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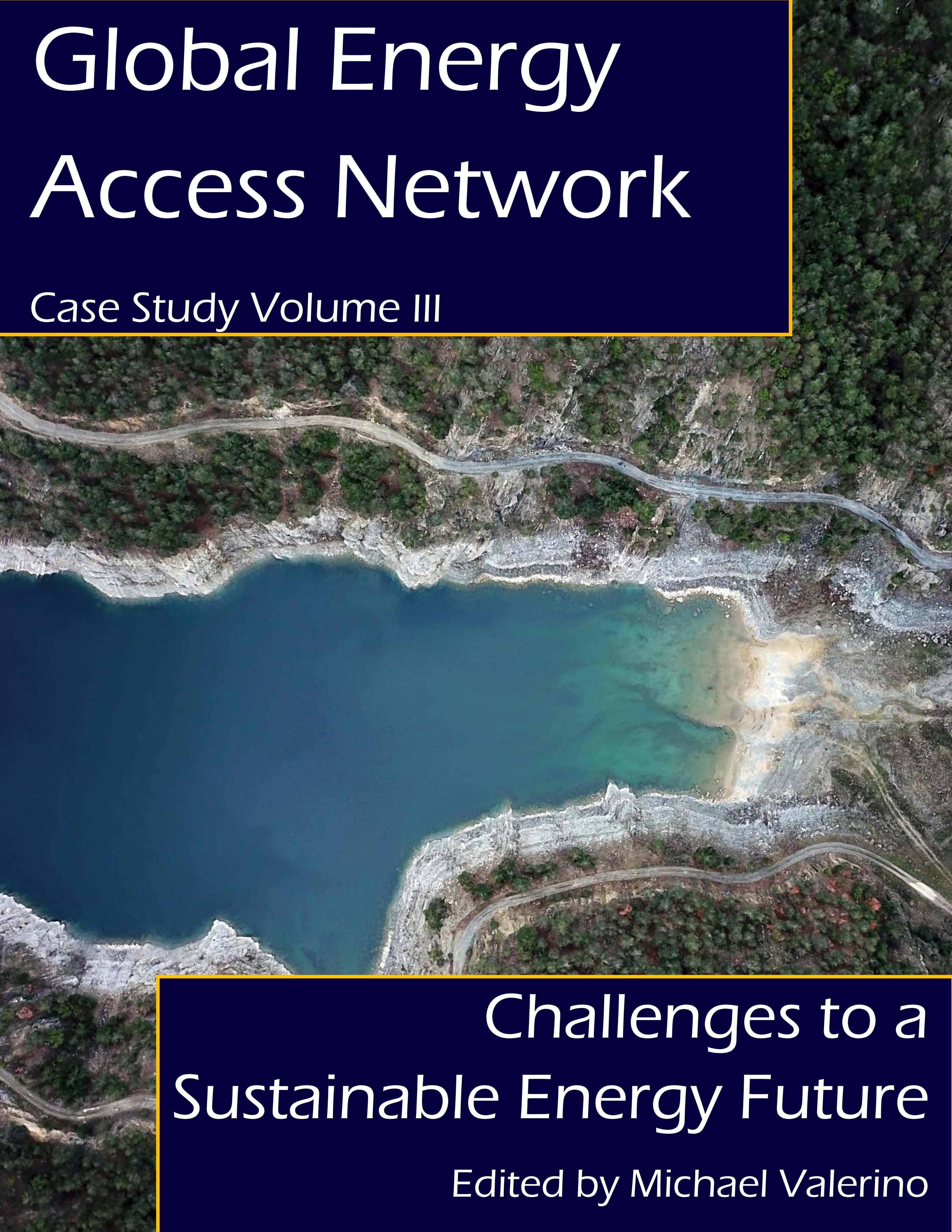
Case Study Volume III



Challenges to a Sustainable Energy Future

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Foreward

Michael Valerino

Michael (michael.valerino@duke.edu) is a PhD Candidate in Environmental Engineering in the Pratt School of Engineering at Duke Univesity.

The International Energy Agency states that "There is no single Internationally-adopted definition of modern energy access." An issue as technologically, economically, socially, and politically complicated as energy access is not expected to have a set definition. 14% of the global population is without access to electricity, and another 38% without access to clean cooking. What energy access means to individuals across the globe can be very different, and solutions to these problems will need to come from insights that are very different as well. The Global Energy Access Network (GLEAN) understands the magnitude of the energy challenges that the world faces. GLEAN strives to provide Duke University students of all backgrounds and disciplines an outlet to share their relevant experiences and learn more about what can be done. A multi-disciplinary approach by undergraduate, graduate, and professional students provides unique insights into issues surrounding energy access.

The idea for a case study was conceived during the first year GLEAN became a part of the Duke community. Now in the 3rd volume, this case study has used the diversity of its members to share aspects of energy access that have global impacts. Many contributors, past and present, have not conducted work that would be considered directly related to energy access however find that their research, projects, or field work relates to the mission of GLEAN.

In this volume, our authors highlight some of the challenges that face energy access and a sustainable future. Erin Viere explores how renewable energy politics and economics has social impacts in Vietnam. Ryan Calder's work with methylmercury contamination looks at potential impacts on renewable energy exports to native populations in Canada. Junqin Chen's project in China discusses the potential impacts and challenges of a new way to treat food waste, and how this relates to energy access in the country. The team of Simeng Deng, Asger Hansen, Galen Hiltbrand, Sean Maddex, and Santiago Sinclair Lecaros perform analysis of the potential for solar microgrids in Puerto Rico using lessons learned from Hurricanes Maria and Irma.

Energy Access in Southeast Asia: A Focus on Hydropower Development in Vietnam

Erin Viere

Erin (erin.viere@duke.edu) is a doctoral candidate in the Chemistry Department at Duke University.

Keywords: Vietnam, hydropower, climate change

Like many Southeast Asian countries, Vietnam has experienced explosive energy growth over the past few decades; growth which is both encouraged and met with trepidation. For those who want to increase the standard of living, augmented energy use is vital, yet for those who aim to curtail increasing carbon dioxide emissions, this type of growth can be controversial. As a result, Vietnam is at the forefront of trying to maximize energy production and implement renewable energy options that make the most sense for the natural resources the country already possesses. Even as this 'green transformation' occurs, over 70% of Vietnam's energy supply comes from coal and oil.[1] In a global sense, Vietnam's fossil fuel usage pales in comparison to more developed countries like China and the United States. Even though the country is not a major contributor to climate change, vulnerability to higher intensity weather events such as typhoons and flooding leave Vietnam highly motivated to seek alternative energy sources.

Initially, development of hydropower was a highly attractive solution for Vietnam, as there are many large watersheds near sparsely populated locations and hydropower is considered the most reliable and cost-effective renewable energy source.[2] Currently, hydropower accounts for 7% of total energy supply in Vietnam, mostly coming from small-scale operations.[1,2] The problem with empowering hydropower development comes when considering the social and environmental impacts that displacement for dam construction has on local communities as well as the realities of who has access to the generated electricity. This case study aims to refocus the understanding of hydropower development through the lens of local people affected by displacement and contrast that perspective with the stakeholders who profit from pushing for development.

Experiences from Displaced Farmers in Central Vietnam

I traveled to Vietnam in February and March of 2016, studying the politics of food, energy, and water in the context of climate change. While in Huế, Vietnam, I visited the Binh Dien hydropower dam in the Thừa Thiên-Huế province and met with a famer, Anh, who was displaced by the dam's construction. Anh is a 57-year-old father of five and was a farmer of rice, peanuts and vegetables on the 5 hectares of land he owned before being forced to move for the dam's construction. After being relocated in 2004, Anh was only allotted half a hectare of land, on a steep and rocky hill, leaving him unable to continue farming to support his family. He explained that when they were forced to move the family received money from the government to build a new house, but it was not enough to sustain them. Initially, the family also received rice for the first 30 months but now receive no aid even though they remain unable to grow food for themselves. Before the construction of the dam, the family owned plenty of nutritious land. Their current land now only grows a specific type of tree that can be used only for paper or furniture construction. Anh and the 60 other families who live in the same commune are contracted by a forestry company to grow the trees. Some of the families travel to work for someone who owns more land, but that employment is only seasonal and very labor intensive. Even worse, while there is more clean water available for household use and irrigation, the monthly costs are too high and there is no land for it to be useful for farming. Similarly, the cost for electricity is very high so these families effectively receive none of the benefits that the dam provides. As a result, many children have dropped out of school in order to find a job, often moving to Ho Chi Minh city where there is a lot of factory work. One of the main takeaways from my conversation with Anh was that while there are good policies and procedures in place for families who are forced to relocate, the problem is that no one follows through on these promises. For example, he stated that there was a consultation process where local people could give input but following that conversation none of their suggestions were implemented. Similarly, there is a government program to help poor families afford the monthly premium for clean water but for families that do not qualify, water resources are extremely strained. Anh says he has been working with local organizers and journalists to write letters to the government, reminding them of what they were promised, but nothing has come of that initiative.

Binh Dien Hydropower Dam, February 26, 2016

Image Credit: Erin Viere

Insight from Local NGOs: Environmental Impact of Dam Construction

In addition to the social issues that arise from hydropower dam construction, there are serious environmental considerations. When in Hanoi, I was able to meet with Mrs. Nguy Thi Khanh, co-founder and managing director of Vietnam Green Innovation Development Center, an organization that works to promote sustainable energy in Vietnam and the Mekong Delta.[3] Mrs. Khanh explained how Vietnam's power demand has increased sevenfold in the last 20 years, with coal continuing to increase as well. She founded the Local Energy Planning initiative to give marginalized groups a voice when it comes to concerns they have over current fossil fuel use or future renewable development in their communities. Mrs. Khanh explained that hydropower is managed by the state energy company Vietnam Electricity (EVN), which provides over 60% of the power for the entire country. Of that, a third comes from coal and the largest portion from hydropower at 38%.[4] Yet individual hydropower dams are operated by smaller groups without as much expertise or organization because the current set-up allows anyone with enough money to invest in hydropower. This problem is exacerbated due to provisions in Vietnam's National Plan for Power Development for the period 2011-2020 with perspectives to 2030 which is referred to as PDP7. PDP7 strongly encourages private sector investment in the development of small hydropower, while oversight from government and even local authorities lags.[2] As a result, severe problems arise with respect to biodiversity loss, flooding, and dams breaking. More specifically with respect to environmental issues, I met with Mr. Chu Manh Trinh at the Thu Bon River Basin in Quảng Nam province. He explained that one of the problems with dams is their positioning in the middle of the river. This is done in order to harness power from water movement but also prevents natural migration of fish upstream, causing a breakdown of local ecosystems and loss of livelihoods for the community.[2] Additionally, these dams often release water without warning in preparation for a large storm, causing flooding for downstream riverside communities which inundates and destroys their crops as well as being physically dangerous. In addition to the direct effects of creating artificial reservoirs of water for hydropower dams, the country has experienced severe deforestation, which reinforces cycles of drought in some areas and flooding in already vulnerable floodplains. Hydropower increases the susceptibility of these areas to flooding because the cascades implemented to harness energy often do not follow procedure for excess water discharge. As a result, water overflows into steep areas without the infrastructure to contain such an influx.[2,5]

Binh Dien Hydropower Dam Reservoir, February 26, 2016

Image Credit: Erin Viere

Forest Land Designation in Vietnam

Mr. Anh's experience of not receiving arable land after being resettled is a common problem for hydropower development in Vietnam, where most of the land eligible for farming is located along rivers that are also ideal for dam development. A recent study revealed that Vietnam has only 0.07 ha of tillable land per capita, most of which is in the mountains.[6] The threat to cultivatable land is only exacerbated by the decline in water quality and river volume, particularly during dry seasons, a decline which is linked to dam construction.[8] In addition to the problems already mentioned, Anh spoke about the inaccessibility of forested land for public use. Vietnam's forest land is owned by the state and designated as special use, production forest, or protection forest. The production forest cultivates acacia and bamboo as income generating trees, but most displaced peoples are housed near protection forests, where it is illegal to clear trees for farmland or sell them for financial gain.[6] When communities are relocated to areas without adequate farmland, they often resort to illegal logging and/or clearing nearby wooded areas in an attempt to generate more farmland. Moreover, a recent study showed that due to the decreased quality and area of land received by resettled families, fertilizer use increased by over %1,500, from 68.60 kg/ha to 1065.10 kg/ha on paddy rice, although this increased use did not correlate with greater crop production.[7] The increase in agricultural land area and use of chemical fertilizers and pesticides also pollutes groundwater, further endangering local ecosystems.[8]

Increased Vulnerability of Ethnic Minorities

One of the most critical effects caused by increased hydropower development comes from the reality that over 90% of communities displaced are ethnic minorities.[2] In these communities, which are more closely tied to ancestral land, crucial indigenous knowledge is at risk from forced displacement. Moreover, the goals of these communities differ from those of cities, yet their cultural integrity is compromised for the energy development goals of the government and stakeholders. Vietnam's 54 ethnic groups often live in the mountains and have livelihoods which depend on agriculture along rivers. The disproportionate rate of resettlement for ethnic minorities thus causes not only loss of indigenous culture but loss of land cultivation knowledge.[9] As displaced farmers move to cities seeking employment, struggling rural communities lose skilled laborers and the gap in knowledge creates a broader social problem as farmers must learn new skillsets to work in industrial jobs.[10] Due to these factors, scholars have suggested that the destruction of worldwide river ecosystems is one of the largest drivers of global poverty rates.[8]

Conclusion and Future Outlooks

The problems related to hydropower development in Vietnam are by no means unique. In fact, countries around the world are turning to hydropower, with 3700 dams planned or built in 2014, which increased global hydropower production by 73%.[10] Some experts call for project involvement and funding from organizations with well-established livelihood restoration priorities such as the World Bank and the Asian Development Bank[6], but solutions to the problem of lack of agency for displaced ethnic minorities cannot be sought by bringing in even more removed foreign interests. Like many developing countries, the impact of colonialism still lurks in the form of neo-colonialist stakeholders and foreign funding for development projects.

While many local NGOs and national lobbyists now recognize the social and environmental costs to dam construction, some scientists still push for hydropower development, saying that a well-managed dam reduces flooding which in turn reduces methane emissions and thus is crucial for climate change mitigation.[11] This type of singular analysis – arguing that the negatives of hydropower dams have been misrepresented through selective analysis of methane production – lacks the holistic understanding of political, social, and cultural realities that are implicit in any hydropower construction in a developing country. Any advocacy for hydropower that relies on perfect implementation and management is orthogonal to advocacy for sustainable and locally-informed energy access and development. Too often, the science behind new technologies is developed in the West with Western ideals about productivity infused and financially incentivizing such development. Subsequent implementation of this kind of technology will always be at odds with local groups who have a different framework for the goals of their communities.

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Coupled Human-Natural Modeling for Hydroelectric Development: Understanding the Health Impacts of America's Renewable Energy Imports

Ryan S.D Calder, ScD

Ryan Calder (ryan.calder@duke.edu) is an Associate Professor of Environmental Health and Policy and Assistant Professor of Health Sciences at Virginia Tech University, Blacksburg, VA, USA, as well as Adjunct Professor in the Department of Civil and Environmental Engineering at Duke University.

Keywords: hydropower, indigenous population, methylmercury, renewable energy

Hydropower accounts for 71% of renewable electrical generation worldwide, and installed capacity may more than double by 2050.[1] Major hydroelectric projects involve construction of reservoirs to buffer the periodicity of river discharge, meaning hydropower typically does not suffer from supply intermittency of other renewables such as wind and solar.[2] Meanwhile, average greenhouse gas emissions are likely substantially lower than fossil fuel alternatives per unit energy produced.[3] Domestic hydropower production in the United States is unlikely to increase substantially in the foreseeable future, but imports from Canada play an increasingly important role in achieving renewable energy targets in northern U.S. markets.[4]

While hydropower presents an attractive alternative to fossil fuels at global scales, it radically transforms regional landscapes, rupturing local environmental and social systems. In settler-colonial societies such as Canada and Brazil, transformation of environments far from urban areas predominantly impacts indigenous populations. While these impacts have been understood in principle for many years, environmental management has relied on reactive mitigation measures rather than using potential impacts to screen design and development alternatives.[5] For instance, reservoir creation increases microbial production of neurotoxic methylmercury (MeHg), which accumulates in local food webs, but these risks are normally managed by issuing food advisories to impacted populations.[6,7] However, indigenous populations are increasingly exercising their right to be informed of impacts on water resources and food systems before development, underlining the need to understand environmental risk prospectively.[8] Meanwhile, risk mitigation measures have typically been one-dimensional, focusing for instance on chemical contaminants in traditional foods without accounting for nutritional or cultural benefits.[9, 10]

The research program described here proposes tools to forecast mercury-related human health risks from hydroelectric projects as a function of design and location and to characterize nutritional tradeoffs of food consumption advisories. This work aims to create generalizable tools to prospectively characterize a broader set of interacting risks while supporting the large uncertainties inherent in socio-environmental systems. Overall, this work increases the ability of planners to anticipate risks associated with hydropower in order to develop renewable energies in a way that preserves the integrity of food systems and minimizes human health impacts. Here, I describe how imports of Canadian-produced hydropower underlies U.S. renewable energy plans, how these imports can impact Indigenous communities in Canada and how work my colleagues and I have undertaken allows for these impacts to be anticipated and managed proactively.

Canadian Hydropower, U.S. Energy Transitions and Environmental Management

The importance of renewable sources in the United States' overall energy portfolio is increasing quickly, and electrical generation in Canada is a key part of this transition. Overall, the proportion of domestic electrical generation from renewable sources is expected to increase by 43% between 2010 and 2030.[11] Beyond domestic production, many northern states are relying on imports of Canadian hydroelectricity to meet ambitious renewable energy targets. For example, between 2005 and 2015, net hydroelectric imports from Canada to New England tripled, and at least four separate projects are currently under evaluation or construction to expand transmission capacity from Canada into the border states of Maine, New Hampshire and Vermont.[12] Nationally, on average since 1990, the United States has increased electrical imports from Canada by the equivalent of the installed capacity of Vermont every two years (1 TWh/year) with imports in 2019 equivalent to electrical generation of Arkansas (>60 TWh).[4, 13, 14]

American critics have suggested that importing Canadian hydroelectric power contributes to "eco-imperialism by deflecting the environmental costs" of an energy-intensive lifestyle onto disadvantaged populations in other countries.[15] Hydroelectric development in Canada transforms environments far from southern population centers, disrupting traditional food and social systems of local Indigenous populations. For instance, the La Grande hydroelectric complex in Quebec flooded over 10,000 km^2 of land, diverting and diking rivers over 176,000 km^2 of traditional Cree territory.[5] (For comparison, Delaware and Florida occupy surface areas of 6,446 km^2 and 170,312 km^2 respectively.) These changes resulted in a loss of (and impairment of access to) traditional hunting and fishing territory and mercury (Hg) contamination of key fish species.[16] Decades of research have linked excess burden of disease among Indigenous populations globally to the loss of nutritional and psychosocial support afforded by traditional food systems.[17-20] Hydroelectric development has therefore tended to exacerbate existing environmental contributors to health disparities in Canada, although a lack of baseline data and rapidly changing diets have made the role of hydropower in overall risks difficult to quantify.[21, 22]

Legal obligations within the United States to consider non-U.S. impacts are subject to interpretation. The National Environmental Policy Act (NEPA) requires U.S. federal agencies to undertake an environmental impact assessment when an action is likely to have "significant" environmental impacts (40 CFR 1500).[23] In the context of electrical imports, this is triggered by the authority of U.S. Department of Energy (DOE) over construction, connection, operation and maintenance of electrical transmission infrastructure over international borders (10 CFR 205).[24] Federal agencies must consider transborder impacts in NEPA assessments when these impacts are causally related to the proposed federal action.[25-27] Recent legal arguments that NEPA reviews for electrical imports must consider impacts in Canada are based on the observation that increased transborder capacity makes future hydroelectric development more likely.[28, 29] Indeed, the U.S. export market has underlain the viability of Canadian hydroelectric operations for decades and is a major factor driving expansion of capacity.[15, 30] However, the U.S. DOE has taken the position that projects and associated impacts in Canada "will occur regardless of whether DOE issues a Presidential permit" and that these impacts must be evaluated within the scope of Canada's "own sovereign laws".[31]

Canada's sovereign laws leave Indigenous populations subject to the judgment of the legislatures far from impacted environments and to the government-owned utilities that have been charged with developing hydroelectric resources. For instance, the Quebec Court of Appeal ruled in 1974 that the La Grande hydroelectric development could proceed notwithstanding impacts on the Cree owing to the financial losses that Hydro-Québec would otherwise suffer, while recognizing the obligation of Hydro-Québec to negotiate a settlement.[32] Government-owned utilities have historically had wide latitude to define the scope, scale and methods of environmental, social and human health impact assessments, creating a situation likened to "the fox guarding the henhouse".[5] Therefore, while the standards for assessment, monitoring and engagement have undoubtedly improved since the 1970s, the extent to which impacts on Indigenous populations are factored into hydroelectric development remains a political question.

Hydroelectric Development, Methylmercury and the Inuit of the Labrador Coast

The research program described here grew out of a controversy surrounding impacts of Muskrat Falls, an 824-MW hydroelectric facility under construction upstream from three Inuit communities on the Labrador Coast with a total population of roughly 3,000 (**Error! Reference source not found.**). Power generated at Muskrat Falls will be transmitted over the Strait of Belle Isle to Newfoundland, replacing the island's aging coal-fired powerplant, with excess being transmitted back to mainland North America via Nova Scotia and onward to the U.S. market via Maine.[33] Muskrat Falls is therefore expected to contribute to renewable energy transitions of northeastern North America while impacting Indigenous populations in the vicinity of the project.

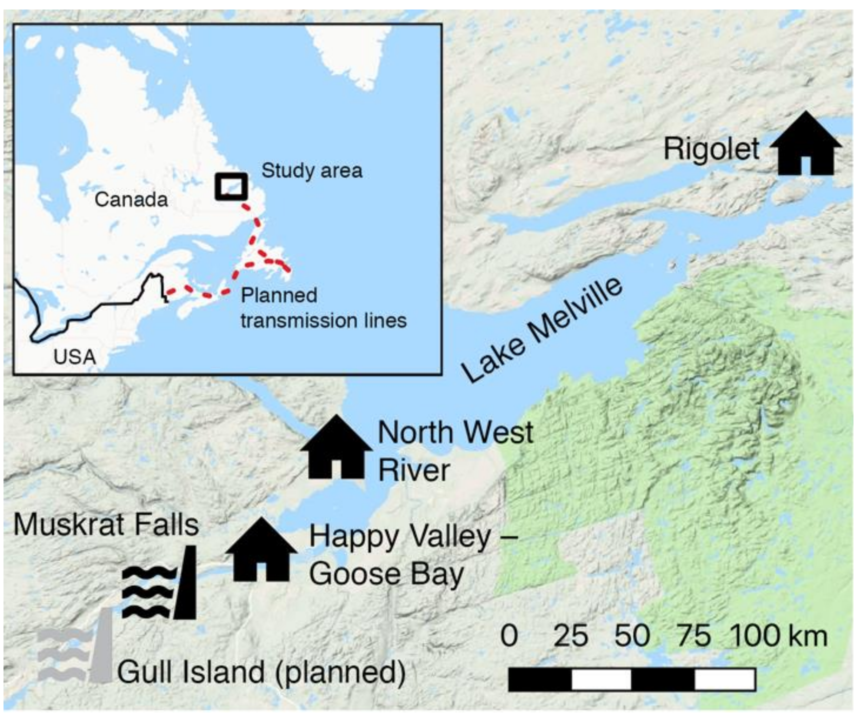

Figure 1: Map showing three Inuit communities settled around Lake Melville downstream from hydroelectric development on the Churchill River, Labrador, Canada. Planned transmission infrastructure to the United States is shown in the inset map.

It is well-known that development of hydroelectric reservoirs causes levels of methylmercury (MeHg), a potent neurotoxin, to increase in local fish. Methylmercury (MeHg) is produced by anaerobic microbes in soils flooded for hydroelectric development and bioaccumulates in local food aquatic food webs.[34, 35] This greatly increases uptake of

MeHg into affected food webs, a process that occurs in all aquatic environments as microbes methylate inorganic mercury deposited from the atmosphere.[36] Virtually all mercury (Hg) present in the muscle of fish and marine mammals is MeHg, and virtually all human exposures to MeHg are from seafood.[37, 38] MeHg is the most toxic form of Hg and has been linked to a host of developmental, neurologic and cardiovascular risks with clear effects on diverse endpoints at exposures typical of moderate fish consumers.[39-41] In the case of Muskrat Falls, however, analysis of likely impacts on downstream Inuit was limited by scientific unknowns about how Hg and MeHg cycles in estuarine environments, an absence of baseline data and poor understanding of the importance of such increases in the context of overall exposures. While the government-owned utility acknowledges the risk that fish MeHg levels are likely to increase in the reservoir but excluded the downstream environment from its environmental impact assessment altogether claiming that there would be no impacts to assess.[42-46]

Mercury Cycling Studies and Exposure Forecasts

Our research program set out to characterize the biogeochemical mechanisms controlling downstream cycling of MeHg produced in a newly created reservoir. Monitoring data from previous hydroelectric development suggest that impacts persist up to several hundred kilometers downstream.[47, 48] However, impacts on downstream estuaries had not previously been investigated. The estuary downstream from Muskrat Falls, Lake Melville, is the traditional fishing territory for Indigenous Inuit, so understanding MeHg fate and transport there is crucial to understanding the potential for human exposure increases. We characterized inputs, losses and chemical transformations of primary mercury species in Lake Melville by combining results of chemical analyses of water and sediment samples with computer simulations. This work demonstrated that strong stratification of northern estuaries concentrates local plankton and MeHg delivered from rivers into relatively shallow surface layer. This is significant because uptake of aquatic MeHg by plankton is the most important step for MeHg entering the food web. This work thus suggested that MeHg levels in northern estuarine food webs are sensitive to perturbations in river MeHg levels, for example due to climate change or hydroelectric development, and was published in The *Proceedings of the National Academies of Sciences of the United States of America* in 2015.[49]

In order to estimate the likely impact of a newly created reservoir on MeHg levels in the environment, we developed a broader predictive model around the Lake Melville budget proposed by Schartup et al.[49]. This work synthesized available evidence on the magnitude of the MeHg response in newly created reservoirs as a function of site conditions and proposed a mechanistic pathway by which flooded soil MeHg would propagate through the downstream aquatic environment. To reflect the large uncertainties inherent in environmental systems, these processes were modeled probabilistically, and key parameter values were modeled as distributions. The result is a probabilistic forecast for peak MeHg levels in the downstream Churchill River and Lake Melville surface layer. Potential future changes in aquatic MeHg concentrations were translated to changes in MeHg levels in the food web impact by accounting for the lifetime average importance of each environment for the feeding patterns of key species.

We recruited 1,145 people from the three Inuit communities around Lake Melville into a dietary survey and mercury exposure assessment in order to evaluate how MeHg increases in key local species may impact human exposures. Participants reported their consumption of local and store-bought foods over the preceding three months. This data was combined with data on present-day MeHg levels in the surveyed foods to evaluate present-day MeHg intakes. These estimates were evaluated with respect to measurements from hair samples supplied by willing participants. Forecasted peak MeHg levels in local species were substituted into the exposure model to assess the maximum impact of seafood MeHg increases on exposures among Indigenous Inuit.

This work provides a tool to explicitly characterize the likely range of changes to MeHg exposures among populations whose local environments are impacted by hydroelectric development as a function of site properties and assumptions about local and downstream cycling. The generalizable framework for forecasting MeHg exposures as a result of hydroelectric development and the case study of the Inuit around Lake Melville was published in *Environmental Science and Technology* in 2016.[50]

Risks of MeHg Exposures and Food Consumption Advisories

Food consumption advisories are the default response to elevated levels of contaminants in seafood and have been deployed extensively following hydroelectric development to control exposures to MeHg.[6, 51] However, advisories are controversial because they can cause targeted populations to lose confidence in the safety of traditional foods and because they do not necessarily balance risks of contaminants with nutritional, social and other benefits.[9, 10, 52] Many seafoods are rich in n-3 polyunsaturated fatty acids (PUFAs) which are protective on the cardiovascular and neurodevelopmental endpoints acted on by MeHg; net benefits on these endpoints are thus achieved by selecting fish that are high in n-3 PUFAs and low in MeHg.[53] Meanwhile, seafoods tend to have higher concentrations of a number of key nutrients than most other protein sources, exerting protective benefits on a wider range of other health endpoints.[54] Therefore, the net health impacts of fish

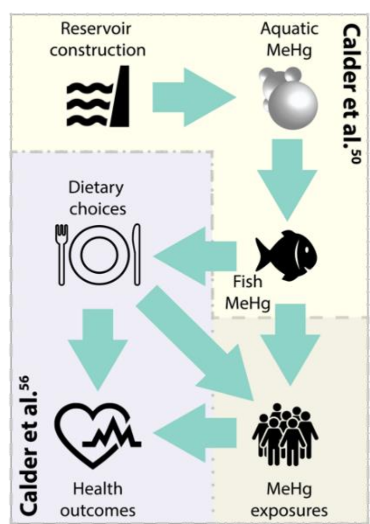

Figure 2: Coupled social-biophysical modeling of human health risks from hydroelectric development and potential dietary responses with citations to underlying scientific articles.

advisories are highly uncertain and may not be health-protective if the avoided MeHg risks are outweighed by risks associated with net loss of nutrients from seafood. The final phase of this research coupled Hg-related risk forecasts outlined above with a characterization of nutritional risks from potential policy or individual-level responses in order to characterize net risks of various decisions. This workflow is diagrammed in **Error! Reference source not found.**.

We characterized the significance of local foods for intake of calories and a suite of nutrients by cross-referencing dietary intake data with government nutritional databases. The dietary survey described previously provided data for intake of all local foods and store-bought seafood, while data for other store-bought food was derived from a government database of subsidies for various nutritional foods in remote communities. Results indicate that traditional foods account for < 5% of all caloric intake on average across demographic groups. However, they account for roughly 70% of n-3 PUFAs and a disproportionate share of a longer list of other nutrients. This is consistent with previous observations that traditional diets play a key nutritional role in indigenous populations who face generally high rates of food insecurity.[55] While reducing intake of local foods would have a large effect on population-wide exposures to MeHg both at present day and after flooding, it may also have a large nutritional impact.

To evaluate the competing risks of increased exposures to MeHg vs. changes in nutritional sufficiency from consumption advisories, we developed hypothetical scenarios for replacement of local foods that bounded potential impacts on nutritional sufficiency. We evaluated net changes to nutrient intake if community members substituted local foods with 1) empty-calorie junk foods; 2) vegetables; 3) processed meat; and 4) a representative basket of nutritious foods based on current intakes (derived from government subsidy data). We also evaluated the impacts of replacing intake of all current local foods with local Atlantic salmon, which is a low-MeHg, nutrient-rich and primarily marine local food that is unlikely to be materially affected by upstream hydroelectric development. Results indicate that all scenarios negatively impact overall nutritional sufficiency (although Atlantic salmon increases per-capita intake of n-3 PUFAs and vitamin D). However, intakes of MeHg were reduced by about 70% relative to present day.

We compared the net health impacts of A) reduced nutritional sufficiency but avoided MeHg exposures from food substitution vs. B) present-day nutritional sufficiency but increased MeHg exposures from hydropower by combining statistical relationships between intake of foods, nutrients and MeHg vs. neurodevelopmental, cardiovascular and cancer. Results showed that impacts from increased MeHg exposure are likely smaller than the effect of lost nutrients in all substitution scenarios based on store-bought foods with the exception of neurodevelopmental impacts which were reduced but not eliminated by substitution scenarios. However, substitution with Atlantic salmon showed protective effects on all outcomes relative to present day.

This work provided a quantitative framework for evaluating the competing risks of food consumption advisories as a strategy for controlling exposures to bioaccumulative contaminants, applied in the context of hydroelectric development and MeHg on the Labrador Coast. It demonstrates that among populations with high levels of food insecurity (e.g., Indigenous populations), advisories that have the effect of displacing local foods from the diet may exacerbate rather than mitigate risks, and that a more health-protective approach may consist of encouraging intake of traditional foods that are relatively higher in nutrients and lower in contaminants. This work was published in *Environmental Research* in 2018.[56]

Global Implications and Future Directions

The body of work described here aims to develop tools inform decisions about siting and design of hydroelectric projects and risk mitigation measures such as food consumption advisories. We explored the potential of this work to serve as a screening tool by extrapolating forecasts for Muskrat Falls to other potential future hydroelectric sites across Canada to the extent possible with publicly available information. Findings suggest that >90% of potential future hydroelectric capacity is located within 100 km of indigenous communities and that impacts on water column MeHg suggested for Muskrat Falls may be about a median case. However, more site-specific risk assessments are required to translate this into implications for human exposures.

Global growth in hydroelectric power is concentrated in developing economies of Asia, Africa and South America, where governments are seeking to meet both a growing demand for electricity and targets for sustainable development.[57, 58] However, little is known about how design and siting decisions in these contexts interact with the local environment to produce MeHg-related risks, or how these environmental risks translate into human health risks as a function of present diets or dietary alternatives. More research is needed to understand the human health implications of the worldwide growth in hydroelectric power.

Overall, hydropower is playing a key role in renewable energy transitions in the United States and worldwide. In the U.S., state governments have focused on the potential of expanding generation capacity in Canada to meet renewable energy targets. However, there is increasing legal and social pressure both in the U.S. and in Canada to proactively anticipate health and environmental impacts on Indigenous populations whose environments are transformed by these projects. The work presented here contributes to a more proactive approach.

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Energy Implications of a New Food Waste Treatment in Shanghai, China

Junqin Chen

Junqin (junqin.chen@duke.edu) is a PhD candidate in Mechanical Engineering and Materials Science (MEMS) Department at Duke University.

Keywords: food waste, fertilizer, biochemical hydrolysis

In 2015, electricity consumption of electricity in China reached 5560 billion kilowatt hours (kWh).[1] Most of this energy (71%) was used in the industrial sector, highlighting the energy demands of rapid industrialization.[2] Population growth of the country has led to increased energy demands in the residential sector as well, with large cities like Shanghai and Beijing leading the countries' residential power demands.[3] While these large cities do not suffer from daily energy concerns, energy poverty in other regions of China is an ongoing struggle. 29% of the country still uses traditional woody biomass for cooking and heating.[4] The competition for energy resources between the industrial and residential sectors will continue to create energy scarcity in many regions.

While energy poverty remains present, the way China is currently producing energy creates other problems for the country. In 2016, more than 65% of electricity in China was generated by burning coal.[5] Coal power is a primary source of hazardous air pollutants including particulate matter, sulfur dioxide, and ozone. In an effort to reduce health and environment impacts of energy generation, the Chinese government has launched a series of policies that focus on gradually converting thermal power generation into other environment-friendly forms like hydro, wind, and solar power. However, increasing energy demands and further implementation of sustainable power generation remain urgent problems to solve for China.

Introduced in China in the 1980s, incineration technology converts municipal solid waste into energy by combustion. In 2014, the electricity generated by incineration plants reached 18.7 billion KWh, which occupied 1.2% of total "new and renewable" energy production.[6] An issue with incineration is that the heat value of solid waste in China is low due to discarded food mixing in the solid waste, which has rich organic composition and moisture content.[6] If the food waste can be separated from municipal solid waste and converted into energy, the efficiency of incineration plants will increase, helping to alleviate energy poverty in the country. This case study will focus on ways Shanghai JY Environmental Protection Technology Co. Ltd. is developing energy-efficient equipment and investigating new energy sources and transmission, which includes the pre-development of a project aiming to converting the food waste into fertilizers.

Food Waste as a Global Problem

Food waste can be defined as any uneaten food or potential source of food that has been discarded from households, restaurants, factories and shops. Roughly 30% of all food produced for human consumption does not reach the table.[7] In highly-developed countries, the amount of food wasted per year can be expressed in terms of billions of dollars.

In developing countries, problems surrounding food waste are more serious due to rapid economic and population growth. In China, food waste and depleting natural resources are related issues. With high demand for agricultural products and livestock, China has to contend with depleting natural resources and maintaining productivity of agricultural commodities. In some areas, farmers use great amounts of chemical fertilizers to increase crop production at the cost of soil acidification, water pollution and even food safety problems. Despite this, Chinese consumers wasted no less than 60 million tons of food each year starting from 2015.[8] Around 30% of the total food waste came from four big cities including Beijing, Shanghai, Chengdu and Guangzhou,[8] which as mentioned before, also have the highest residential energy demands.

Traditional Food Waste Treatment

Food waste faces challenges in collection, transportation, classification, and reclamation. The oldest method used to treat the food waste is landfills, where 90% of food waste is disposed currently.[10] While landfills are low in energy consumption, the decaying biological matter emits methane, a potent greenhouse gas and precursor to secondary pollutants. According to the data from United States Environmental Protection Agency, around 18% of U.S. methane gas emissions come from landfills.

Composting is an environment-friendly alternative to landfills although it occupies only 1% to 6% of food waste in developed countries, and even less in China.[10] Under controlled anaerobic conditions, the organic waste such as food or plant materials mixing with bulking agents can be decomposed into fertilizers, biogas and heat after a period of months. According to Save on Energy, a person in North America wastes 231 pounds of food every year. If all of this can be converted into electricity, that can power a 100 watt lightbulb for 2 weeks. For a country with 319 million people, all food waste in a year can produce enough energy to power an electric heater for over 6,000 centuries. While composting may be a solution for small scale household operations, it requires complete source-separated food waste system and excessive investment, which make large scale operations difficult to implement.

Waste-to-Fertilizer System

In Shanghai, the food waste collected by sanitary departments reaches 500 tons per day.[11] Around 10% of this is recycled by nine small companies focusing on transferring foot waste into organic fertilizers and fodders through anaerobic digestion.[12] The remaining food waste is sent to a factory in the outskirts of city and treated by aerobic decomposition.

According to preliminary statistics, for a waste treatment plant with a capacity of 100 tons per day, the cost on food waste transportation, which includes automated compactor trucks, shipping containers, and labor costs, accounts for 20% of the total investment. The energy consumed during transportation, such as fuel and electricity, reaches $4000 per month, which occupies 5% of the total processing fee.[12] Due to excessive transportation expenses and large investments, those companies normally receive financial assistance from the local government to support normal operation of their factories.

The biggest problem with typical food to fertilizer treatment is that it normally accompanies unpleasant smells and secondary pollutions. Therefore, Shanghai JY Environmental Protection Technology Co. Ltd. looks to towards developing a more efficient and productive way to convert food waste into useful products with the lowest energy consumption. In addition, to reduce transportation costs, the final target was to provide food-waste-disposal service for a community, large restaurant, or school by installing a set of small-scale facilities on the spot.

In order to reduce investments and development period, our group used existing facilities in the market instead of customizing them. For mobility and minimizing the projects footprint, we placed all equipment into a standard shipping container (~ 6 x 2.5 x 2.5 m). The completed equipment can process 30 tons food waste and 2-7 tons straws and saw powders per day, while producing 4 tons of organic fertilizers. Figure 1 shows the process flow diagram of the system.

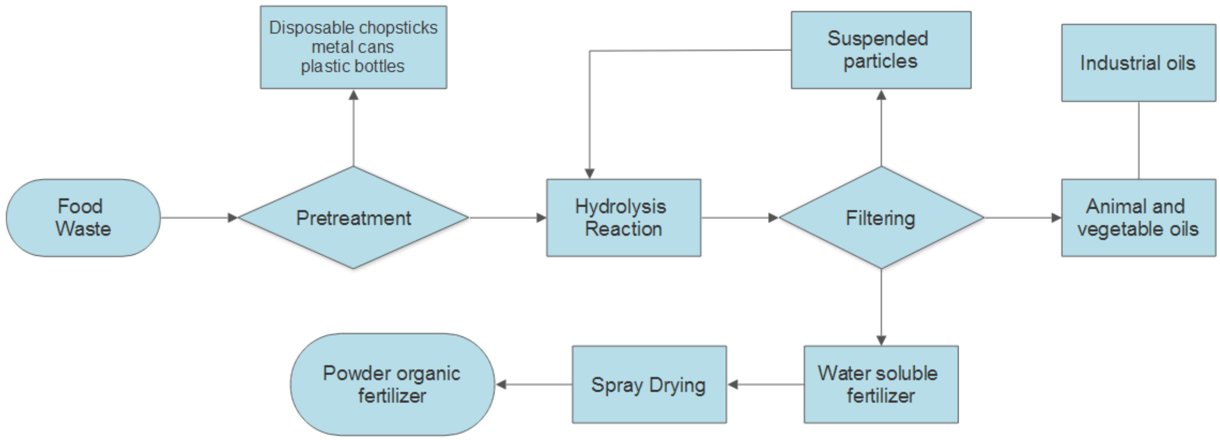

Figure 1: The process flow diagram of the food to fertilizer system capable of generating four tons of organic fertilizer per day.

Pretreatment
The first step is removing large solid waste using a screening machine. Screening will also remove tissues, which provide little benefit as fertilizer. Next, the remaining food waste will be crushed into pieces as small as possible.

Hydrolysis Reaction
Biochemical hydrolysis uses high temperature and pressure to convert macromolecular compounds in the food waste into micromolecular organics, which will be easily absorbed by crops. The extreme conditions of the step also sterilize the fertilizer by killing and viruses or bacteria. The duration of the reaction is 3 hours. To reduce the energy consumption during this step, our group used a high temperature water heating system outside of the reaction vessel.

Filtering
After hydrolysis, the resulting fluid continues to filtering. First, the fats and oils, which do not participate in the reaction, are collected and recycled. Then the other insoluble matters such as animal skeletons and plant peels are recycled back into the reactor until the complete decomposition.

Spray drying
The final step is to convert liquid fertilizers into powders. A spray dryer uses air as a heated drying medium. The air is passed in a co-current direction with sprayed liquid containing organic matter so that the solute can be separated from the solvent rapidly. The advantage of this method is that the particle size of products from the machine is always consistent.

Benefits

This new method provided by JY company, addresses some of the problems caused by standard food decomposition processes. First, the smell caused by food deterioration and bacterial growth can be completely removed by the hydrolysis reaction.

Second, the system consumes less energy than other processes to provide fertilizer. In 2012, American nitrogenous fertilizer plants consumed $175 million in electricity.[13] In China, nitrogen fertilizer production still largely depends on coal power generation, which is facing reserve depletion and creating environmental problems. This system consumes only 125kW a day. Not only is this eco-friendly, but also economically viable, equating to only seven thousand dollars annually in energy costs.

Finally, the fertilizers produced through the system can meet requirements from the market of organic fertilizers with high efficiency. Since people's living standards has improved greatly in China, the demand for agricultural output keeps growing. The organic fertilizers produced by traditional food waste treatment such as compositing cannot meet market demand due to their long fermentation time, low fertilization efficiency, and high frequency of usage. As a result, the amount of chemical fertilizers applied to crops has been increasing. This application of chemical fertilizers has greatly weakened the original fertility of soils in China, which is characterized by a rapid decrease of soil organic matter over generations. In 1958, the soil organic matter in the northern area of China was 5%, and the current data shows that only 2% of them remains in the soil.[14] Therefore, the market has an urgent need for efficient organic fertilizer products, which can achieve mass production and improve soil quality effectively.

Challenges in Implementation

The implementation and popularization of this new kind of food waste treatment will face several challenges. Due to the differences in geographic regions, eating habits, and cultural traditions, significant spatial and temporal variations in the components of food waste exist among different areas in China.[11] If this new method provided by JY company is to be used across the whole country, the first challenge will be doing market research in each area. This investigation should include the amount of food waste produced per day, component analysis of food waste, and any food waste regulations published by local governments. Since there is little reliable data about food waste in China, the investigation will be difficult and tedious.

The source of food waste is another consideration for this project. Residents tend to mix family kitchens with other household rubbish, and not every city has a unified recycling system. For example, in Shanghai, some kitchen waste is used by famers to irrigate the soil, plant vegetables, and raise livestock. Instead of focusing on residential food waste, JY company will need to focus on the food waste collected from large restaurants, schools and food processing factories, as the food waste from these places is relatively pure.

Steps in the Future

Given China's population and economic growth, food waste and energy consumption will continue to be important issues. Treating food waste as a recyclable resource will be crucial in bridging the gap between food waste and energy access. The JY company has made a good start for the industrialization development of food waste disposal. The new equipment can convert 30 tons food waste into 4 tons organic fertilizers per day by using 125kW of electricity per day. If the size and handling capacity of the equipment is increased, this method can be used in large food processing factories so that the food waste can be treated on the spot and the economic and energy cost of transportation will be reduce dramatically. For places where the amount of food waste is relatively small such as restaurants and schools, a set of miniaturized equipment with 2-3 tons of processing capacity can be provided. This proposed solution will reduce landfill space, provide clean fertilizer for food production, and reduce energy costs associated with traditional fertilizer use.

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Evaluating Viability of Community Solar Microgrids for Resilience in Puerto Rico

Simeng Deng, Asger Hansen, Galen Hiltbrand, Sean Maddex, and Santiago Sinclair Lecaros

Simeng is a Consultant, China Power at Woods Makenize (simeng.deng@duke.edu). Asger is Co-Owner of Kauil Energy-Mexico (asger.hansen@duke.edu). Galen is a US Energy & Climate Research Analyst at Rhodium Group (Galen.Hiltbrand@gmail.com). Sean is a Energy Industry Analyst at FERC (seanmaddex@gmail.com). Santiago is a Geospatial Energy Analyst at World Resources Institute (Santiago.Sinclair-Lecaros@wri.org).

Keywords: microgrid, solar power, renewable energy, natural disaster

Introduction

Hurricane Impacts

Hurricane Maria, which hit the Caribbean two weeks after Hurricane Irma in September 2017, caused the largest electricity blackout in U.S. history. Eight months after the storm, the tropical cyclone had already caused 3.4 billion lost customer-hours of electricity in Puerto Rico and the U.S. Virgin Islands.[1] It took nearly a year – eleven months – for Puerto Rico to fully regain power,[2] and today the island's grid remains fragile.

Unfortunately, as global temperatures continue to rise due to anthropogenic climate change, the intensity of hurricane activity is projected to become more extreme. Climate change leads to warmer sea surface temperatures which enhances the amount of energy available to hurricanes. According to NOAA's Geophysical Fluid Dynamics Laboratory, climate models do not project an increased number of hurricanes; however, the proportion of hurricanes that reach destructive Category 4 and 5 levels are projected to increase.[3] Also, warmer atmospheric temperatures allow for the air in tropical areas to hold more moisture. As a result, models predict that with an increase in global temperatures of 2˚C above preindustrial levels, the average rainfall rates of hurricanes will increase by 10-15%.[3] Another concern is that sea level rise will contribute to higher storm surge levels than those of present-day hurricanes. These factors are particularly concerning to island states and coastal communities that are vulnerable to the worst impacts of these storms.[3]

As Hurricane Maria demonstrated, prolonged power outages can limit access to water supplies and medical services, resulting in increased mortality rates. A study published by the New England Journal of Medicine suggests that the death toll on Puerto Rico may have been over 4,600 people.[4] This places Hurricane Maria as the second deadliest natural disaster on record in the United States. To limit the destruction of hurricanes, it is critical for communities to become more resilient to storms. The rural village of Toro Negro, Puerto Rico, is an example of a community taking the initiative to do so.

Microgrids

Puerto Rican energy policy defines a microgrid as a "group of interconnected loads and Distributed Energy Resources within a clearly defined electrical boundaries that act as a single controllable entity that can connect and disconnect from the Electrical Power Grid to enable it to operate in either grid-connected or off-the-grid (islanded) mode (Regulation 9028 of 2018)." In simpler terms, a microgrid is a set of generation units that and demand sources that can be managed as a group and connected to or disconnected from the electricity grid.

Microgrids can be powered by a variety of generation sources, including fossil fuels and renewable energy. They function as a localized energy supply and are capable of maintaining power when disconnected from the main energy grid in the region. For this reason, microgrids are an attractive option for communities in Puerto Rico looking to gain energy independence and increase storm resiliency.

The microgrid system in Toro Negro is powered by solar panels and connected to batteries. The battery storage allows for the microgrid to have back-up electricity and run off of this stored power when the sun is not shining. The diagram below provides a simplified example of how a microgrid is organized (Figure 1).

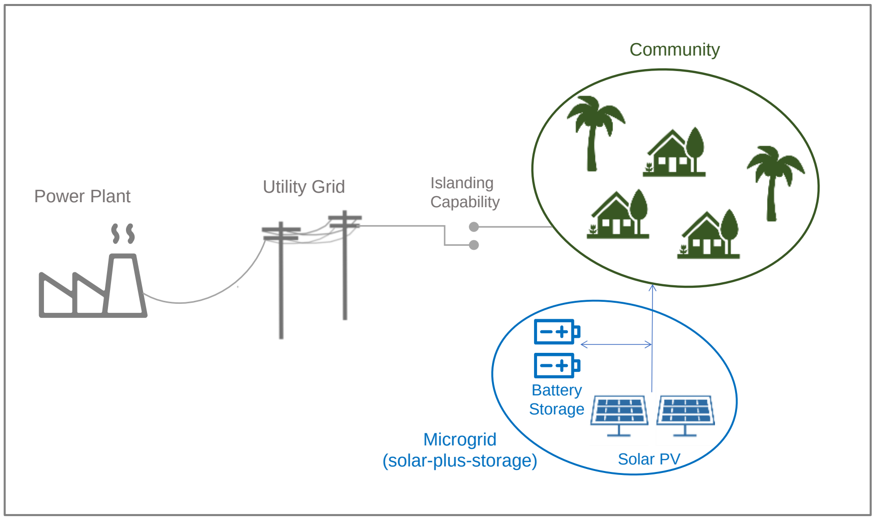

Figure 1: Organizational flow diagram of a solar-plus-storage microgrid.

Toro Negro

Toro Negro is a rural community nestled into the mountains of Ciales, Puerto Rico. It is located almost directly in the center of the island (**Error! Reference source not found.**).

Figure 2: Toro Negro, Puerto Rico is located near the center of the island. [13]

After Hurricane Maria, Toro Negro went without electricity for a staggering 8 months.[5] This experience led the self-starting and well-organized community to take the initiative to gain energy independence from the unreliable grid. Toro Negro contacted the non-profit Fundación Comunitaria de Puerto Rico (FCPR), a philanthropic organization that invests in community-based projects in Puerto Rico.

FCPR and Somos Solar, a non-profit with the mission of boosting solar markets in Puerto Rico, donated solar panels and battery storage to Toro Negro in March 2018.[5] The community went further by establishing a community solar microgrid system, which powers 28 houses. This is the first community microgrid system operating on Puerto Rico. Toro Negro established a non-profit, *Comunidad Solar Toro Negro,* which consists of an elected team of community leaders to manage this project.

Since the installation of the microgrid, the residents using the system in Toro Negro have yet to pay for their power on an energy use basis. The next step for this microgrid is to establish a price rate at which the community can pay for their electricity and an operations and maintenance plan to ensure that the system remains economically feasible for years to come.

Objectives

The overarching objective for the project was to develop a management strategy for *Communidad Solar Toro Negro* and other community solar microgrid systems in Puerto Rico.

Specific Aims

1. Conduct a community governance analysis of microgrids: Analyze community participation and readiness, as well as the role of different potential stakeholders/actors in the governance and operations of the system. We will provide recommendations to Toro Negro and similar microgrid projects through extensive research in common resource governance.
2. Develop a microgrid operations and maintenance plan: Plan that will revise technical variables, steps and processes for the optimal operation and maintenance of the designed microgrid in time. This will focus on equipment maintenance and replacement as well as the required costs and timeline for these activities. This plan will also analyze potential expansion and level of resilience of the microgrid.
3. Propose a business model for the existing microgrid: This aim will include an analysis of the different operational business models. The business model will identify ways to incorporate local workforce and maximize benefits to local community.
4. Review and analyze the political feasibility for microgrid plans in Puerto Rico: Evaluation of the policies, plans, and programs already in place in Puerto Rico that can support or constrain a potential microgrid system with renewable energy in the territory. Continue to monitor policies that would affect Puerto Rico's energy sector. Identify gaps within the policy framework, including any potential policies that would support or inhibit microgrids in Puerto Rico.

Governance

Community solar microgrids, such as the one in Toro Negro, require local governance. There are numerous management risks that arise when transitioning to a new system that depends upon the self-governance of a resource. Therefore, it is critical to ensure that the community of Toro Negro is prepared to take on this responsibility.

To provide the community with concrete advice about governing the system, our team identified the strengths, weaknesses, opportunities and threats (SWOT) of Toro Negro's microgrid. This analysis is based upon countless conversations with Toro Negro community members and staff from FCPR which we compared to literature regarding best practices for the governance of a common resource. Strengths and weaknesses are factors that are internal to the Toro Negro's governance of the microgrid. Opportunities and threats are factors which are external to the community's governance of the microgrid but could impact the system's functionality. **Error! Reference source not found.** provides a visual summary of the SWOT analysis.

STRENGTHS (S)	WEAKNESSES (W)
S1: Engaged participation from decision makers **S2:** Clearly defined boundaries and users **S3:** Environment that fosters trust **S4:** Dependable solar resource plus battery storage	**W1:** Ability of the microgrid to be monitored and easily understood by users **W2:** System payment monitoring **W3:** Capacity of Toro Negro to address technical issues without external help
OPPORTUNITIES (O)	**THREATS (T)**
O1: High need for increased resilience **O2:** Generate revenue **O3:** Strong working relationship with FCPR **O4:** Favorable policies	**T1:** Less external involvement **T2:** Variability in electricity demand **T3:** Competitive pricing from PREPA

Table 1: Current Swot analysis of Toro Negro's microgrid.

Here is further detail about one factor from each quadrant:

- Strengths:
  - S1: The community has engaged participation from the microgrid decision makers, which is key to the successful governance of a common resource.[6] Toro Negro established a non-profit, Comunidad Solar Toro Negro, to form a directive for managing the microgrid. This team consists of four of community leaders elected by the microgrid users and an employee from FCPR.
- Weaknesses:
  - W1: According to literature, effective governance is easier to achieve if the system is straightforwardly monitored and understood by its users.[7] A potential weakness of the microgrid is the ability of the system to be monitored and understood by users.
- Opportunities:
  - O3: Toro Negro has a strong working relationship with FCPR, an organization with the mission and expertise to help Puerto Rican communities achieve economic development and access to clean energy.
- Threats:
  - T3: Competitive electricity rates from the utility, PREPA, could render using the microgrid system economically unattractive and too expensive for users.

Next, we used the SWOT analysis above to conduct a TOWS analysis, which is simply SWOT backwards. The TOWS analysis is a tool to identify strategies that use internal strengths to maximize external opportunities and minimize external threats. Moreover, this tool helps identify strategies to minimize internal weaknesses by capitalizing on external opportunities and avoiding external threats. It divides these varying strategies into four quadrants (**Error! Reference source not found.**).

Internal / External	**STRENGTHS (S)**	**WEAKNESSES (W)**
	S1: Engaged participation from decision makers **S2:** Clearly defined boundaries and users **S3:** Environment that fosters trust **S4:** Dependable solar resource plus battery storage	**W1:** Ability of the microgrid to be monitored and easily understood by users **W2:** System payment monitoring **W3:** Capacity of Toro Negro to address technical issues without external help
OPPORTUNITIES (O) **O1:** High need for increased resilience **O2:** Generate Revenue **O3:** Strong working relationship with FCPR **O4:** Favorable policies	***S-O STRATEGIES*** • ***S1 to O3/O4:*** Closely monitor relevant energy policies with FCPR • ***S1/S3 to O2***: If pricing remains affordable, Toro Negro can add a marginal fee to fund community projects • ***S4 to O1:*** Uphold O&M of the system so that Toro Negro has a reliable source of energy when the main grid is experiencing a blackout	***W-O STRATEGIES*** • ***W1/W3 to O1/O3:*** Organize educational programs for users with FCPR & system provider • ***W1 to O1/O3:*** Share best practices for monitoring with other communities developing microgrids • ***W2 to O1/O3:*** Ensure accountability of those monitoring the system[8]
THREATS (T) **T1:** Less external involvement **T2:** Variability in electricity demand **T3:** Competitive pricing from PREPA	***S-T STRATEGIES*** • ***S3 to T2:*** Continue monthly meetings to reinforce electricity limits and foster open dialogue to account for any changes in population size • ***S1 to T3:*** Monitor the electricity prices and regulations of PREPA	***W-T STRATEGIES*** • ***W3 to T1:*** Maintain strong relations with FCPR and implement educational programs about the system for the community • ***W2 to T2:*** Explore potential for online billing options

Table 2: Current TOWS analysis of Toro Negro's microgrid

Here is one strategy from each quadrant:

- S-O Strategies: Using internal strengths to maximize opportunities
  - S2 to O3-4: Closely monitor relevant energy policies with FCPR. As more communities in Puerto Rico establish microgrids, Toro Negro could collaborate with these communities to support favorable regulations with grassroots efforts.

- W-O Strategies: Minimizing weaknesses by utilizing opportunities
  - W1,W3 to O1,O3: Organize educational programs with FCPR & the system provider so that users can better understand the system powering their homes. Toro Negro had their first of educational program held by Somos Solar, the company that installed the microgrid, at the end of March 2019.
- S-T Strategies: Using strengths to mitigate threats
  - S3 to T2: Continue monthly meetings to reinforce electricity payments and foster open dialogue to account for any changes in population size.
- W-T Strategies: Minimizing weaknesses and avoiding threats
  - W2 to T2: Explore online billing options to find a billing system that would work for the community.

As common property literature suggests, there is no one-size-fits all approach that can be applied to every common governance project.[6] However, in order to install similar solar-plus-storage microgrid systems in more communities across the Caribbean, it is important to have established principles for the community to effectively govern the resource.

Policy Analysis and Recommendations

In 2010, Puerto Rico passed the Public Policy on Energy Diversification by Means of Sustainable and Alternative Renewable Energy in Puerto Rico Act, hereinafter referred to as the Policy on Energy Diversification. The Act affirmed a commitment to increase renewable energy development across the island and transition away from fossil fuels (Act 82 of 2010). Subsequent energy policies followed this trend. However, despite the intentionality to support a renewable transition, the legislative framework suffers from two significant gaps.

The first gap is a focus on incentives for development rather than incentives for existing projects. Most of Puerto Rico's incentive policies offer financial assistance for the construction of new renewable energy projects. The Green Energy Incentives Act established the Green Energy Fund to financially support renewable energy projects. The Act also created the Green Energy Investment Reimbursement program as a means of disbursing the funds (Act 83 of 2010). In 2015, updated regulations on the eligibility requirements for the Green Energy Investment Reimbursement Program created the requirement that specifically disqualified any projects that began construction before receiving an Incentive Reservation Notice Letter from the State Office of Energy Policy, effectively prohibiting the granting of incentives retroactively (Regulation 8601 of 2015).

The second gap is that policies that do incentivize existing projects fail to support smaller renewable energy projects. Net metering, the sale of energy back to the grid, and Renewable Energy Certificates (RECs), a payment to renewable energy producers for each megawatt-hour of energy generated, are two of the only nontax-based financial incentives available to existing renewable energy generators. Net metering is available to both large and smaller projects, but RECs are not. The REC program specifically requires "*the issue of RECs to sustainable renewable energy and alternative renewable energy producers through the renewable's registry, as this term is defined in this Act* (Act 82 of 2010, Section 2.7)." The definitions for *sustainable renewable energy* and *alternative renewable energy producers* do not include renewable energy producers that generate less than 1 MW.

From a policy standpoint, a direct subsidy tailored to small renewable energy producers would be optimal. Net metering only provides compensation in the form of credits which may only be used to reduce payments for energy bought from the grid (Act 114 of 2007). RECS offer direct financial support but are subject to low prices limiting their revenue potential and are subject to price uncertainty.[9,10] A direct subsidy offers the highest economic impact of the discussed policy options. A subsidy of $0.05 per kWh would result in an estimated annual revenue stream of $5,000, which is significantly greater than the $200-400 per year estimate from Renewable Energy Credit sales. Unfortunately, the current political feasibility of enacting a direct subsidy is low because Puerto Rico is more than 70 million in debt and it may not have sufficient funding available.[11]

Despite an imperfect legislative framework, the future of microgrids and small-scale renewable energy projects remains promising. At the end of March 2019, Puerto Rico passed their own Green New Deal, Senate Bill 1121. The Green New Deal commits Puerto Rico to a 100 percent RPS by 2050 and makes sweeping changes to the islands energy policies and incentive programs.[12] While it is too early to determine the full impacts of the bill and how specifically it will affect community microgrids, the statement of intent attached to S.B. 1121's enactment should fill renewable energy producers a sense of optimism.

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