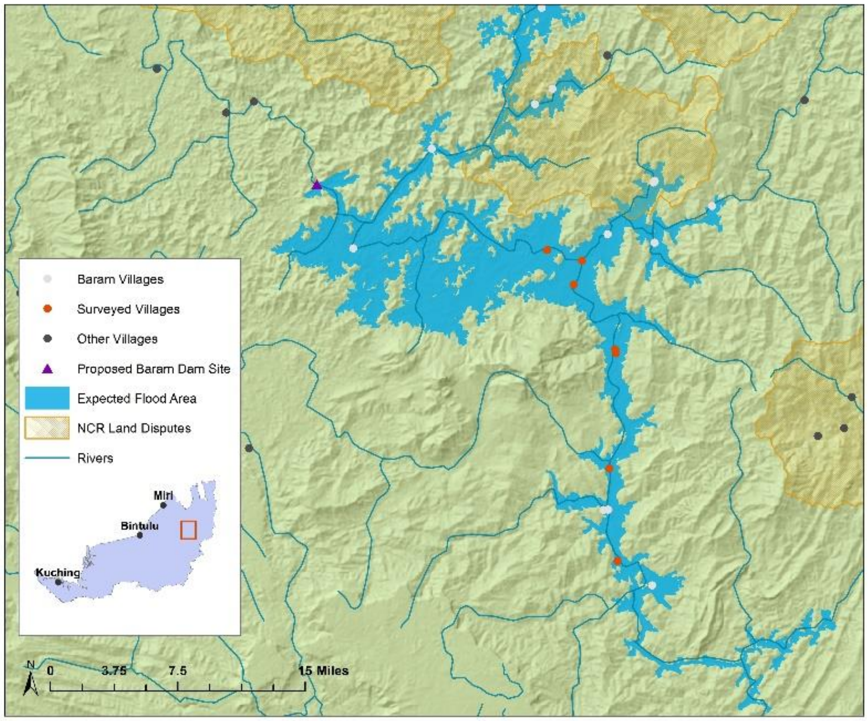

Figure 16 Map of Study Area: the Baram Basin, Sarawak, East Malaysia

In preparing this study we conducted multiple site visits to 12 villages along the Baram River (Figure 16). This study was conducted with assistance from Green Empowerment and Tonibung – international non-profit and local project developer partners that have over fifteen years of experience in micro-grid deployment and management together in Borneo. Each village was surveyed using field observation, household energy audits and interviews. At each village we interviewed village leaders, household representatives and held a community meeting.

We also did site visits to a number of local biogasification projects and conducted interviews with over 20 government agencies and NGO groups on small scale energy incentives, opportunities and limitations. Through surveying and data measurement we collected information on energy use and energy resource availability in various Baram villages. The Baram River is the second longest in Malaysia. There are over 20 villages along the Baram River upstream of the dam site representing different indigenous ethnic groups.

The Kenyah settlement of Long San for instance is one of the largest Baram villages, roughly 150 km southeast of Miri (the nearest major city). Long San is comprised of multiple *long houses* (single building comprised of adjoining rooms that houses all families within a community) totaling 160 *doors* (a single housing unit within a long house shared by two to three families of approximately five persons each) representing roughly 800 people. A major trading base for goods from the city, Long San has become a hub of the Baram community. Another Kenyah village Long Anap, 35 km from Long San, is medium sized with two long houses comprised of 54 doors total. Tanjung Tepalit is a much smaller village community located about 22 km south along the river from Long San. It comprises of a single long house with 25 doors. Trade in meat and produce creates the economic base which makes modern energy services available. Produce (fruit, vegetables and meat) from surrounding villages is taken to Long San along the river for trading and further transport.

Based on site visits and household interviews we recorded the number and type of generators operational within each village, along with time of use and total fuel consumption to estimate current energy supply. Aside from the long houses each village generally consists of a community church or clinic and a primary or secondary school, each with its own generator. Local state departments supply diesel to supply electricity to these public buildings. In Long San, for instance, there are four 20 kW generators for the school buildings and clinics which are maintained by government. We opt not to include these loads in our model as they do not impact domestic spending.

We also opt not to model ad-hoc loads which occur on a non-regular basis during the course of a year. Villages that plant hill rice primarily for subsistence, such as these Baram Villages, harvested rice is milled to separate grain from the husk after the harvest season. The number of mills, number of days and number of hours run are dependent on the strength of the season. Further, mills may be run at other times during the year when extra rice is needed – during large family visits, community celebrations or holidays. As such, it is difficult to create a daily and seasonal demand profile for this type of load. We are concerned primarily with the evening demand load.

We find on average across villages 60 – 70% of doors have access to electricity by owning small generators. A 3kW 220-V Chinese imported synchronous generator is the most common household generator across villages. Typically portable generators can achieve 15-20% total efficiency or 7-8 kWh/gal. Generators operate at low efficiencies in such circumstances due to ill-frequent maintenance and being run below rated capacity. However we assume generators in the village are operating at 15% efficiency to be conservative. The average door housing 2-3 families operates a generator from 6pm to 12pm consuming 0.5-1 gallon per night, the equivalent of 3.5 -6.5 kWh per night. Our electricity consumption and daily demand profile findings are very consistent with other village level energy audits published for Malaysia (Sari Murni, Whale, Urmee, Davis, & Harries, 2012; S. Murni, Whale, Urmee, Davis, & Harries, 2013; Ponniran, Mamat, & Joret, 2013; Yatim, 1990).

In surveying we audited the type and number of appliances as well as frequency of use for each door. Our survey shows that where available electricity is primarily used for lighting and fans while many households also have washing machines, televisions, DVD players and other appliances. A large number of the families that own generators note that they cannot afford a consistent monthly diesel fuel supply and thus run these additional appliances sparingly. Based on standard wattage ratings found in literature, we approximate nightly power demand at 0.7 kW per door. The types of appliances and their use patterns noted are consistent with those found in local and regional literature (Ponniran et al., 2013).

Beyond daily profiles we also use survey results to develop a seasonal demand profile which scales daily demand according to a monthly average. Demand is higher in the June-July holiday period when children are home from boarding school, and peaks in the December-January holiday period when family members from urban areas return to the village.

At approximately 105 kWh per month per door, village load is relatively small compared to the average domestic electricity use in Sarawak of 205 kWh/month per household (Sarawak Energy, 2010; State Planning Unit, 2011b) where primary loads can also include air conditioners, ceiling fans, refrigerators and water heaters (Kubota, Jeong, Toe, & Ossen, 2011). Nevertheless, though sold at a standard retail subsidy of 1.8 RM/l (US$0.55/l) (International Institute for Sustainable Development, 2013), electricity from diesel effectively costs 1.1RM/kWh (US$0.34/kWh) under our efficiency assumption, two and a half times more than the 0.31RM/kWh (US$0.10/kWh) domestic electricity tariff for state utility customers (Energy Commission, 2012a; Sarawak Energy, 2010). A single village door may therefore spends roughly US$ 35/month on electricity where funds to purchase diesel are available compared to the average household in Malaysia which spends US$19/month (Kubota et al., 2011). See Table 11 and Table 12 for electricity cost and demand properties.

Diesel Energy Content (BTU/gal)	139,000
Assumed Average Generator Efficiency (%)	0.15
Electricity per Unit Diesel (kWh/gal)	6.11
Standard Subsidized Diesel Price (US$/L)	0.55
Effective Cost of Electricity (US$/kWh)	0.34
SESCO Domestic Electricity Tariff (US$/kWh)	0.10

5.4.2. Model Framework

We employ the Hybrid Optimization Model for Energy Resources (HOMER) developed by the National Renewable Energy Laboratory (NREL) (Lilienthal, Gilman, & Lambert, 2005). HOMER simulates thousands of system configurations, optimizes for lifecycle costs, and generates results of sensitivity analyses on most inputs. Initially developed for application in developing countries, HOMER is now the most popular commercial design software for remote micro-grids. We provide HOMER with resource and technology inputs for each village including monthly biomass residue availability, daily solar insolation and monthly averaged flow rates. A summary of the main properties used in HOMER is seen in Table 12.

Micro-hydro sites within 5km of the longhouses are suitable for development. As most communities settle on river banks for each of transportation, this is particularly appropriate for rural Sarawak villages. Green Empowerment stream flow measurements were correlated with 40-year precipitation data ("SIWRM," 2008) to estimate monthly average flow rates. Using NASA Surface Solar Energy data ("SWERA," 2014) and the coordinates of the villages we determine solar potential for the region. Annual averaged insolation is 5.34 $kWh.m^{-2}.day^{-1}$ in the Baram peaking at 6 $kWh.m^{-2}.day^{-1}$ in March.

We estimate the potential for small scale biogasification using rice husk as a feedstock. Baram villages are based on subsistence agriculture, with each family owning land used for hill paddy planting. A large family typically owns 6-7 acres of land within the village bounds while a smaller family might own 2-3 acres with a conservative average yield of 10 bags of rice per acre every year. Rice is stored in bags after the harvest and is milled for consumption as needed during the year. The rice husk waste produced during milling is not currently used. We can approximate rice husk distribution across the year based on monthly rice consumption. We do not consider rice straw under conservative assumption that waste from rice fields cannot be transported to the long house.

The higher heating value (HHV) of rice husk is 15.84 MJ/kg (Lim, Abdul Manan, Wan Alwi, & Hashim, 2012; Yi & Yonghao, 2009). Literature shows gas yield rate is between 1.63~1.84m^3/kg with gasification efficiency is between 80.8%~84.6% (Yi & Yonghao, 2009). We assume 1.7m^3/kg gasification ratio and observe sensitivity. Lower gas yields have been recorded in (Bond & Templeton, 2011). Finally based on NASA data roughly 50% of the year wind speeds at 50m are below 2m/s because of the interior location and rugged geography of the region. We assume that given the low wind speed patterns in the region that wind is not a feasible energy option.

We provide HOMER input data on hydro-turbine design flow rate, biomass gasification feed rates, expected efficiencies, expected life, input capital, replacement and operation/maintenance costs for each technology. Hydro and solar capital cost figures (US$ 1300/kW and US$2,300/kW respectively) are based on data from Green Empowerment. Small scale biogasification capital costs (US$1500/kW) were taken from literature (IRENA, 2012; Sieger, Brady, Donovan, & Shea, 2002). Diesel engine costs were reported in surveys (US$440/kW) which align with costs cited in literature (Bhattacharyya, 2014; Rolland & Glania, 2011). We take the diesel generator fuel curve from (Nayar, 2010). We use standard deep-cycle lead acid battery properties, already populated in HOMER (capital cost US$350/kWh). We assume an interest rate of 7%, set a maximum energy shortage constraint of 10% and a total system lifetime of 25 years. We use sensitivity analysis to observe outcomes with varying technology prices, resource availability and shortage constraint.

Table 12 Estimated Energy Demand and Energy Resource Properties used for each village

Location				Size			Estimated Household Demand					Non-Household Loads			
Village Name	Indigenous Group	Coordinates		No. Doors	No. Families	No. People	Generation Capacity (kW)	Consumption (kWh/month)	Annual Consumption (kWh/year)	Diesel Consumption (gal/year)	Fuel Expense (US$/year)	Community Hall	School	Church	Clinic
		N Lat.	E Long.												
Tanjung Tepalit	Kenyah	3 14 396	114 48 975	25	50	250	18	2,633	32,029	5,242	10,807	No	No	Yes	No
Long Anap	Kenyah	3 03 747	114 49 140	54	108	540	38	5,686	69,182	11,322	23,343	No	Yes	Yes	No
Long San	Kenyah	3 17 888	114 46 855	80	160	800	56	8,424	102,492	16,773	34,583	Yes	Yes	Yes	Yes

Location				Biomass Resource			Hydro Resource					Solar Resource		
Village Name	Indigenous Group	Coordinates		Padi Acreage	Estimated Annual Rice Husk Waste (tonnes/yr)	Annual Biogas GenerationPotential (kWh)	Available Head (m)	Monthly Averaged Flow Rates (L/s)			Nominal Capacity (KW)	Mthly Avg Insolation (kWh/m2-day)	Average Radiation (W/m2)	
		N Lat.	E Long.					Max	Min	Avg			Max	Min
Tanjung Tepalit	Kenyah	3 14 396	114 48 975	100	10.5	10,172	20	103	25	62	5.8	5.34	0.43	0.37
Long Anap	Kenyah	3 03 747	114 49 140	216	15.5	15,016	70	23	11	17	8	5.34	0.43	0.37
Long San	Kenyah	3 17 888	114 46 855	320	33.6	32,552	25	98	31	65	13.3	5.34	0.43	0.37

a. assumes Residue Ratio Rice:Husk is 1:0.3
b. Assumes Diesel Generator Efficiency is 15% in the villages
c. Assumes Hydro Turbine Efficiency is 60%
d. Assumes roughly 2 families living per door of a long house
e. Solar data available from NASA Surface meteorology and Solar Energy groups all three villages within the same resolution pixel

5.4.3. General Model Results

HOMER delivers optimal configuration for each possible technology combination ranked according to Total Net Present Cost (NPC). Here we present models of three *Kenyah* villages along the Baram River – Long San, Tanjung Tepalit and Long Anap. These three villages represent high, medium and low energy use based on size and village activity. Results can be seen in Figure 17 Optimal system configuration through sensitivity analysis on different variables and in Table 13.

Tanjung Tepalit, the smallest village by number of doors, has a low level of demand but a larger hydro potential given the available head and relatively steady annual stream flow patterns. The least cost system for the village is a single 9kW hydro-turbine with 60kWh battery pack, with LCOE of US$0.15/kWh. The diesel base case is a 20kW diesel system with no battery back-up required. The hydro system is a third the total net present cost (NPC), with a fifth of its annual operating costs (predominantly fuel costs) and results in a levelized cost of electricity (LCOE) that is a third of the effective diesel LCOE. We find that the battery pack is the bulk of the cost in this system. The battery system maintains near 100% state of charge except for the drier summer months and in February. The next least expensive option adds a 5kW PV onto the hydro system showing the potential for solar to contribute to low cost systems. This is discussed more in the section below on Sensitivity Analysis.

Long Anap is a village with higher total demand but lower annual average stream flow. As such, though the least cost system for the village revolves around a 7kW hydro turbine, it also requires 20kW diesel and 120kWh of battery. The hydro unit produces 54% of total annual electricity. In fact all optimal configurations for Long Anap include at minimum a 20kW diesel backup. This least cost system is roughly four fifths the NPC and four fifths the LCOE of the diesel base case, which is a 40kW diesel system. It has a much lower annual operating cost due to much lower averaged fuel consumption per day. Due to larger population the rice husk waste resource is greater in Long Anap, thus biogas generators factor in to optimal design at lower cost than in Tanjung Tepalit. This can be seen in the section below on Sensitivity Analysis.

Long San has the largest population, with 80 doors, and an estimated demand of 45kW. The least cost system includes 11 kW of hydro-turbine and 40kW diesel where total electricity production is 60% hydro and 40% diesel. This system is roughly two thirds the NPC and LCOE of the 60kW diesel base case. The least cost system for Long San that does not call upon diesel generators would require significant battery storage (240kWh) and either PV or biogas generators. Thus diesel, even at the subsidized government retail rate, is the most expensive form of electric production for Baram villages given the recurrent fuel costs.

HOMER tracks system operability through annual energy shortage. This was the main fault of renewable systems, with NPC increasing significantly to meet a zero shortage constraint. Diesel systems are the most technically flexible and thus reliable - though fuel shortage is increasingly an issue as described in the survey. The optimal configuration for meeting demand gradually becomes more expensive as the shortage constraint tightens, and while low cost, high renewable fraction systems are possible, they are more complex, requiring three or more fuel types and battery storage.

Overall, we find that systems which incorporate renewable energy technologies (RET) are less expensive than the standard system of individual household diesel generators. In each village case, despite the level of demand and despite availability of biomass waste and hydro resources, the least cost system incorporates an RET that will satisfy at least 50% of electricity production. In each case the NPC, LCOE and annual operating cost of these least cost systems are significantly less than their diesel base cases. We note however one limitation in interpreting these results is that the diesel sunk costs have largely already been incurred for households with existing generators. This highlights the potential role that local, small scale RETs can have in satisfying rural energy needs.

Table 13 Optimization results under Least Total Cost and the Diesel Base Case for each village

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

5.4.3. Sensitivity Analysis

We observe the impact of variables with uncertainty on optimal system configuration. We perform sensitivity analysis for resource availability (biomass waste and average stream flow) and demand needs (scaled annual demand, shortage constraint). Though sold at a standardized price we also observe the effect of diesel fuel cost on systems to understand the implication of the existing government subsidy and potential future price increases. We also observe the effect of PV technology cost as the technology with the most rapidly changing capital costs (Figure 17 Optimal system configuration through sensitivity analysis on different variables).

We find that across all sensitivities hydro turbines are the most cost effective technology for village communities. As estimates of stream flow increase the need for battery support declines. However meeting load in dry months is a challenge for villages with higher demand and particularly under the zero shortage constraint, requiring additional technologies and cost increase. Studies show stream flow may become more extreme due to temperature and rainfall changes (Tan, Ficklin, Ibrahim, & Yusop, 2014). This is consistent with the literature's description of small hydro limitations (Schnitzer et al., 2014). There is a minimum biomass availability above which small scale gasification technology becomes cost effective in combination with hydro. This can be seen in Long Anap and Long San. PV is not often selected for optimal systems, largely due to evening loads, but can be cost effective at high diesel prices and low PV capital costs. Generally, increased diesel price and increased estimates of village demand improve the cost effectiveness of RET systems.

5.4.1. Limitations

We reiterate limitations of our rural energy assessment which primarily revolve around demand and supply data availability. We use international data sets where available, at which resolution location specific differences between villages in close proximity to one another will not factor into estimates of resource quality. In lieu of annual stream flow records for each tributary studied, stream flow data is estimated through correlation with precipitation. The lack of local high resolution hydrological data for sizing hydro turbines is cited as a major limitation in all studies we found for Borneo (Bhattacharyya, 2014; Sari Murni et al., 2012; S. Murni et al., 2013; Yeo, Chen, Shen, & Chua, 2014).

Similarly our estimates of biomass waste availability are based not on weight or volume records but on estimates of rice production and then monthly use. Again, cited as a common data limitation for project developers (Schnitzer et al., 2014), this highlights the need for long term monitoring studies to accurately record rural agricultural productivity and waste disposal. Finally, our demand estimates are based on appliance audits and survey results of diesel usage. We do not include projections of day-time loads (such as rice mills, freezers and refrigerators) which can often follow quickly when a micro-grid is established in a village community (Sari Murni et al., 2012). This will affect total energy production and load factor. Our focus is meeting existing demand in these remote communities. However a detailed study of existing micro-grid systems would give insight on the increases in day-time loads.

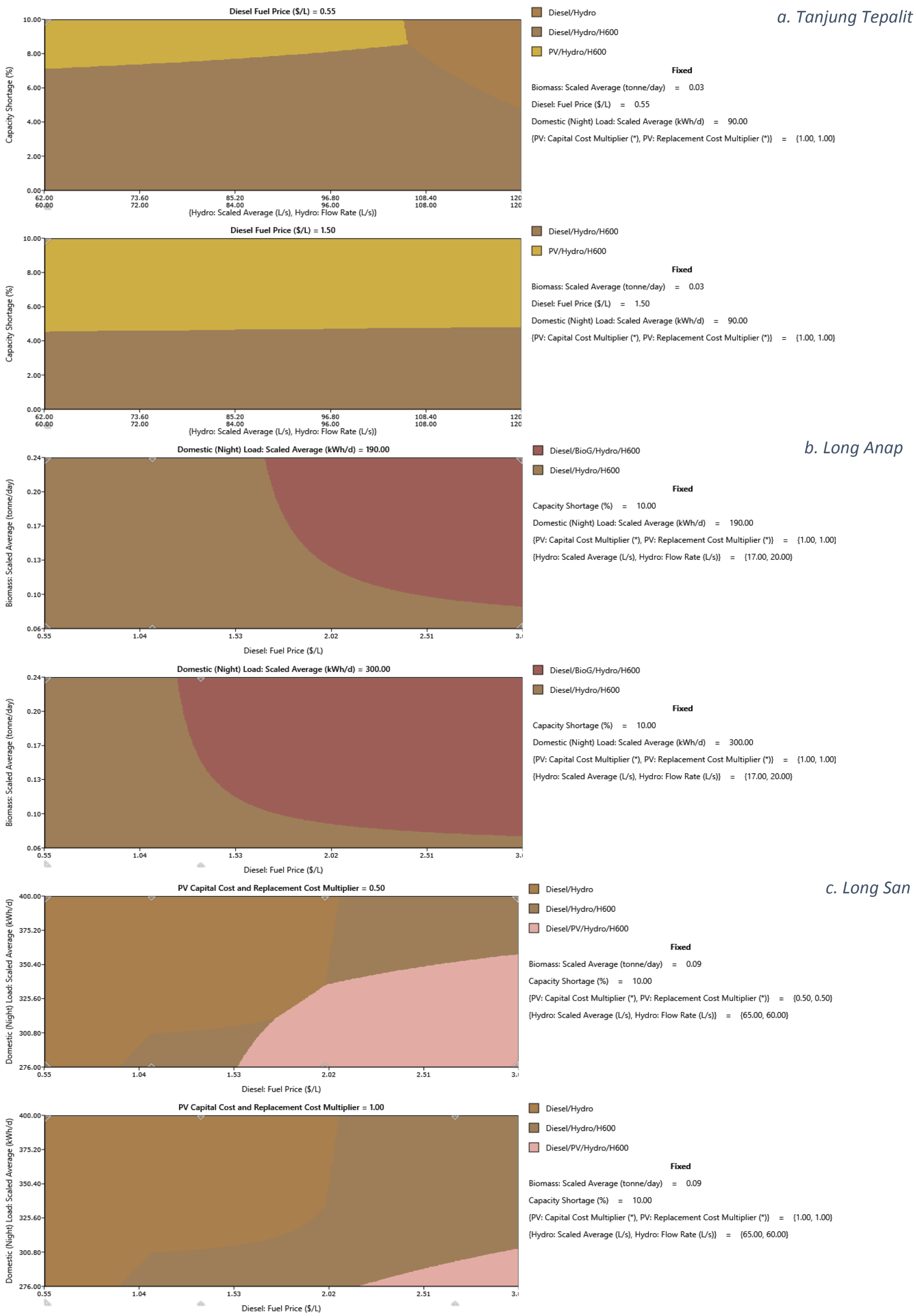

Figure 17 Optimal system configuration through sensitivity analysis on different variables

5.5. Opportunities in Providing Rural Energy Access

Our findings align with a number of recent studies which find PV, hydro-turbines and biogasification becoming more popular as micro-grid technologies (Coelho & Goldemberg, 2013). Regional successes with rice husk biogasification, such as Husk Power in India, and other forms of biomass waste use more locally - such as Kina BioPower in the neighboring state of Sabah which uses EFB waste from its mill operations - demonstrate the potential for deployment. As noted, Green Empowerment and Tonibung have many years of experience installing micro-grids and small scale renewable energy technologies across Borneo. They have installed micro-hydro turbines and the accompanying grid system in more than seventeen villages across Borneo, providing energy access to almost 400 households.

The literature discusses barriers to development of small scale technologies (Sovacool, 2012). There are the specific challenges of meeting load in dry season for hydro-turbines, maintaining constant fuel supply for biomass waste technologies, demand side management to prevent overloading, fee collection and equipment maintenance. Nevertheless these are feasible technologies as demonstrated for instance by a number of successful installations across Borneo, some operating independently for over a decade (Bhattacharyya, 2014; Sari Murni et al., 2012; S. Murni et al., 2013).

Reports and research on these existing systems highlights the opportunities that come with increased rural energy access: increased access to entertainment, new enterprises which increase household income (lighting means longer work periods for craft production, electricity means blenders and freezers which can be used for selling frozen foods and meats), improved community lighting which promotes safety, and greater access to entertainment (Borhanazad et al., 2013; Green Empowerment, 2004; Sari Murni et al., 2012; S. Murni et al., 2013). These benefits are significant to rural economic development, especially as more than 44% of Sarawak's rural population does not have access to electricity. This represents a sizeable market for stand-alone renewable energy systems. Even the local utility company SEB has cited the potential for and benefits of micro-hydro in meeting demand in remote areas and has started a rural electrification program focused largely on micro-hydro turbine technology (Sarawak Energy, 2010).

One of the most prominent Green Empowerment and Tonibung case studies is in Long Lawen - a village in which half of the residents rejected relocation plans during the inundation of the Bakun Dam in 1998 and moved to higher terrain within their ancestral land claim while the other half were resettled at the Asap Reservation. Eventually, after Green Empowerment and Tonibung completed survey works, an 8kW hydro-turbine and micro-grid network was commissioned in 2002. This project was financed in part through donation and in part through community in-kind contributions (labor and materials). In line with our findings, the new micro-grid system cost 50% less than the total prior investment in generators by the community (Green Empowerment, 2004). This micro-hydro turbine and grid system are still functional today (we visited this site). In fact, since a number of families have returned to Long Lawen from the resettlement camps, the hydro system is now being expanded.

The village and its micro-grid system also represent the role that local solutions play in social movements. In Sarawak, the micro-grid and more specifically the micro-hydro turbine, has come to take on a social symbolism for the environmental movement and in particular the indigenous grass roots movement that lobbies to save the Baram River. Groups involved in the campaign often note that as plans for the development of large scale dams with high voltage transmission in the state unfold, this has never translated into electricity access for affected or upland rural river communities. The micro-hydro system is an explicit representation of alternative use of the very same river resource. It is thus more than an end in itself, but a means to community empowerment. A new political ecology has evolved with the successful spread of micro-hydro systems across villages in East Malaysia because of this stark juxtaposition.

In 2013 Green Empowerment and Tonibung established a joint training center in Sabah, CREATE, which has training space and facilities for product testing. These spaces are used along with a specially developed technical curriculum delivered in modules to train local community members in product design and installation. In collaboration with PACOS Trust, a local community-based organization, students are also trained in community leadership skills. This is a growing operation that has evolved from technology deployment to local capacity building, creation of a local, rural industry and involvement in the indigenous environmental movement. This case study represents a novel, practical real-time application of technology for bottom up solutions.

5.5. Discussion

Increasing electricity access in largely rural states such as Sarawak requires a comprehensive 'two-track' approach involving both centralized and decentralized solutions (Tenenbaum et al., 2014). Furthermore, from a national point of view, subsidies for fossil fuels and petroleum products were together more than 10% of government operating expenditure in 2011, and accounted for more than 43% of gross development expenditure (International Institute for Sustainable Development, 2013). More than half of the gas price subsidy spending goes to the power sector and IPPs. Natural gas is the major electricity fuel source. Generators are subsidized through a centrally imposed low gas price from Petronas - the government owned gas produced and distributor. Consequently, Malaysia has the second lowest end user gas prices in Southeast Asia.

Further analysis is made difficult by the opacity of PPA information, but research stresses that fossil fuel subsidies has created an inefficient IPP sector "with bloated cost structures" (International Institute for Sustainable Development, 2013). Further, it is found that subsidies are ineffectively distributed between urban and rural communities and across economic classes, failing to mitigate the effect of relatively high fuel prices on the poor and widening the socioeconomic gap. Economic analysts find it in the government's interest to reform subsidy spending and encourage more efficient resource allocation (Hamid & Rashid, 2011; Kim et al., 2014). In fact, both the Tenth Malaysia Plan and the National Fifth Fuel Policy of 1999 highlight the importance of, and make provisions for, diversifying the generation mix as well as increasing rural electricity access (Maulud & Saidi, 2012).

The Small Renewable Energy Program (SREP) for instance was established in 2001 as a central component of contemporary Malaysian energy policy (Sovacool & Drupady, 2012). It was designed to allow renewable projects of up to 10 MW to sell their output to state utilities at set tariff levels. Though having an initial target to integrate 500 MW of small renewable energy capacity by 2005, further reduced to 350 MW by 2010, only 53 MW of capacity had been installed through the program by 2012 (Sovacool & Drupady, 2013). Despite the physical potential and economic rational that favors renewables in Malaysia, studies cite the lack of economies of scale, poor perception of commercial viability and high risk premiums for financing as major barriers to the success of SREP (Sovacool & Drupady, 2011). Since then the SREP program has been replaced through the Renewable Energy Act of 2011, which provides for the establishment and implementation of a country wide Feed-in Tariff (FiT) to catalyze investment in renewable resources.

The FiT has been established in every state except Sarawak, where energy development is happening at the fastest pace and where many marginalized communities stand to be significantly affected by energy planning decisions. Furthermore, what current incentive schemes do exist in the state do not apply to off-grid project developers. Thus further study is required on designing policy appropriate to local developers and residential communities. There are a number of proven enabling policy tools for micro-grid systems that may be applicable, such as maximum tariffs and establishing minimum quality-of-service standards (Tenenbaum et al., 2014).

When considering cost and benefit through a lens of natural capital value, diversifying energy sources along with other initiatives to green the economy have been shown to have significant economic benefit in the long run. 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 would be a crucial step toward harmonizing government development plans 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 (van Paddenburg et al., 2012). The HoB is a transboundary governmental collaboration among Brunei, Indonesia and Malaysia established in 2007 to protect over 23 million hectares of high land forest in central Borneo (van Paddenburg et al., 2012). Even this study uses economic values of biodiversity and other ecosystem services based on general ranges found in literature (van Paddenburg et al., 2012, p. 82), highlighting the need to improve local assessments. Other studies also show the remaining secondary forests of Borneo's highlands are highly valuable based on carbon stock value alone (Naidoo, Malcolm, & Tomasek, 2009). Naidoo et al. study Indonesian plans to develop a series of oil palm plantations in the HoB highlands. A rapid ecological assessment which assumes default values 15 USD/tonC and a 15% discount rate, finds these lands to have NPV of over 1,500 USD/ha based on storage potential (Naidoo et al., 2009).

Thus the discussion of appropriate energy landscapes will change as we also consider rural economy, forest land value, ecotourism value, biodiversity and other ecosystem service values. My study shows example of models that use multiple criteria to determine appropriate energy resources for investment. In participatory management schemes or multi-criteria decision analysis approaches that explicitly consider tradeoffs amongst criteria other than project cost, methods such as the one presented are critical to inform planning priority. In our case study a tense state and national level debate on the suitability of the hydroelectric dams is unfolding, involving widely ranging stakeholders -- affected village communities, subsistence farming populations, commercial plantation interests, timber interests, land-rights advocacy groups, conservationists, utility companies, forest management authorities and state development planners (Sovacool & Bulan, 2011b, 2012b).

Our first method allows these stakeholders to gauge the risk to species population and settlement that different energy regimes represent. Regardless of the weight or priority that different stakeholders give to species abundance, the ability to collectively consider this risk in manageable terms allows for more informed opinions and discussion of tradeoffs. At the global scale, carbon storage and biodiversity values of preserving forest lands are high, but mechanisms such as this help make that value relevant to national and local interests. Comprehensive approaches for estimating national and state level energy production potentials from renewable energy sources are still few and often not transparent. This is especially the case for developing countries (IRENA, 2014). Our study contributes to this gap by providing indicative estimates of the solar, biomass and hydro energy potential in Sarawak. These estimates can be used for transparent energy modeling and energy systems analysis, which is the basis for proper energy planning.

It is important to make sure that economies at the village and rural levels are integrated and their parameters accommodated into any green economy framework. This chapter uses another method to show the potential of distributed resources to improve rural energy access as well. Together this is an example of how existing rapid assessment tools can be used in combination to include spatial, biophysical and human infrastructure variables in designing energy landscapes. Future work will involve expanding the model to include other ecosystem services. We use biodiversity as one proxy for ecosystem service or land value. But the extent to which locations valuable for biodiversity also coincide with ecosystem services of critical importance requires further investigation for designing constraints and land management strategies. Landscape levels of such covariance is necessary. Existing studies show that the relationship may be very location specific and difficult to generalize, even for an island (Anderson et al., 2009). However the very location specific nature of ecosystem service underscores the importance of multi-scale environmental decision making, or a resource planning continuum (Stoeglehner, Niemetz, & Kettl, 2011).

CHAPTER SIX
Conclusion

6.1. Contextualizing Energy Infrastructure

The preceding analysis focuses on the debate over hydropower development in Northern Borneo. This case study exemplifies the many conflicts revolving around energy infrastructure that are increasingly prevalent in the twenty first century's developing country regions. I began by conceptualizing energy infrastructure as a socio-technical system, a technical system embedded within existing socio-political environments. Energy infrastructure is influenced by and in turn influences relationships between people and resources - which has implications for both local and global landscapes. The goal of this dissertation, then, is to deconstruct a local energy infrastructure conflict and explore the question of how modeling can support a more integrated planning framework.

I start in Chapter Two by using a critical political ecology approach to explore the dynamic relationships between people, nature and the mega-dams in Sarawak. Such analysis fills an important niche since to date there is little critical analysis of this conflict in the literature. I find that relationships governing development of the hydropower sector – the pool of actors and their respective claims over rights to resource – have evolved out of and operate in parallel to the relationships that have historically governed other primary commodities in Southeast Asia. As Nevins and Peluso observe, 'commodity orientations have penetrated contemporary capitalist societies so profoundly that we can speak of them as commodity producing societies, ones in which almost everything is potentially for sale, and where the *social* has been extracted from new commodity forms' (Nevins & Peluso, 2008, p. 15).

In decomposing actors and claims we saw the direct use of political power to accumulate personal wealth from resources; the use of law as a mechanism for the denial of land rights, displacement and enclosure of spaces; and the use of law to criminalize dissention and to create barriers for public participation and access to knowledge. We saw that benefits to local communities and landscapes are largely foregone in the current top-down centralized model of intensive large-scale hydro development. Yet these communities bear the true costs of the dams through increased insecurity, loss of livelihoods and land rights violations.

My analysis highlights that Sarawak's commodification of large-scale hydro resources is proceeding in ways that retain 'the residue of authoritarian, centralized government' (Rob A. Cramb, 2007a). Hydro resource commoditization through the SCORE mega-dam agenda can thus be seen as a recycled 'high modernist' form of state control, where the state continues to use its power of land rights designation to redistribute resource wealth and the benefits of development (Rob A. Cramb, 2007b).

Such articulation has broad implications for the processes of planning, decision-making and hydro governance in Sarawak. First of all, as we saw, there are clear inadequacies in the state's land and forest-related legislation, which allow concessions and licenses to be established on indigenous communities' customary land without their free, prior and informed consent. As exemplified by recent gazette announcements on land acquisition, the state's authority to declare what is and is not legal almost always takes precedence over any claims for forest rights by the indigenous communities. The lack of transparency or regulation in the issuance of such concessions and licenses creates highly charged conflict situations across space and time and generations. Yet Sarawak law is also inadequate in establishing mechanisms for resolving conflict between industry and indigenous communities as we observed in the lethargic treatment of land dispute court cases.

Beyond these legal and regulatory issues there are also more immediate implications for knowledge production and planning. Through my analysis it also became clear that at the heart of the hydro resource conflict in Sarawak are differences in the definitions and understanding of concepts such as 'energy security'. These differences then influence ideas of 'problem' and 'solution' and reflect the situated perspectives of different actors in the conflict. Even scientific knowledge, we have seen, is part of a narrative, and can be used to shape popular perceptions of problems and solutions. This highlights the exploration of diverse problem understandings as a critical first-step to integrated problem solving.

6.2. Current Debates on the Role of Modeling

Initiatives that orient themselves around problem solving without precedent of consensus on the definition of 'problem' run the risk of undermining their own objectives by pre-determining the ways in which the problem can be conceptualized and discussed and solutions assessed. In fact, some scholars see defining the problem space versus problem solving itself as separate objectives and chronological stages in decision-making (Ramsey, 2009). There are inherent biases in the interpretation of information and results that come from different disciplines of analysis and different perspectives of the problem definition. Thus, whether intentional or not, every map, every model, every graph result actually tells a particular kind of story that represents a particular perspective on the idea of 'problem'.

Some authors argue that this inherent bias can become manifest in the role that technical assessment and 'scientific authority' have in participatory processes, as the knowledge production space can be used for the exercise of cultural hegemony (Kakonen & Hirsh, 2014). A model and its results can become the central focus of negotiation and thus a key factor in establishing the language of a debate. However, according to King and Kraemer, a model's ability to forward different perspectives and support different biases is arguably its greatest contribution to decision-making (King & Kraemer, 1993b). King and Kraemer study the political nature of models, their uses and outcomes and argue that the effective use of models in decision-making ironically depends on making them political. This has been true since the early introduction of models into the political process in the 1980's, starting with economics and social welfare. King and Kramer find that as modeling spread to other domains like agriculture, transportation, health care and energy the same held true - models are useful as weapons in debate.

More than provide a base of information or analysis that produces some universally correct answer, models are a means to facilitate discussion and provide defensive or offensive support to particular parties in the discussion depending on model design. To some this is an unfortunate politicizing use of models. To others, this very politicizing is what allows scientific modeling to be part of the anti-politics machine. And yet to others this shows that models can be incorporated into inherently political processes of democratic decision-making and the separation of modeling from politics would be the surest way to marginalized models as tools for policy analysis (King & Kraemer, 1993b; Biggs, 2008; Ramsey, 2009; Kakonen & Hirsh, 2014). Rather than conceive of models as 'arms' political warfare, I find that the very nature of the inherent assumptions and biases in models allows them to act as 'bounding objects' of conflict (King & Kraemer, 1993b). When used appropriately, a model helps identify core issues of debate through focused disciplinary attention on topics of concern and by bounding the space of possible outcomes.

Multi-criteria land use suitability models and optimization models all pre-determine the ways in which the energy problem can be conceptualized – namely as a trade-off between multiple quantitative criteria. This is useful only to the extent that all parties agree on the definition of the problem, the conceptualization of the problem space and the discipline(s) of analysis. In the remaining chapters of this dissertation I therefore explored ways in which energy system modeling and spatial modeling tools can be used in integrative fashion to broaden the understanding of problem and solution spaces for energy infrastructure development in the case of Sarawak. The overarching goal of this body of work is to contribute to improved methods of energy planning in the South. In the following section I will briefly reflect on major findings and limitations of this research.

6.3. Review of the Developed Models and Limitations

6.2.1. Modeling Energy Systems at Different Scales

I began by using macro- and micro- power system simulation models to explore both commercial and rural energy demand and supply opportunities. PLEXOS is a very powerful integrated power market simulation software with wide ranging functionality. HOMER is a program whose fundamental function is simulating operation of micro-power systems. In using one model with power market focus and one model with micro-grid specificity, I am able to simulate large and small scale systems, use linear programming to earmark optimal configurations over the long-term, according to specified objective functions and with sensitivity analysis on chosen parameters.

In Chapter Three I began with PLEXOS' capacity expansion module to determine the least cost dispatch for generating resources to meet future energy demand in Sarawak under a range of economic assumptions. I used a deterministic linear programming technique to minimize expected cost subject to reliability constraints, and based on assumptions of current and future fuel costs, and technology and environmental costs. I used my model setup to consider the technical and environmental trade-offs of various energy technology mixes over the long-term (fifteen years) under different policy and market scenarios.

My results from this exercise highlight the gross overestimation of generation capacity required to satisfy even high expectations of growth despite the rationale behind the plans. My results also highlight the potential for distributed energy infrastructure to displace large centralized dams under incentive schemes such as Feed in Tariffs or Renewable Portfolio Standards. These findings are consistent with other studies that find PV and waste-to-energy technologies to be feasible for Borneo and support the case for incentivizing and incorporating small power producers into future energy infrastructure development plans (Abnisa, Daud, Husin, & Sahu, 2011; Shafie et al., 2012; Sulaiman et al., 2011).

In Chapter Five I described planning tools for rural application. I used HOMER to perform a comparative analysis between diesel, hydro, biomass waste and photovoltaic technologies, to observe the field performance of different off-grid generation technologies in the Baram. Through simulation I used HOMER to identify feasible systems within the search space that I specified based on village energy audits and available localized resource data. These are sorted according to total net present life cycle cost in HOMER so that the optimal system is defined as the configuration which minimizes total cost and which meets modeler specified constraints. I performed this study for three representative villages.

In this study I found that rural communities pay much more relative to income on energy services than their urban counterparts and that this situation does not become resolved through resettlement. Village households can spend twice as much as urban households on electricity. Given the natural resources that exist in these areas, energy access can be provided at lower cost than through the current diesel default using small-scale technology solutions such as micro run-of-river hydroelectric systems. I find the main drawback of renewable energy systems is reliability, especially during the dry season and especially as existing land use activity has altered stream flow patterns.

There are a number of limitations faced in applying these types of energy system models. The most significant was quality of data. Both analyses were affected by poor demand data due to the lack of local historical data from the utility company. There is also little data on the type of industry anticipated under SCORE, so it is difficult to forecast future demand profiles. Ideally demand would be represented as a chronological time series at high (30 minute or less) resolution. Instead of a chronological demand profile I used Load Duration Curves (LDC) or a series of demand blocks. This then meant I was not able consider technical characteristics such as minimum stable generation, ramp rate constraints, minimum up and down times, start costs and fuel costs in simulating system operation which subsequently limits my consideration of reliability as a constraint. I therefore used basic metrics for reliability – reserve capacity and capacity shortage, rather than more sophisticated standard utility metrics such as Loss of Load Expectation. In modeling rural villages I also use granular demand blocks, though there is likely less fluctuation at this scale.

Another consequence of the lack of data is in the consideration of variability. Variability comes from both demand and resource availability fluctuations. Variation occurs at various time scales. Hourly and daily variations are important for power system modeling. Variability of power sources in a power system can cause issues for system balancing and affect the commitment and dispatch of conventional power. In general the more variability within a power system the more flexible the power system is required to be. The challenge when modeling variable generation is to ensure the adequate representation of the variable source. Modeling demand through LDC rather than time series makes simulating interactions across time scales difficult. I am able to approximate renewable energy integration but higher resolution data in the future will allow for a more refined examination of the impacts of high levels of renewables on the local grid system.

Together these models highlight different perspectives on the idea of 'demand' that need to be included in the planning process. My study is the first instance of a commercial energy model being applied to SCORE, and one of the first instances of PLEXOS being used for Southeast Asia in the academic literature. It represents a contribution to the public conversation by demonstrating a framework for integrated analysis despite data constraints.

6.2.2. Spatial Modeling and Multi-criteria Decision Support

I then used two spatial analysis methods to address direct inclusion of multiple stakeholder perspectives and objectives in the assessment process. Reconciling development objectives with stakeholder values (or visions) is the most important task of the planning process. In spaces of critical global ecological importance and multiplicity of stakeholder representations, such as Borneo, this process is even more challenging. Adapting multi-criteria decision analysis tools and their systems of weighted valuation to local contexts may at best represent a practical way to incorporate economic, ecological and cultural differences into the planning framework, and at least represents a means of generating knowledge on development opportunities, risks and impacts for public digestion.

Recent advances in multi-criteria decision analysis tools and the availability of high resolution global spatial data sets together provide new ways of explicitly exploring local land use change while considering the preferences and objectives of multiple stakeholders (Malczewski, 2004). New high-resolution satellite imagery data now provides highly accurate metrics of variables such as forest cover, carbon storage and biodiversity, variables which were either poorly measured or largely undocumented by conventional satellite approaches (Bryan et al., 2013; de Bruyn et al., 2014; Dong et al., 2014; Hansen et al., 2013). Along with more flexible power system models (such as those described above), and constantly evolving methods for forecasting environmental impacts, there is a new era of scientific methods that may offer opportunities to advance and modernise the planning process to be more inclusive and also more refined.

In the first spatial study we addressed biodiversity in particular. We used a hybrid top-down and bottom-up approach to the indirect estimation of biodiversity impacts. I used global species range data and GIS functionality to calculate the fraction of total and local species range affected by direct habitat loss from different energy projects for birds and mammals. With published population density data and allometric scaling relationships I extended these results to estimates of individual organisms lost and species extinctions anticipated. We used macro-ecological scaling laws and local survey data to do the same for tree and arthropods.

Applying these methods to the three most immediately planned dams under SCORE (Bakun, Baram and Murum) I found that although the dam reservoirs represent only 0.2% of Borneo's total land area, conservatively they together affect more than 55% of all bird, mammals, tree and arthropod species found on the island. These results find commonality with a recent literature on Bornean biodiversity and projections of climate change impact. This method allows stakeholders to gauge the risk to species population and settlement that different energy regimes represent. Regardless of the weight or priority that different stakeholders give to species abundance, the ability to collectively consider this risk in manageable terms allows for more informed opinions and discussion of tradeoffs. At the global scale, carbon storage and biodiversity values of preserving forest lands are high, but mechanisms such as this help make that value relevant to national and local interests.

There are a number of limitations to the method developed. First, the application of area scaling laws do not account for topography. In Sarawak the steep slopes of the central highlands which I am studying are likely to contain greater diversity of abiotic conditions and thus higher numbers of species and individuals than predicted. Furthermore, neither estimates from scaling laws nor habitat range maps will reflect impacts at the subspecies or local population level and do not account for undiscovered species. Finally, our study focuses on the land footprint of energy infrastructure, and in this case, the dam reservoir area in particular. A full accounting of biodiversity impacts from the dams would require additional study on the impact of roads and other civil works, downstream changes to the river and resulting flood regimes and more. This was beyond the scope of our study but highlights a useful area for future work.

In the second spatial study I explore a broad platform for bringing many data types and objectives to the same table for conversation. I take a multi-criteria decision analysis approach to GIS and use publicly available data sets to create a multi-layered spatial representation of Sarawak. By combining these layers with energy resource data, I then use opportunities and constraints to identify suitable areas for distributed energy technology development. I apply this method to compare the mega-dam business as usual scenario with a distributed energy scenario.

The study shows that total capacity needs in the future can be provided through the distributed scenario, while excluding areas of socio-cultural and ecological importance. I find that together solar and biomass could represent an additional 1.5 GW of capacity in addition to already built dams and existing thermal generation, satisfying demand under assumption that energy demand from 2012 increases at a 7% growth per annum for both total annual energy and maximum demand. As solar and biomass are constrained to non-forested areas the impact on biodiversity is significantly reduced in the Distributed scenario. My future work will be to prepare an expanded Borneo-wide model that captures more ecological services using new spectral imagery LiDAR data to be collected in 2016 by the Carnegie Airborne Observatory[8].

Comprehensive approaches for estimating national and state level energy production potentials from renewable energy sources are still few and often not transparent, especially in developing countries (IRENA, 2014). My study contributes to this gap by providing indicative estimates of the solar, biomass and hydro energy potential in Sarawak which can be used for transparent energy modeling and energy systems analysis. Together these complementary spatial studies show examples of models that incorporate multiple criteria to determine appropriate energy resources for investment. In participatory management schemes or multi-criteria decision analysis approaches that explicitly consider tradeoffs amongst criteria other than project cost, methods such as the one presented are critical to inform planning priority.

[8] https://cao.carnegiescience.edu/

6.4. Contributions of My Work

Inherent bias aside, knowledge production and distribution have a major role to play in shifting perspectives on development objectives and options (Hirsch, 2002). In this dissertation, without defaulting to pure economic valuation theory, I present an assembly of decision support tools to identify actions for assessing energy infrastructure through techno-economic and socio-ecological objectives, including multiple-objective optimization algorithms, ecological impact modeling, multi-criteria spatial analysis and cost-benefit analysis. Together this provides example of how existing rapid assessment tools can be used in combination to include spatial, biophysical and human infrastructure variables in designing energy landscapes.

These studies not only address the wide gap in environmental information in contexts such as East Malaysia were data is limited, but they also extend the possibilities for informed decision-making on development alternatives. They challenge the relatively closed status quo planning process and arm civil societies with information for formulating opinion, which supports the participatory process. Energy demand in the region is growing rapidly and the need for energy solutions is imminent. My study shows key areas for improving governance and energy planning in the state. The socio-political planning structure in Sarawak, while complex, would benefit from greater participation, inclusion of local knowledge, inclusion of growing pool of local energy technology developers, increasing information access, lateral coordination and support from state government ministries and federal support. Addressing these challenges could improve the model for energy planning in the state, with implication for planning in other developing economies at similar crossroads.

Important priorities for future research and practice include: defining formal frameworks of communication between actors, exploration of necessity and developing methods for integration of objectives. Deliberative and participatory methods will be needed to facilitate development in these fields and enable the opportunities and constraints for effective management to be identified, pursued and overcome. Only by increasing public participation and transparency in decision making with decentralization of institutional power at national, regional and global levels, will appropriate energy projects be pursued to provide sustainable and socially beneficial outcomes for the future.

Personally, I have found the exercise of deconstructing an energy resource conflict in a developing country to be very instructive. Beyond the tools gained in this process, it has sensitized me to the potential for cultural hegemony in different spaces, especially given my own role as a producer of scientific knowledge. I will continue to observe the unfolding of SCORE over time. Even within in the two years that I have worked on this case study, there has been a marked growing awareness of the conflict and articulation of its issues both locally and globally. The progression of the hydropower mission has been neither smooth nor unquestioned. The controversial consequences of dam building are patently visible in Bakun, which is now mired in controversy and scandal, and which, two years after its commissioning is still operating at less than half capacity.

Meanwhile many innovations in micro-grid technology, design and economics are being made by project developers working in Borneo and throughout Southeast Asia. Small-scale grid solutions have arguably been the fastest growing sector of the global energy system over the past few years. And at the time of writing, the Baram blockades have just celebrated their second anniversary, making this the longest standing dam blockade in Sarawak's history. Only a few weeks prior, the new Chief Minister publicly declared a moratorium on the Baram Dam and has ordered all civil work to cease. Furthermore, popular new studies on dam economics (Ansar et al., 2014) and greenhouse gas impacts (Deshmukh et al., 2014; dos Santos, Rosa, Sikar, Sikar, & dos Santos, 2006) are drastically changing the global discussion on the sustainability of energy infrastructure in relation to the global commons. The findings in this dissertation contribute to that growing literature and, I hope, have done justice to the people of Sarawak.

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APPENDICIES

APPENDIX A

List of Institutions Interviewed, 2013-2014

1. State and Federal Agencies

   - The Chief Minister of Sarawak
   - Sarawak Energy Berhad (SEB)
   - Malaysia Energy Commission
   - Sabah Energy Corporation Sdn Bhd (SESB)
   - Sarawak Forestry Department
   - Sabah Forestry Department
   - Sarawak Department of Irrigation and Drainage

2. Civil Society Groups

   - Save Rivers
   - Jaringan Orang Asal SeMalaysia (JOAS)
   - Center for Orang Asli Concerns (COAS)
   - Partners of Community Organization Sabah (PACOS Trust)

3. Malaysian Environmental NGOs

   - Malaysia Nature Society
   - South East Asia Rainforest Research Program (SEARP)
   - Center for Environmental Technology and Development Malaysia
   - Land, Empowerment, Animals, People (LEAP)

4. Directly Supporting International Advocacy NGOs

   - International Rivers
   - Bruno Manser Fonds
   - The Borneo Project

5. Federal Development Agencies

   - Sustainable Energy Development Authority
   - Human Rights Commission of Malaysia, Sabah Commissioner

6. Regional/International Governance Agencies

   - Association for Southeast Asian Nations (ASEAN)
   - United National Development Program (Regional Office)
   - USAID Regional Development Mission for Asia

7. International Non-Governmental Organizations

- World Wildlife Fund
- Wetlands International
- Roundtable On Sustainable Palm Oil
- Sustainable Forestry Council

8. Local Renewable Energy Technology Developers

- Cymao Plywood
- Seguntor Bioenergy
- Kinta Biomass Plant
- Wilmar Plantations
- Tonibung

9. Local Academia

- UNIMAS, Sociology
- UNIMAS, Center of Excellence for Renewable Energy
- University of Malaysia, Economics and Law
- University Tenega Malaysia, Engineering

10. Indigenous Villages

- Long San
- Long Liam
- Tanjung Tepalit
- Long Selatong Dikan
- Long Apu
- Long Anap
- Long Keluan
- Long Na'ha
- Long Lawen
- Long Lama
- Sungai Asap
- Mundung Abun

Appendix B

Additional PLEXOS Model Results

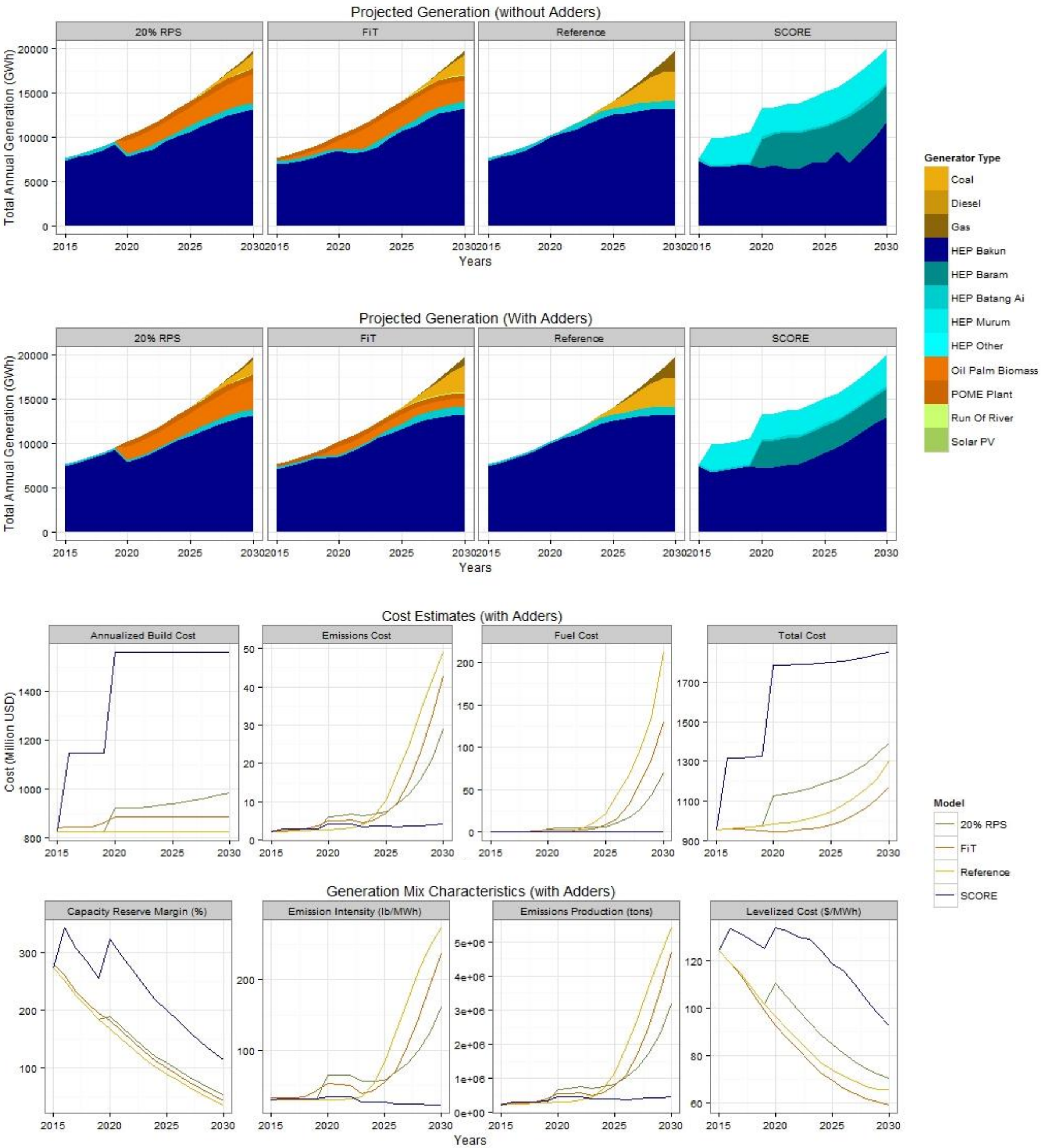

Figure 1 Generation Profile, Cost Components and Generation Characteristics of Scenarios under 7% Demand Growth

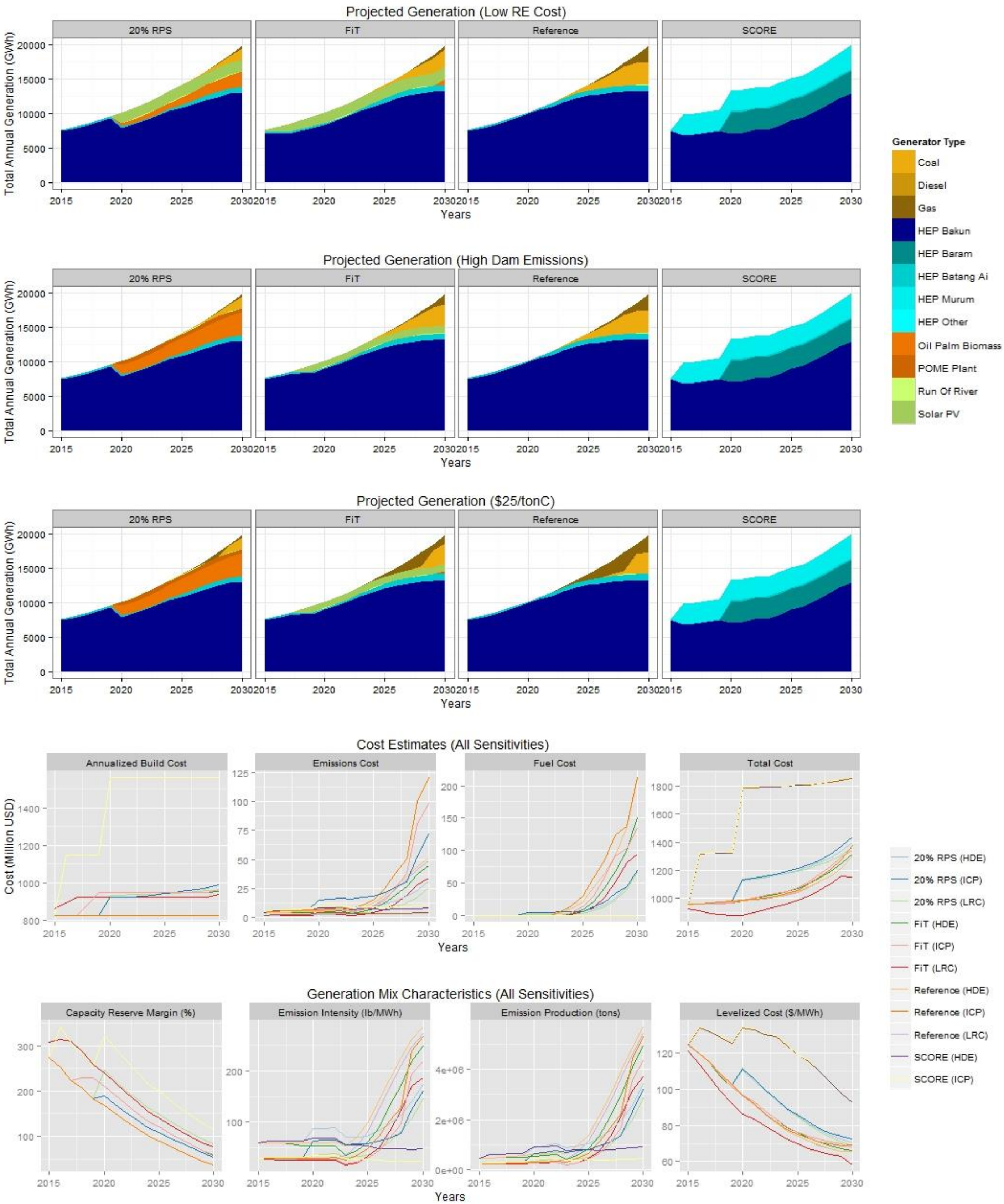

Figure 2 Generation Profile, Cost Components and Generation Characteristics of Sensitivity Scenarios under 7% Growth. [LRC = Low RE Cost; HDE = High Dam Emissions; ICP = Increased Carbon Price]

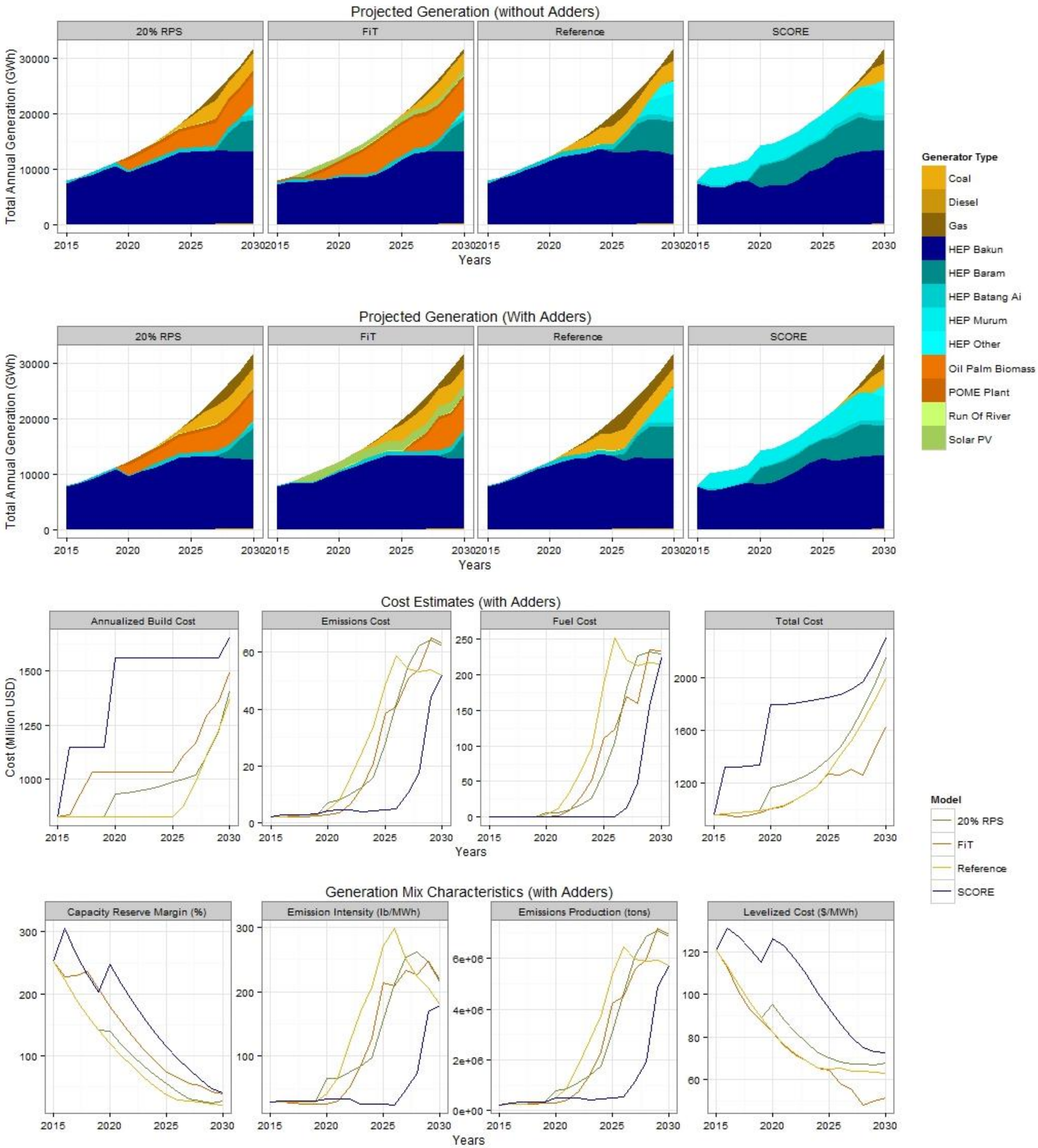

Figure 3 Generation Profile, Cost Components and Generation Characteristics of Scenarios under 10% Demand Growth

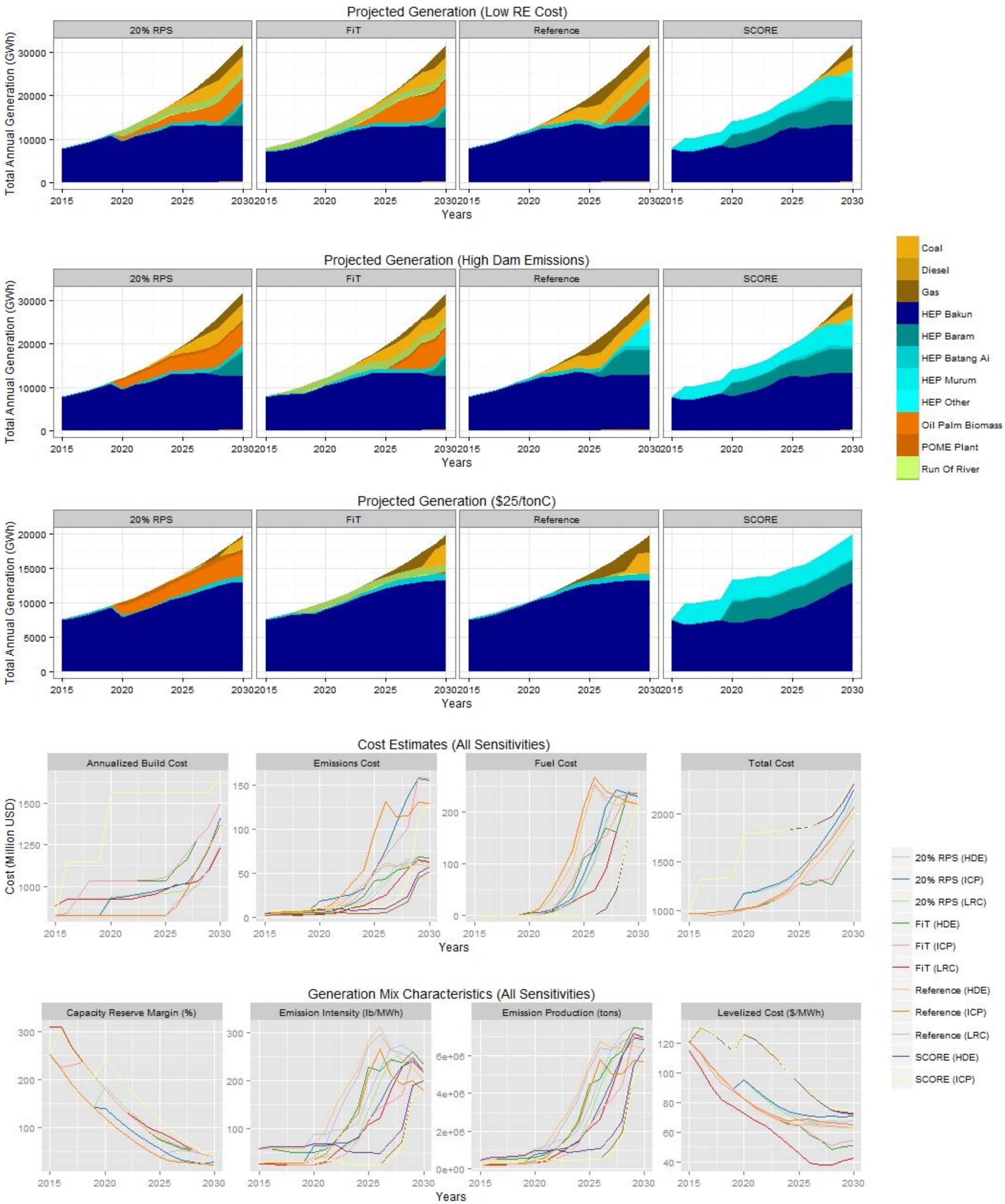

Figure 4 Generation Profile, Cost Components and Generation Characteristics of Sensitivity Scenarios under 10% Growth. [LRC = Low RE Cost; HDE = High Dam Emissions; ICP = Increased Carbon Price]

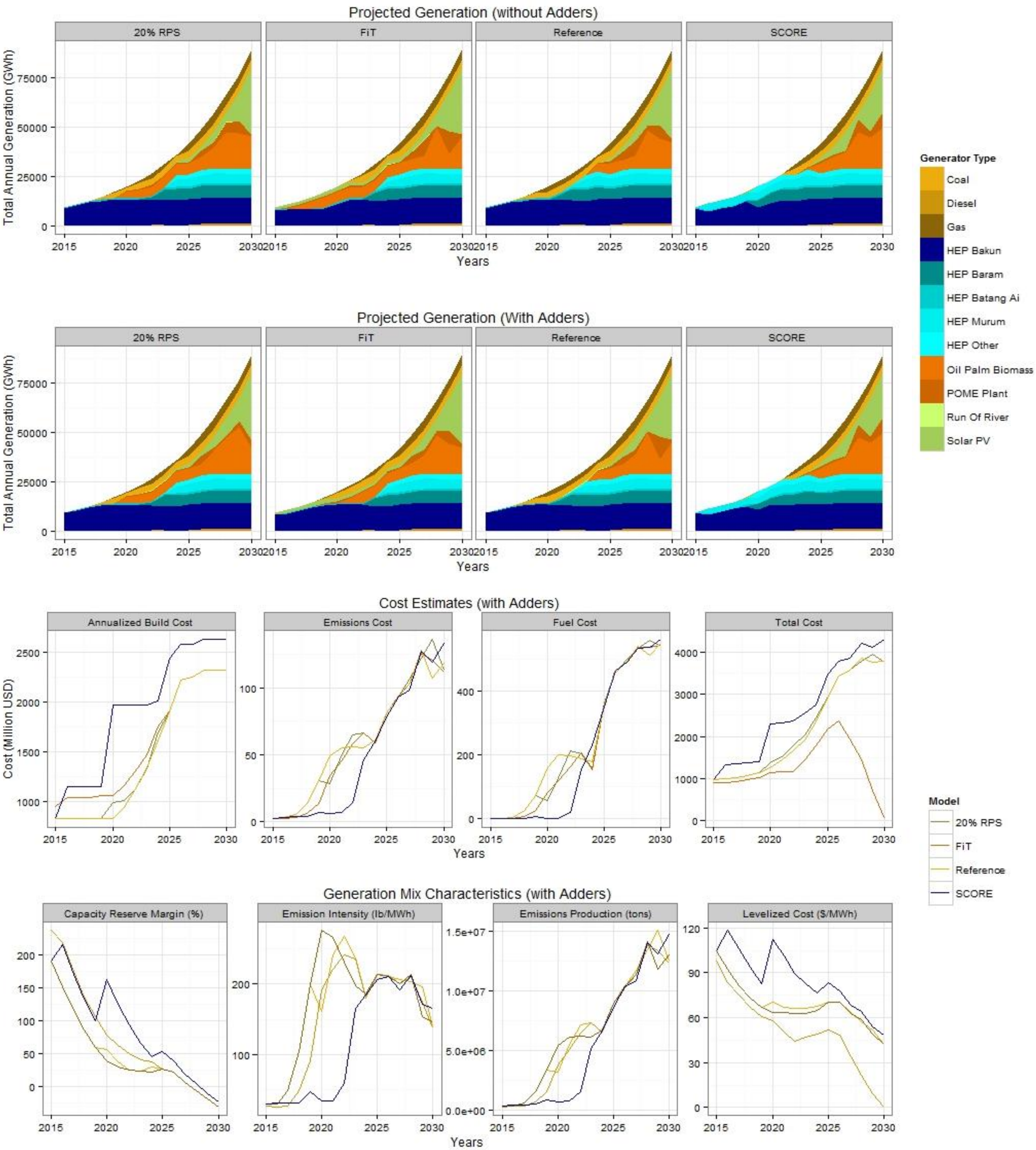

Figure 5 Generation Profile, Cost Components and Generation Characteristics of Scenarios under SCORE Assumptions for Growth

APPENDIX C

Table 1: Total Area of Habitat and Fraction of Global Range Lost by Species

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Mammal	Aeromys tephromelas	DD		341		341	0.09%
Mammal	Aeromys thomasi	DD	701	414	242	1357	0.30%
Mammal	Aethalops alecto	LC	12	414	237	663	0.10%
Mammal	Aonyx cinerea	VU	701	414	242	1357	0.03%
Mammal	Arctictis binturong	VU	701	414	242	1357	0.04%
Mammal	Arctogalidia trivirgata	LC	701	414	242	1357	0.05%
Mammal	Balionycteris maculata	LC	701	414	242	1357	0.24%
Mammal	Callosciurus adamsi	VU	322		53	375	0.42%
Mammal	Callosciurus baluensis	LC		414	95	509	1.05%
Mammal	Callosciurus notatus	LC	701	414	242	1357	0.09%
Mammal	Callosciurus orestes	LC		414	15	429	0.85%
Mammal	Callosciurus prevostii	LC	701	414	242	1357	0.10%
Mammal	Catopuma badia	EN	701	414	242	1357	0.50%
Mammal	Cheiromeles torquatus	LC	701	414	242	1357	0.10%
Mammal	Chiropodomys major	DD	701	414	242	1357	0.18%
Mammal	Chiropodomys muroides	DD	328	401	9	738	0.38%
Mammal	Chiropodomys pusillus	DD	701	414	242	1357	0.18%
Mammal	Crocidura foetida	LC	701	414	242	1357	0.18%
Mammal	Crocidura monticola	LC	701	414	242	1357	0.10%
Mammal	Cynogale bennettii	EN	701	414	242	1357	0.12%
Mammal	Cynopterus brachyotis	LC	701	414	242	1357	0.05%
Mammal	Cynopterus horsfieldii	LC	701	414	242	1357	0.09%
Mammal	Cynopterus minutus	LC	701	414	242	1357	0.09%
Mammal	Dendrogale melanura	DD	581	87	242	910	1.31%
Mammal	Diplogale hosei	VU		370		370	1.65%
Mammal	Dremomys everetti	LC		68	26	94	0.14%
Mammal	Dyacopterus spadiceus	NT	346	345		691	0.15%
Mammal	Echinosorex gymnura	LC	701	414	242	1357	0.10%
Mammal	Emballonura alecto	LC	701	414	242	1357	0.11%
Mammal	Emballonura monticola	LC	701	414	242	1357	0.08%
Mammal	Eonycteris major	DD	701	414	242	1357	0.18%
Mammal	Eonycteris spelaea	LC	701	414	242	1357	0.04%
Mammal	Exilisciurus exilis	DD	701	377	242	1320	0.19%
Mammal	Exilisciurus whiteheadi	LC	701	414	242	1357	0.87%
Mammal	Galeopterus variegatus	LC	671	391	111	1173	0.08%
Mammal	Glischropus tylopus	LC	701	414	242	1357	0.05%
Mammal	Helarctos malayanus	VU	701	414	242	1357	0.03%
Mammal	Hemigalus derbyanus	VU	701	414	242	1357	0.10%
Mammal	Herpestes brachyurus	LC	701	414	242	1357	0.11%
Mammal	Herpestes semitorquatus	DD	701	414	242	1357	0.18%
Mammal	Hipposideros bicolor	LC	701	414	242	1357	0.09%
Mammal	Hipposideros cervinus	LC	701	414	242	1357	0.07%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Mammal	Hipposideros diadema	LC	701	414	242	1357	0.04%
Mammal	Hipposideros doriae	NT	701	414	242	1357	0.11%
Mammal	Hipposideros dyacorum	LC	701	414	242	1357	0.18%
Mammal	Hipposideros galeritus	LC	701	414	242	1357	0.06%
Mammal	Hylobates muelleri	EN	701	414	242	1357	0.26%
Mammal	Hylomys suillus	LC	165	414	242	821	0.05%
Mammal	Hylopetes lepidus	DD		414		414	0.22%
Mammal	Hylopetes spadiceus	LC	701	414	242	1357	0.12%
Mammal	Hystrix brachyura	LC	701	414	242	1357	0.02%
Mammal	Hystrix crassispinis	LC	701	414	242	1357	0.18%
Mammal	Iomys horsfieldii	LC	701	414	242	1357	0.17%
Mammal	Kerivoula hardwickii	LC	701	414	242	1357	0.03%
Mammal	Kerivoula intermedia	NT	701	414	242	1357	0.16%
Mammal	Kerivoula papillosa	LC		363		363	0.05%
Mammal	Kerivoula pellucida	NT	701	414	242	1357	0.11%
Mammal	Kerivoula whiteheadi	LC		414	237	651	0.29%
Mammal	Lariscus hosei	NT		338	21	359	0.68%
Mammal	Lariscus insignis	LC	481	381	227	1089	0.08%
Mammal	Lenothrix canus	LC	701	408	227	1336	0.56%
Mammal	Leopoldamys sabanus	LC	701	414	242	1357	0.05%
Mammal	Lutra sumatrana	EN	701	414	242	1357	0.22%
Mammal	Macaca fascicularis	LC	701	414	242	1357	0.05%
Mammal	Macaca nemestrina	VU	701	414	242	1357	0.10%
Mammal	Macroglossus minimus	LC	701	414	242	1357	0.04%
Mammal	Manis javanica	CR	701	414	242	1357	0.06%
Mammal	Martes flavigula	LC	701	414	242	1357	0.02%
Mammal	Maxomys baeodon	DD		189		189	0.24%
Mammal	Maxomys ochraceiventer	DD	701	414	242	1357	0.54%
Mammal	Maxomys rajah	VU	701	414	242	1357	0.10%
Mammal	Maxomys surifer	LC	701	414	242	1357	0.05%
Mammal	Maxomys whiteheadi	VU	701	414	242	1357	0.10%
Mammal	Megaderma spasma	LC	701	414	242	1357	0.03%
Mammal	Megaerops ecaudatus	LC	701	414	242	1357	0.11%
Mammal	Megaerops wetmorei	VU	701	414	242	1357	0.81%
Mammal	Miniopterus australis	LC	701	414	242	1357	0.06%
Mammal	Miniopterus fuliginosus	LC	701	414	242	1357	0.01%
Mammal	Miniopterus magnater	LC	701	414	242	1357	0.04%
Mammal	Miniopterus medius	LC	701	414	242	1357	0.11%
Mammal	Muntiacus atherodes	LC	701	414	242	1357	0.18%
Mammal	Muntiacus muntjak	LC	701	414	242	1357	0.09%
Mammal	Murina suilla	LC	701	414	242	1357	0.09%
Mammal	Mustela nudipes	LC	701	414	242	1357	0.10%
Mammal	Mydaus javanensis	LC	701	414	242	1357	0.12%
Mammal	Myotis gomantongensis	LC	701	414	242	1357	0.18%
Mammal	Myotis hasseltii	LC	701	414	242	1357	0.14%

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Mammal	Myotis horsfieldii	LC	701	414	242	1357	0.05%
Mammal	Myotis muricola	LC	701	414	242	1357	0.03%
Mammal	Myotis ridleyi	NT	701	414	242	1357	0.16%
Mammal	Nannosciurus melanotis	LC	701	414	242	1357	0.13%
Mammal	Neofelis diardi	VU	701	414	242	1357	0.28%
Mammal	Niviventer cremoriventer	VU	701	414	242	1357	0.11%
Mammal	Niviventer rapit	LC	701	414	242	1357	0.54%
Mammal	Nycteris tragata	NT	701	414	242	1357	0.10%
Mammal	Nycticebus menagensis	VU	701	414	242	1357	0.18%
Mammal	Paguma larvata	LC	701	414	242	1357	0.02%
Mammal	Paradoxurus hermaphroditu	LC	701	414	242	1357	0.02%
Mammal	Pardofelis marmorata	VU	701	414	242	1357	0.09%
Mammal	Penthetor lucasi	LC	701	414	242	1357	0.11%
Mammal	Petaurillus emiliae	DD		14		14	4.73%
Mammal	Petaurillus hosei	DD		141		141	0.19%
Mammal	Petaurista elegans	LC		273		273	0.01%
Mammal	Petaurista petaurista	LC	701	414	242	1357	0.04%
Mammal	Petinomys genibarbis	VU	701	414	242	1357	0.16%
Mammal	Petinomys setosus	VU	701	414	242	1357	0.19%
Mammal	Petinomys vordermanni	VU		356		356	0.31%
Mammal	Philetor brachypterus	LC	701	414	223	1338	0.10%
Mammal	Pipistrellus stenopterus	LC	701		179	880	0.14%
Mammal	Presbytis frontata	VU	700	66	242	1008	0.32%
Mammal	Presbytis hosei	VU	414	414	242	1070	0.43%
Mammal	Presbytis rubicunda	LC		414	242	656	0.13%
Mammal	Prionailurus bengalensis	LC	701	414	242	1357	0.01%
Mammal	Prionailurus planiceps	EN	614	405		1019	0.41%
Mammal	Prionodon linsang	LC	701	414	242	1357	0.09%
Mammal	Pteromyscus pulverulentus	EN	697	321	42	1060	0.27%
Mammal	Pteropus vampyrus	NT	701	414	242	1357	0.07%
Mammal	Ptilocercus lowii	LC	160	204		364	0.10%
Mammal	Rattus argentiventer	LC	701	414	242	1357	0.06%
Mammal	Rattus exulans	LC	701	414	242	1357	0.02%
Mammal	Rattus norvegicus	LC	701	414	242	1357	0.00%
Mammal	Rattus tiomanicus	LC	701	414	242	1357	0.09%
Mammal	Ratufa affinis	NT	701	414	242	1357	0.10%
Mammal	Rheithrosciurus macrotis	VU	701	414	242	1357	0.18%
Mammal	Rhinolophus borneensis	LC	701	414	242	1357	0.18%
Mammal	Rhinolophus creaghi	LC		8		8	0.00%
Mammal	Rhinolophus luctus	LC	701	414	242	1357	0.02%
Mammal	Rhinolophus philippinensis	LC		15		15	0.01%
Mammal	Rhinolophus sedulus	NT	701	414	242	1357	0.17%
Mammal	Rhinolophus trifoliatus	LC	701	414	242	1357	0.10%
Mammal	Rhinosciurus laticaudatus	NT	701	414	242	1357	0.15%
Mammal	Rousettus amplexicaudatus	LC	701	414	242	1357	0.03%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Mammal	Rousettus spinalatus	VU		344		344	0.48%
Mammal	Rusa unicolor	VU	701	414	242	1357	0.02%
Mammal	Suncus etruscus	LC		56		56	0.00%
Mammal	Suncus hosei	DD		52		52	0.41%
Mammal	Suncus murinus	LC	701	414	242	1357	0.01%
Mammal	Sundamys infraluteus	LC		271	53	324	0.31%
Mammal	Sundamys muelleri	LC	701	414	242	1357	0.10%
Mammal	Sundasciurus brookei	LC	488	414	109	1011	0.39%
Mammal	Sundasciurus hippurus	NT	701	414	242	1357	0.10%
Mammal	Sundasciurus jentinki	LC		20	16	36	0.07%
Mammal	Sundasciurus lowii	LC	701	414	242	1357	0.10%
Mammal	Sundasciurus tenuis	LC	701	414	242	1357	0.11%
Mammal	Sus barbatus	VU	701	414	242	1357	0.23%
Mammal	Tadarida mops	NT	701	414	242	1357	0.22%
Mammal	Tadarida plicata	LC	701	414	242	1357	0.05%
Mammal	Taphozous longimanus	LC	701	414	242	1357	0.03%
Mammal	Taphozous melanopogon	LC	701	414	242	1357	0.02%
Mammal	Tarsius bancanus	VU	701	414	242	1357	0.16%
Mammal	Trachypithecus cristatus	NT	701	414	242	1357	0.11%
Mammal	Tragulus kanchil	LC	701	414	242	1357	0.06%
Mammal	Tragulus napu	LC	701	414	242	1357	0.10%
Mammal	Trichys fasciculata	LC	701	414	242	1357	0.11%
Mammal	Tupaia dorsalis	DD	701	414	242	1357	0.27%
Mammal	Tupaia gracilis	LC	701	414	242	1357	0.21%
Mammal	Tupaia longipes	LC	701	414	242	1357	0.18%
Mammal	Tupaia minor	LC	701	414	242	1357	0.11%
Mammal	Tupaia montana	LC	418	414	242	1074	0.60%
Mammal	Tupaia picta	LC	544	414	242	1200	0.77%
Mammal	Tupaia tana	LC	701	414	242	1357	0.14%
Mammal	Tylonycteris pachypus	LC	701	414	242	1357	0.03%
Mammal	Tylonycteris robustula	LC	539	346	8	893	0.03%
Mammal	Viverra tangalunga	LC	701	414	242	1357	0.08%
Bird	Accipiter trivirgatus	LC	685	177		862	0.02%
Bird	Accipiter virgatus	LC	69	21	148	238	0.00%
Bird	Actenoides concretus	NT	701	414	242	1357	0.13%
Bird	Aegithina tiphia	LC	701	414	242	1357	0.02%
Bird	Aegithina viridissima	NT	701	368	222	1291	0.12%
Bird	Aerodramus fuciphagus	LC	701	414	242	1357	0.08%
Bird	Aerodramus maximus	LC	701	414	242	1357	0.13%
Bird	Aerodramus salangana	LC	701	414	242	1357	0.28%
Bird	Aethopyga mystacalis	LC	701	414	242	1357	0.19%
Bird	Aethopyga siparaja	LC	701	414	242	1357	0.02%
Bird	Alcedo meninting	LC	701	414	242	1357	0.03%
Bird	Alcedo peninsulae	NT	696	396	2	1094	0.09%
Bird	Alcippe brunneicauda	NT	700	303	74	1077	0.24%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Bird	Alophoixus bres	LC	248			248	0.03%
Bird	Alophoixus finschii	NT	701	395	222	1318	0.17%
Bird	Alophoixus ochraceus	LC	510	414	242	1166	0.22%
Bird	Alophoixus phaeocephalus	LC	701	414	242	1357	0.10%
Bird	Amaurornis phoenicurus	LC	701	414	242	1357	0.01%
Bird	Anhinga melanogaster	NT	701	414	242	1357	0.02%
Bird	Anorrhinus galeritus	LC	701	414	242	1357	0.10%
Bird	Anthracoceros albirostris	LC	701	414	242	1357	0.03%
Bird	Anthracoceros malayanus	NT	460		64	524	0.07%
Bird	Anthreptes malacensis	LC	512	127	214	853	0.04%
Bird	Anthreptes simplex	LC	488	42	216	746	0.07%
Bird	Anthreptes singalensis	LC	444	225	216	885	0.03%
Bird	Aplonis panayensis	LC	701	414	242	1357	0.06%
Bird	Apus nipalensis	LC	701	414	242	1357	0.02%
Bird	Arachnothera affinis	LC	701	414	242	1357	0.09%
Bird	Arachnothera chrysogenys	LC	701	148	242	1091	0.09%
Bird	Arachnothera crassirostris	LC	667	319	241	1227	0.14%
Bird	Arachnothera flavigaster	LC	701	414	242	1357	0.12%
Bird	Arachnothera juliae	LC		39	7	46	0.10%
Bird	Arachnothera longirostra	LC	701	398	240	1339	0.03%
Bird	Ardea alba	LC	701	414	242	1357	0.00%
Bird	Ardea intermedia	LC	701	414	242	1357	0.01%
Bird	Ardea purpurea	LC	701	414	242	1357	0.00%
Bird	Argusianus argus	NT	701	414	242	1357	0.09%
Bird	Artamus leucorynchus	LC	701	414	242	1357	0.02%
Bird	Aviceda jerdoni	LC	701	387	222	1310	0.08%
Bird	Batrachostomus auritus	NT	417		205	622	0.09%
Bird	Batrachostomus cornutus	LC	701	346	235	1282	0.15%
Bird	Batrachostomus harterti	NT	185	191	33	409	1.49%
Bird	Batrachostomus javensis	LC	701	414	242	1357	0.09%
Bird	Batrachostomus stellatus	NT	701	395	222	1318	0.18%
Bird	Berenicornis comatus	NT	701	414	224	1339	0.11%
Bird	Blythipicus rubiginosus	LC	701	414	242	1357	0.10%
Bird	Brachypteryx montana	LC	701	414	242	1357	0.03%
Bird	Bubo sumatranus	LC	701	388	225	1314	0.09%
Bird	Buceros rhinoceros	NT	701	414	242	1357	0.09%
Bird	Butorides striata	LC	701	414	242	1357	0.00%
Bird	Cacomantis merulinus	LC	649	403	237	1289	0.02%
Bird	Cacomantis sonneratii	LC	701	414	242	1357	0.03%
Bird	Caloperdix oculeus	NT	701	414	242	1357	0.25%
Bird	Caloramphus fuliginosus	LC	701	414	242	1357	0.19%
Bird	Calyptomena hosii	NT	183	394	33	610	0.42%
Bird	Calyptomena viridis	NT	701	414	242	1357	0.09%
Bird	Calyptomena whiteheadi	LC	169	138	18	325	0.34%
Bird	Caprimulgus concretus	VU	696	396	2	1094	0.11%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Bird	Caprimulgus macrurus	LC	701	414	242	1357	0.02%
Bird	Carpococcyx radiceus	NT	701	371	240	1312	0.28%
Bird	Centropus bengalensis	LC	701	414	242	1357	0.02%
Bird	Centropus rectunguis	VU	696	396	2	1094	0.10%
Bird	Centropus sinensis	LC	687	414	242	1343	0.01%
Bird	Cettia vulcania	LC	701	305	242	1248	0.14%
Bird	Ceyx erithaca	LC	701	414	242	1357	0.04%
Bird	Chalcites minutillus	LC	439	313	79	831	0.03%
Bird	Chalcophaps indica	LC	701	414	242	1357	0.03%
Bird	Chlamydochaera jefferyi	LC	106	52	9	167	0.26%
Bird	Chlorocharis emiliae	LC	701	414	242	1357	0.66%
Bird	Chloropsis cochinchinensis	LC	594	375	242	1211	0.04%
Bird	Chloropsis cyanopogon	NT	701	183	238	1122	0.09%
Bird	Chloropsis sonnerati	LC	621	374	242	1237	0.09%
Bird	Chrysococcyx xanthorhynch	LC	701	414	242	1357	0.04%
Bird	Chrysocolaptes validus	LC	701	403	221	1325	0.10%
Bird	Chrysophlegma humii	NT	615	414	155	1184	0.12%
Bird	Chrysophlegma miniaceum	LC	701	414	242	1357	0.10%
Bird	Ciconia stormi	EN	696	396	2	1094	0.11%
Bird	Cissa jefferyi	LC	233	386	25	644	0.82%
Bird	Collocalia esculenta	LC	701	414	242	1357	0.05%
Bird	Copsychus malabaricus	LC	701	414	242	1357	0.03%
Bird	Copsychus saularis	LC	701	414	242	1357	0.01%
Bird	Coracina fimbriata	LC	701	25	211	937	0.07%
Bird	Coracina larvata	LC	701	414	242	1357	0.26%
Bird	Coracina striata	LC	639	32	223	894	0.06%
Bird	Corvus enca	LC	701	377	242	1320	0.08%
Bird	Corydon sumatranus	LC	701	414	242	1357	0.06%
Bird	Cuculus lepidus	LC	212	151	31	394	0.05%
Bird	Cuculus micropterus	LC	701	414	242	1357	0.01%
Bird	Culicicapa ceylonensis	LC	701	414	242	1357	0.02%
Bird	Cymbirhynchus macrorhync	LC	701	414	242	1357	0.08%
Bird	Cyornis banyumas	LC	150	414	18	582	0.02%
Bird	Cyornis caerulatus	VU	696	396	2	1094	0.11%
Bird	Cyornis concretus	LC	311	414	182	907	0.10%
Bird	Cyornis superbus	LC	701	382	234	1317	0.19%
Bird	Cyornis unicolor	LC	400	303	108	811	0.03%
Bird	Cypsiurus balasiensis	LC	701	414	242	1357	0.02%
Bird	Dendrocitta occipitalis	LC	575	51	212	838	0.26%
Bird	Dicaeum chrysorrheum	LC	701	150	201	1052	0.03%
Bird	Dicaeum cruentatum	LC	461	4	198	663	0.01%
Bird	Dicaeum everetti	NT	464	294	78	836	0.17%
Bird	Dicaeum trigonostigma	LC	701	414	242	1357	0.06%
Bird	Dicrurus aeneus	LC	519	8	115	642	0.01%
Bird	Dicrurus hottentottus	LC	701	414	242	1357	0.02%

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Bird	Dicrurus leucophaeus	LC	596	414	242	1252	0.01%
Bird	Dicrurus paradiseus	LC	701	414	242	1357	0.02%
Bird	Dinopium rafflesii	NT	515	232		747	0.07%
Bird	Ducula aenea	LC	701	414	242	1357	0.02%
Bird	Ducula badia	LC	701	414	242	1357	0.04%
Bird	Elanus caeruleus	LC	701	414	242	1357	0.00%
Bird	Enicurus leschenaulti	LC	701	414	242	1357	0.02%
Bird	Enicurus ruficapillus	NT	701	368	222	1291	0.12%
Bird	Erpornis zantholeuca	LC	701	414	242	1357	0.03%
Bird	Erythrura prasina	LC	701	414	242	1357	0.08%
Bird	Eudynamys scolopaceus	LC	701	414	242	1357	0.01%
Bird	Eumyias thalassinus	LC	696	414	242	1352	0.02%
Bird	Eupetes macrocerus	NT	701	368	222	1291	0.12%
Bird	Eurylaimus javanicus	LC	701	414	242	1357	0.06%
Bird	Eurylaimus ochromalus	NT	701	395	222	1318	0.12%
Bird	Eurystomus orientalis	LC	701	414	242	1357	0.01%
Bird	Falco peregrinus	LC		40		40	0.00%
Bird	Ficedula dumetoria	NT	701	414	242	1357	0.36%
Bird	Ficedula westermanni	LC	181	414	21	616	0.01%
Bird	Gallicrex cinerea	LC	701	414	242	1357	0.01%
Bird	Gallinula chloropus	LC	701	414	242	1357	0.00%
Bird	Garrulax mitratus	LC	439	414	242	1095	0.25%
Bird	Garrulax palliatus	LC	6	414	206	626	0.58%
Bird	Glaucidium brodiei	LC	254	414	242	910	0.03%
Bird	Gracula religiosa	LC	701	414	242	1357	0.03%
Bird	Halcyon coromanda	LC	701	414	242	1357	0.03%
Bird	Haliastur indus	LC	701	414	242	1357	0.01%
Bird	Harpactes diardii	NT	557	388	2	947	0.09%
Bird	Harpactes duvaucelii	NT	699	414	199	1312	0.10%
Bird	Harpactes kasumba	NT	701	414	229	1344	0.14%
Bird	Harpactes orrhophaeus	NT	701	346	238	1285	0.27%
Bird	Hemicircus sordidus	LC	701	371	242	1314	0.11%
Bird	Hemiprocne comata	LC	513	348	218	1079	0.07%
Bird	Hemiprocne longipennis	LC	647	395	46	1088	0.07%
Bird	Hemipus hirundinaceus	LC	701	337	242	1280	0.09%
Bird	Hemipus picatus	LC	701	414	242	1357	0.02%
Bird	Hierococcyx fugax	LC	701	414	242	1357	0.10%
Bird	Hierococcyx vagans	NT	701	394	222	1317	0.13%
Bird	Hirundapus giganteus	LC	701	414	242	1357	0.05%
Bird	Hypogramma hypogrammic	LC	628	403	235	1266	0.06%
Bird	Hypothymis azurea	LC	701	414	242	1357	0.02%
Bird	Icthyophaga humilis	NT	638	355	204	1197	0.04%
Bird	Icthyophaga ichthyaetus	NT	129			129	0.00%
Bird	Ictinaetus malaiensis	LC	695	412	217	1324	0.04%
Bird	Indicator archipelagicus	NT	701	368	222	1291	0.12%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Bird	Iole olivacea	NT	701	368	222	1291	0.11%
Bird	Irena puella	LC	701	414	242	1357	0.03%
Bird	Ixobrychus cinnamomeus	LC	701	371	242	1314	0.01%
Bird	Ixobrychus sinensis	LC	701	395	96	1192	0.01%
Bird	Ixos malaccensis	NT	701	368	222	1291	0.13%
Bird	Ketupa ketupu	LC	701	414	242	1357	0.05%
Bird	Lacedo melanops	LC	701	414	242	1357	0.21%
Bird	Lalage nigra	LC	701	13	222	936	0.06%
Bird	Lewinia striata	LC	701	414	242	1357	0.02%
Bird	Lonchura atricapilla	LC	701	414	242	1357	0.03%
Bird	Lonchura fuscans	LC	701	414	242	1357	0.18%
Bird	Lonchura leucogastra	LC	396	176	202	774	0.05%
Bird	Lonchura malacca	LC	701	414	242	1357	0.03%
Bird	Lophotriorchis kienerii	LC	701	414	242	1357	0.03%
Bird	Lophura bulweri	VU	701	216	242	1159	0.42%
Bird	Lophura ignita	NT	701	395	222	1318	0.27%
Bird	Lophura pyronota	VU	458	177	208	843	0.14%
Bird	Loriculus galgulus	LC	701	414	242	1357	0.10%
Bird	Lyncornis temminckii	LC	668	414	242	1324	0.10%
Bird	Macheiramphus alcinus	LC	701	414	242	1357	0.01%
Bird	Macronous bornensis	LC	20	300		320	0.09%
Bird	Macropygia emiliana	LC	321	414	76	811	0.14%
Bird	Macropygia ruficeps	LC	701	414	242	1357	0.07%
Bird	Malacocincla abbotti	LC	701	414	242	1357	0.06%
Bird	Malacocincla malaccensis	NT	701	387	222	1310	0.12%
Bird	Malacocincla sepiaria	LC	539	273	226	1038	0.11%
Bird	Malacopteron albogulare	NT	701	397	235	1333	0.22%
Bird	Malacopteron cinereum	LC	701	404	242	1347	0.09%
Bird	Malacopteron magnirostre	LC	613	414	219	1246	0.24%
Bird	Malacopteron magnum	NT	701	395	222	1318	0.20%
Bird	Meiglyptes grammithorax	LC	701	414	242	1357	0.10%
Bird	Meiglyptes tukki	NT	469		213	682	0.09%
Bird	Melanoperdix niger	VU	696	396	2	1094	0.10%
Bird	Merops viridis	LC	701	414	242	1357	0.04%
Bird	Microhierax fringillarius	LC	701	380	236	1317	0.09%
Bird	Micropternus brachyurus	LC	701	414	242	1357	0.02%
Bird	Mulleripicus pulverulentus	VU	701	414	242	1357	0.05%
Bird	Muscicapella hodgsoni	LC	165	414	2	581	0.06%
Bird	Napothera epilepidota	LC	701	414	242	1357	0.08%
Bird	Nectarinia jugularis	LC	701	414	242	1357	0.02%
Bird	Ninox scutulata	LC	701	414	242	1357	0.02%
Bird	Nisaetus alboniger	LC	701	414	242	1357	0.17%
Bird	Nisaetus cirrhatus	LC	701	414	242	1357	0.03%
Bird	Nisaetus nanus	VU	696	396	2	1094	0.10%
Bird	Nycticorax nycticorax	LC	701	414	242	1357	0.00%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Bird	Nyctyornis amictus	LC	701	414	242	1357	0.09%
Bird	Oculocincta squamifrons	LC	160	115	18	293	0.36%
Bird	Oriolus xanthonotus	NT	701	368	222	1291	0.11%
Bird	Orthotomus atrogularis	LC	667	414	211	1292	0.04%
Bird	Orthotomus sericeus	LC	446	5		451	0.04%
Bird	Otus lempiji	LC	701	373	242	1316	0.09%
Bird	Otus rufescens	NT	701	387	222	1310	0.15%
Bird	Otus spilocephalus	LC	701	414	242	1357	0.03%
Bird	Pachycephala hypoxantha	LC	131	81	15	227	0.29%
Bird	Pandion haliaetus	LC	701	414	242	1357	0.00%
Bird	Passer montanus	LC	701	414	242	1357	0.00%
Bird	Pelargopsis capensis	LC	701	414	242	1357	0.02%
Bird	Pellorneum capistratum	LC	701	367	241	1309	0.09%
Bird	Pericrocotus flammeus	LC	701	414	242	1357	0.02%
Bird	Pericrocotus igneus	NT	701	183	238	1122	0.09%
Bird	Pernis ptilorhynchus	LC	701	414	218	1333	0.01%
Bird	Phaenicophaeus curvirostris	LC	436		207	643	0.05%
Bird	Phaenicophaeus diardi	NT	701	395	222	1318	0.10%
Bird	Phaenicophaeus sumatranus	NT	701	395	222	1318	0.10%
Bird	Philentoma pyrhoptera	LC	701	391	234	1326	0.11%
Bird	Philentoma velata	NT	701	368	222	1291	0.11%
Bird	Phodilus badius	LC	701	414	242	1357	0.04%
Bird	Phylloscopus trivirgatus	LC	235	393	69	697	0.13%
Bird	Picoides canicapillus	LC	701	414	242	1357	0.01%
Bird	Picus puniceus	LC	701	414	242	1357	0.10%
Bird	Pitta arcuata	LC	701	414	242	1357	0.43%
Bird	Pitta baudii	VU	696	396	2	1094	0.18%
Bird	Pitta caerulea	NT	701	414	242	1357	0.12%
Bird	Pitta granatina	NT	422	242	90	754	0.09%
Bird	Pitta schwaneri	LC	701	414	242	1357	0.18%
Bird	Pitta sordida	LC	531	268	239	1038	0.02%
Bird	Pityriasis gymnocephala	NT	701	414	242	1357	0.18%
Bird	Platylophus galericulatus	NT	701	414	242	1357	0.09%
Bird	Platysmurus leucopterus	NT	701	399	217	1317	0.10%
Bird	Polyplectron schleiermacher	EN	701	216	201	1118	0.59%
Bird	Pomatorhinus montanus	LC	701	414	242	1357	0.13%
Bird	Prinia flaviventris	LC	701	414	242	1357	0.02%
Bird	Prionochilus maculatus	LC	701	414	242	1357	0.10%
Bird	Prionochilus percussus	LC	701	414	242	1357	0.09%
Bird	Prionochilus thoracicus	NT	701	383	242	1326	0.12%
Bird	Prionochilus xanthopygius	LC	701	414	242	1357	0.43%
Bird	Psarisomus dalhousiae	LC	7	13	39	59	0.00%
Bird	Psilopogon chrysopogon	LC	701	323	242	1266	0.14%
Bird	Psilopogon duvaucelii	LC	701	365	240	1306	0.12%
Bird	Psilopogon eximius	LC	219	209	26	454	0.30%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Bird	Psilopogon henricii	NT	469		213	682	0.10%
Bird	Psilopogon monticola	LC	111	54	17	182	0.34%
Bird	Psilopogon mystacophanos	NT	615	411	224	1250	0.10%
Bird	Psilopogon rafflesii	NT	469		213	682	0.10%
Bird	Psittacula longicauda	NT	444		178	622	0.07%
Bird	Psittinus cyanurus	NT	701	414	242	1357	0.10%
Bird	Pteruthius flaviscapis	LC	259	409	180	848	0.02%
Bird	Ptilocichla leucogrammica	VU	696	396	2	1094	0.18%
Bird	Pycnonotus atriceps	LC	701	406	242	1349	0.05%
Bird	Pycnonotus brunneus	LC	701	332	232	1265	0.11%
Bird	Pycnonotus cyaniventris	NT	701	387	222	1310	0.14%
Bird	Pycnonotus erythropthalmo	LC	701	335	232	1268	0.10%
Bird	Pycnonotus eutilotus	NT	469		213	682	0.07%
Bird	Pycnonotus goiavier	LC	701	414	242	1357	0.06%
Bird	Pycnonotus melanicterus	LC	701	414	242	1357	0.04%
Bird	Pycnonotus melanoleucos	NT	701	383	242	1326	0.11%
Bird	Pycnonotus plumosus	LC	701	414	242	1357	0.09%
Bird	Pycnonotus simplex	LC	701	390	242	1333	0.10%
Bird	Pycnonotus squamatus	NT	284	387	18	689	0.23%
Bird	Pycnonotus zeylanicus	VU	701	414	242	1357	0.20%
Bird	Rallina fasciata	LC	475	348	200	1023	0.05%
Bird	Ramphiculus jambu	NT	701	414	242	1357	0.09%
Bird	Rhabdotorrhinus corrugatus	NT	168			168	0.02%
Bird	Rhaphidura leucopygialis	LC	689	79	52	820	0.07%
Bird	Rhinomyias gularis	LC	85	30	9	124	0.39%
Bird	Rhinomyias umbratilis	NT	701	383	242	1326	0.12%
Bird	Rhinoplax vigil	NT	701	352	230	1283	0.11%
Bird	Rhinortha chlorophaea	LC	701	414	242	1357	0.09%
Bird	Rhipidura albicollis	LC	331	232	242	805	0.01%
Bird	Rhipidura perlata	LC	701	414	242	1357	0.11%
Bird	Rhizothera longirostris	NT	12			12	0.00%
Bird	Rhyticeros undulatus	LC	701	414	242	1357	0.04%
Bird	Rollulus rouloul	NT	701	414	242	1357	0.10%
Bird	Rostratula benghalensis	LC	701	414	242	1357	0.00%
Bird	Sasia abnormis	LC	25	115		140	0.01%
Bird	Seicercus montis	LC	14	1	34	49	0.01%
Bird	Setornis criniger	VU	696	396	2	1094	0.14%
Bird	Sitta frontalis	LC	701	414	242	1357	0.02%
Bird	Spilornis cheela	LC	701	414	242	1357	0.02%
Bird	Stachyris erythroptera	LC	701	409	236	1346	0.10%
Bird	Stachyris maculata	NT	696	380	215	1291	0.22%
Bird	Stachyris nigriceps	LC	249	224	33	506	0.02%
Bird	Stachyris poliocephala	LC	701	414	242	1357	0.19%
Bird	Stachyris rufifrons	LC	701	414	242	1357	0.07%
Bird	Strix leptogrammica	LC	701	414	242	1357	0.02%

Group	Species Name	Red List Status	Habitat Lost (km^2) Bakun	Baram	Murum	Total	Frac. Range (%)
Bird	Surniculus lugubris	LC	701	414	242	1357	0.07%
Bird	Synoicus chinensis	LC	701	414	242	1357	0.02%
Bird	Tephrodornis gularis	LC	691	403	242	1336	0.03%
Bird	Terpsiphone paradisi	LC	701	414	242	1357	0.01%
Bird	Todiramphus chloris	LC	701	414	242	1357	0.03%
Bird	Treron capellei	VU	696	396	2	1094	0.10%
Bird	Treron olax	LC	701	403	242	1346	0.10%
Bird	Treron vernans	LC	701	366	220	1287	0.06%
Bird	Trichastoma pyrrogenys	LC	245	215	30	490	0.25%
Bird	Trichastoma rostratum	NT	441		84	525	0.15%
Bird	Trichixos pyrropygus	NT	701	368	222	1291	0.12%
Bird	Tricholestes criniger	LC	701	348	224	1273	0.10%
Bird	Turdinus atrigularis	NT	386	378	225	989	1.76%
Bird	Yuhina everetti	LC	224	359	34	617	0.45%
Bird	Zanclostomus javanicus	LC	701	414	242	1357	0.09%
Bird	Zoothera interpres	NT	701	410	217	1328	0.20%
Bird	Zosterops atricapilla	LC	88	36	9	133	0.11%
Bird	Zosterops everetti	LC	679	82	242	1003	0.20%
Bird	Amaurornis cinerea	LC	701	414	242	1357	0.04%
Bird	Hirundo tahitica	LC	701	399	242	1342	0.04%
Bird	Spilopelia chinensis	LC	701	414	242	1357	0.01%
Bird	Arborophila hyperythra	LC		329	24	353	0.22%
Bird	Batrachostomus mixtus	NT		272	24	296	0.34%
Bird	Cissa chinensis	LC		414	236	650	0.03%
Bird	Eumyias indigo	LC		69	21	90	0.03%
Bird	Harpactes oreskios	LC		2	5	7	0.00%
Bird	Myophonus borneensis	LC		275	102	377	0.33%
Bird	Oriolus cruentus	LC		343	24	367	0.12%
Bird	Urosphena whiteheadi	LC		154	31	185	0.15%
Bird	Abroscopus superciliaris	LC		24		24	0.00%
Bird	Arachnothera robusta	LC		287		287	0.05%
Bird	Ardea cinerea	LC		335		335	0.00%
Bird	Chloropsis kinabaluensis	LC		39		39	0.10%
Bird	Dicaeum agile	LC		77		77	0.00%
Bird	Dicaeum monticolum	LC		96	14	110	0.27%
Bird	Erythrura hyperythra	LC		59	2	61	0.02%
Bird	Ficedula hyperythra	LC		414	1	415	0.01%
Bird	Garrulax calvus	LC		47	10	57	0.15%
Bird	Haematortyx sanguiniceps	LC		118	17	135	0.18%
Bird	Harpactes whiteheadi	NT		28		28	0.15%
Bird	Hierococcyx bocki	LC		414	200	614	0.21%
Bird	Napothera crassa	LC		69	13	82	0.23%
Bird	Nectarinia sperata	LC		52		52	0.00%
Bird	Oriolus hosii	NT		365	19	384	1.87%
Bird	Orthotomus cuculatus	LC		99	21	120	0.01%

Group	Species Name	Red List Status	Habitat Lost (km^2)				Frac. Range (%)
			Bakun	Baram	Murum	Total	
Bird	Pycnonotus flavescens	LC		251	18	269	0.03%
Bird	Spilornis kinabaluensis	VU		18		18	0.05%
Bird	Trichastoma bicolor	LC		221		221	0.03%

Dam	Spp. Affected (thousands)		Extinctions		Individs. Affected (billions)	
	Tree	Arth	Tree	Arth	Tree	Arth
Bakun	2.62 (2.12–3.11)	24.49 (17.74–30.07)	0.38 (0.30–0.45)	3.08 (2.24–3.73)	0.47 (0.45–0.49)	25.83 (17.42–37.99)
Murum	2.35 (1.91–2.79)	22.25 (16.11–27.35)	0.13 (0.10–0.16)	1.06 (0.77–1.29)	0.16 (0.15–0.17)	8.92 (6.01–13.12)
Baram	2.48 (2.01–2.95)	23.37 (16.93–28.71)	0.22 (0.18–0.27)	1.82 (1.32–2.20)	0.28 (0.26–0.29)	15.22 (10.26–22.38)
Total	2.12–3.31	17.74–31.80	0.58–0.88	4.34–7.22	0.87–0.95	33.69–73.49

Table Showing: Estimates of the number of tree and arthropod species affected, number of extinctions, and number of individual organisms lost due to habitat loss from reservoir inundation.