The Marginalization of “Small is Beautiful”: Micro-hydroelectricity, Common Property, and the Politics of Rural Electricity Provision in Thailand

by

Christopher Edmund Greacen

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Committee in charge:

Professor Daniel M. Kammen, Chair
Professor Richard B. Norgaard
Professor Jeffrey Romm

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The dissertation of Christopher Edmund Greacen is approved:

Chair Date

Date

Date

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Abstract

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This study analyzes forces that constrain sustainable deployment of cost-effective renewable energy in a developing country. By many economic and social measures, community micro-hydro is a superior electrification option for remote mountainous communities in Thailand. Yet despite a 20 year government program, only 59 projects were built and of these less than half remain operating. By comparison, the national grid has extended to over 69,000 villages.

Based on microeconomic, engineering, social barriers, common pool resource, and political economic theories, this study investigates first, why so few micro-hydro projects were built, and second, why so few remain operating. Drawing on historical information, site visits, interviews, surveys, and data logging, this study shows that the marginal status of micro-hydro arises from multiple linked factors spanning from village experiences to geopolitical concerns.

The dominance of the parastatal rural electrification utility, the PEA, and its singular focus on grid extension are crucial in explaining why so few projects were built.

Buffered from financial consequences by domestic and international subsidies, grid expansion proceeded without consideration of alternatives. High costs borne by villagers for micro-hydro discouraged village choice.

PEA remains catalytic in explaining why few systems remain operating: grid expansion plans favor villages with existing loads and most villages abandon micro-hydro generators when the grid arrives. Village experiences are fundamental: most projects suffer blackouts, brownouts, and equipment failures due to poor equipment and collective over-consumption. Over-consumption is linked to mismatch between tariffs and generator technical characteristics. Opportunities to resolve problems languished as limited state support focused on building projects and immediate repairs rather than fundamentals. Despite frustrations, many remain proud of “their power plant”. Interconnecting and selling electricity to PEA offers a mutually beneficial opportunity for the Thai public and for villagers, but one thus far thwarted by bureaucratic challenges.

Explanations of renewable energy dissemination in countries with strong state involvement in rural electrification should borrow approaches from political economy concerning the ways in which politics and constellations of other factors eclipse rational economic behavior. At the village level, common pool resource theory reveals causal linkages between appliance use, equipment limitations, power quality, and equipment failures.

Dedication

For my father and for Chom

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Chapter 1: Introduction

If economics and environmental impacts were deciding factors, one might expect that by today thousands of communities in rural mountainous parts of Thailand would be served by electricity from village-scale micro-hydroelectric[1] plants instead of the national grid. The topography and rainfall are ideal for the technology: steep hillsides are abundant in much of the north, northwest, and south; rainfall is generous, and thick forest cover helps ensure that many streams have water throughout the year. The technology is appropriate for the demographics and environment of these areas. Settlements in these areas are generally remote and sparse, so that long grid extensions are required to serve small numbers of people. As a consequence, in many cases electrification with micro-hydroelectricity has a lower overall cost than extending the grid.[2] The systems generally have little or no reservoir, so environmental impact is minimized.

Yet visitors to villages in Thailand's hill areas generally find either the national grid, or no electricity at all. Moreover, of the paltry 59 village-scale micro-hydroelectric plants that have been built over the past 20 years, more than half have been replaced by the grid or fallen into disrepair. Some of the few remaining projects demonstrate the ability of this technology to provide local employment, capacity building, and resource management benefits in addition to affordable electricity. Despite these benefits micro-hydroelectric systems are rapidly being replaced by the grid.

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[1] Definitions of what constitutes the upper limit of "micro-hydropower" vary from 100 kW (Jiandong 2003) to 300 kW (Harvey, Brown et al. 1998). In Thailand, projects under 200 kW are considered "micro" (DEDP 1998). The terms "micro-hydropower", "micro-hydroelectric", and "micro-hydro" are used interchangeably.

[2] An economic analysis is presented in Chapter 4.

My research addresses two questions in a rigorous way: first, *Why were so few micro-hydro projects built?*; and second, *Why have many of the existing projects been abandoned?*

International context

The global stakes for sustainable deployment of clean, cost-effective electrification are high. Conventional electricity generation worldwide already currently accounts for 38% of worldwide CO_2 emissions, which threaten to irreversibly change the environment (Dubash 2002). Electricity consumption in developing countries is expected to increase rapidly (World Bank 1992; World Energy Council 1993; Kassler 1994; Pearson 1996; Anderson 1997; G8 Renewable Energy Task Force 2001). It is now widely recognized among climate change scientists that stabilizing atmospheric CO_2 at twice pre-industrial levels while meeting goals of moderate economic growth implies a massive transition to carbon-free power, particularly in developing nations (Hoffert, Caldiera et al. 1998). Renewable energy appears destined to play an important role in this transition, especially considering that nuclear power faces critical unresolved challenges in long-term management of nuclear wastes; perceived adverse safety, environmental, and health effects; and potential security risks stemming from proliferation (Ansolabehere et al. 2003). With the emergence of global climate change as a credible and serious threat, decades of relative neglect of renewable energy have recently been somewhat reversed, as evidenced by over $1 billion leveraged by the Global Environmental Facility (GEF) for renewable energy for rural electrification, with large amounts as well from the G-8, prominent energy companies, and governments in a number of countries. The emerging global warming crisis demands that these funds be invested effectively and efficiently.

As a component of developing country electricity infrastructure, rural electrification poses a special challenge: 3 billion people enjoy modern energy services today, but 10 billion will need them if universal service is to be provided within the next half century as more than a billion people are added to the human population each decade (Anderson, 1997). Grid extension has made impressive gains: nearly 1.3 billion people in developing countries have received electrification grid service in the past 20 years, but during this same time period the population of these countries has grown by 1.5 billion (Barnes and Floor 1996). Increasing privatization of electric utilities and fiscal austerity programs generally leave even fewer resources for public expenditures on unprofitable rural grid-electrification (Dubash 2002). And it seems questionable that the private sector will respond adequately to the task of grid-based rural electrification. Entities involved in rural electrification in the emerging era of budget cuts would be wise to consider a wide range of technology options and management arrangements, even if they challenge established practices and concepts of ownership and control.

In this context, decentralized community-managed “small is beautiful” technologies like micro-hydroelectricity appear to be particularly promising approaches to providing electricity – if social and technical arrangements can be structured to keep the technology working for communities in the long run. By investigating the mixed record of the deployment of community-based micro-hydrolectricity in Thailand, this research seeks to identify and understand these social and technical factors.

Thai context

In Thailand, community scaled micro-hydroelectric cooperatives represent an important precedent for community ownership and control of clean electricity infrastructure. As such, they provide a functioning (if Lilliputian) alternative to centralized power systems run by parastatal utility companies (Palettu 2002) and to the profit-oriented large investor ownership model of electricity infrastructure advocated by the World Bank and the IMF that has swept the developing world (Tellam 2000). The technologies used for centralized power generation in Thailand -- especially coal and large hydro power -- are increasingly criticized on environmental grounds (Kuankachorn 2000; Janchitfah 2001; Janchitfah 2002), while power plants that burn imported fossil fuels are seen to jeopardize economic security by fostering an unsafe reliance on imports (Amatayakul and Greacen 2002). The parastatal utilities themselves are increasingly accused by the Thai government, the private sector, and multilateral development agencies as being inefficient, monopolistic, and prone to amassing excessive debt, hurting both ratepayers and taxpayers alike (Barnes 1988; NEPO 2000; Crispin 2001; Greacen and Greacen 2004). NGOs and citizens groups also fault these same parastatals for being undemocratic and unfair in their treatment of affected communities (Hirsch and Warren 1998; Janchitfah 2001; Janchitfah 2002). Customer-owned distribution systems such as municipal and rural cooperative utilities in the United States, Europe, and elsewhere have provided valuable yardsticks by which to judge the efficiency and service of the state and investor-owned utilities. Some argue that the same types of yardsticks and alternatives are necessary in Thailand (Palettu 2002).

More broadly, community-managed micro-hydroelectricity accords well with a number of progressive trends within Thai policymaking. These include a move towards decentralization embraced in a newly adopted constitution (Thai Kingdom 1997), capacity building for rural enterprise, and increased environmental protection including reduction in emissions of greenhouse gases (Amatayakul and Greacen 2002).

Dissertation overview

Rural renewable energy has roots that extend deep into complex and politicized terrain. To understand why village-scale community-managed micro-hydro appears to be losing to the grid, my research is by necessity an interdisciplinary journey through the engineering, economic, political, and social aspects of Thai rural electrification, renewable energy, and particularly village-scale micro-hydroelectricity. The analysis operates at a variety of scales – from the international politics of aid to the day-to-day operations and use of village systems.

Chapter two establishes a framework for this investigation, drawing on theoretical perspectives including engineering, microeconomics, “social barriers” to technology adoption, political economy, and common pool resource theories. The chapter concludes by proposing seven hypothetical explanations for the marginal status of micro-hydro in Thailand.

Chapter three analyzes survey data on the system performance and challenges encountered in the field for 59 village micro-hydro projects in Thailand. This broad perspective is complemented with an in-depth technical analysis of two micro-hydro systems that uses datalogging and household appliance surveys to explore linkages between consumption patterns, equipment shortcomings, low voltage, and equipment failures.

Chapter four explores micro-hydro in the context of the ideal of economically optimized rural electrification planning. The chapter addresses relative economic benefits and costs of micro-hydro versus the grid. A simple quantitative model based on empirical Thai data is developed to determine spatial/demographic conditions under which micro-hydroelectricity may be economically optimal. A related analysis considers the relative costs of micro-hydro and the grid in the electrification of 20 villages currently served by micro-hydro. The chapter considers implications of the opportunity to connect micro-hydro generators to the grid, including a basic financial assessment of 27 projects.

Chapter five presents a history of Thai rural electrification with a focus on issues of technology choices, bureaucratic arrangements, implications for centralization and public voice in decision-making, and the role of international aid and domestic political and economic transformations in shaping this trajectory. The chapter also presents a contemporary overview of community micro-hydro in Thailand and draws on the previous two chapters to construct a multi-layered analysis of why micro-hydroelectricity is unable to effectively compete with the grid despite economic and social advantages.

Chapter six reviews evidence for each of the seven hypotheses proposed in Chapter two, and discusses the relevance of each as an explanatory factor. Based on the match between empirical evidence and hypotheses, I draw conclusions regarding the relative importance of these factors, and consider the implications of this research for further developments of theory.

Chapter seven considers implications of the research for policy initiatives including policies that allow the interconnection of micro-hydroelectric and other small renewable energy generation to the grid, and the deployment of decentralized village-scale renewables in countries with low rates of rural electrification.

The remainder of this chapter (Chapter one) discusses theoretical and practical contributions of this study, describes the methods employed in this research, and provides an introduction to some salient technical and social dimensions of village-scale micro-hydroelectricity.

Study methods

My methods include in-depth interviews, archival research, surveys, and computerized data logging. Historical information, government reports (Thai and US), and personal interviews provided much of the information for my analysis. In addition I made site visits to investigate installations, and used datalogging equipment[3] (15 minute interval data for several months duration) to record micro-hydroelectric system performance at micro-hydroelectric systems in two villages.

Between September 1998 and May 2004, I conducted 62 semi-structured interviews with government officials, villagers, village leaders, university researchers and professors, and utility and industry officials. Topics included various aspects of rural electrification policy and practice, including the broader rural development context and specific actions with respect to renewable energy and micro-hydroelectricity.

In the course of the fieldwork I visited a total of 15 villages. In villages in which the micro-hydroelectric project is no longer functioning I briefly interviewed the village headman (and if available) the former operator and/or other villagers. These interviews covered basic details of when and why the project stopped working. At each village with an operating micro-hydroelectric system(s), I conducted (with the help of a native Thai interpreter) semi-structured interviews with the village leader, the powerhouse operator and/or tariff collector, and village residents. These interviews covered a variety of topics including physical characteristics of the system, operating and management arrangements, problems with the system, and ways that the system benefits or troubles the community.

To study appliance ownership and electricity consumption patterns, I surveyed adults in 65 households in the villages of Mae Kam Pong and Huai Bu. The survey interviews were conducted in person with the help of an interpreter.

Further data concerning Thai micro-hydroelectric projects was obtained in collaboration with the “improvement of administration at village micro-hydro” project based at the Industrial Engineering Department, Faculty of Industrial Engineering, Chiang Mai University, which started in June 2002.

Of the 110 total interviews, about 80% were in Thai language. For interviews conducted in year 2001 and 2002 I used a translator. Thai interviews in 2003 and 2004 were conducted without a translator. Most interviews were recorded with in-depth field notes (facilitated by the time lag in translation). Four interviews were recorded on audiotape. For all taped interviews, interviewees were asked permission prior to taping. All interviews were transcribed in order to facilitate analysis using computer programs to search for key words and phrases.

Conditions of participation conformed to the policies of the Committee for the Protection of Human Subjects at the University of California, Berkeley (CPHS number:

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[3] Datalogging equipment consisted of an Onset Computer HOBO H8 (4-channel, external) datalogger, 3 split-core 50 Amp (CT-B) current sensors, and a custom-built

2001-8-133). In order to protect the identity of interviewees I identified each informant by a broad location descriptor (district, province and country) of interview and date.

In addition to formal interviews I employed a form of participant observation by becoming involved as a volunteer in a number of renewable energy activities in Thailand. On the one hand, this gave me the opportunity to “give back” to Thailand. On the other hand, volunteering helped me gain trust and access to the inner workings of Thai energy policy and implementation. I have been careful to not work directly on the micro-hydro projects I study (so as to not influence the object of research), but rather to choose related activities that provide insight into processes and relationships among the bureaucracies engaged in rural electrification and between village residents and outside actors engaged in rural electrification activities. The assistance I provided has been either technical in nature, or has involved helping Thais network with the international community of energy professionals. The resulting situations and experiences have afforded an emergent textured understanding of the politics between electrification bureaucracies, and policy processes that would have been impossible with just two or three months of intensive research. Information from these experiences is not directly used in the dissertation. Rather, it helped inform my choice of interviewees, questions asked, and provided opportunities for triangulation of findings.

In 2000 I volunteered with the System Development Division of the Provincial Electricity Authority (PEA) to provide technical assistance on a project to investigate the use of renewable energy to electrify remote islands. The experience provided insight into

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voltage transducer.

processes of technology choice within PEA, and the ways that projects are proposed and defended within the government budget allocation process.

In late 2001 and 2002 I volunteered with NEPO to draft policies allowing net metering and streamlined interconnection of renewable energy generators (under 1 megawatt). Later I represented NEPO as these policies were amended and adopted by a technical committee of utility and government officials and ultimately adopted into law under a Thai Cabinet resolution. This experience, and subsequent creation of an NGO, *Palang Thai,* to work to facilitate the policy's implementation, has provided significant opportunities to observe inter-bureaucratic rural electrification politics in Thailand, and their masking in technical language.

My research was also informed indirectly by a number of experiences with community-scale renewable energy projects with which I was involved during the course of my doctoral studies. These included working with villagers in Kre Khi village and E Wi Jo village in Tak province, Thailand, to build two community micro-hydroelectric systems; designing and working with North Korean engineers to build a 7-turbine wind-farm in a village in western North Korea; working with Cambodian diesel mini-grid operators to engineer improvements in their distribution systems and to convert them their diesel generators to biogasification; and visits to a variety of village-scale solar, wind, and micro-hydroelectric systems in China and Nepal. These experiences have: (1) helped provide insights into the degree to which challenges that emerge in the Thai context are common to village-scale renewable energy projects, or are, in fact, unique to Thailand; (2) provided insights into ways in which the lessons from Thailand are applicable to other contexts; and (3) suggested approaches to improve Thai village-scale renewables that have been successful in other countries.

Introduction to village scale micro-hydroelectricity

Micro-hydroelectricity uses energy in falling water to spin a turbine to produce electricity. While a variety of configurations are possible (such as low-head or instream turbines) the most economical applications are generally in areas with substantial height drop[4] (10m to 100 m is typical) using a run of the river[5] configuration. Run of the river systems comprise 100% of the Thai village scale systems studied in this research.

The key civil, mechanical, and electrical components of a run of the river micro-hydroelectric system of the type commonly found in rural Thailand are reviewed briefly below (see Figure 1).

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[4] The vertical component of the drop is referred to as "head"

[5] A "run of river" project has no storage reservoir. Water is directly drawn from the stream, or using an intake structure with a small intake pond. Run of river projects generally have far fewer environmental impacts than projects with reservoirs (Santos 1992).

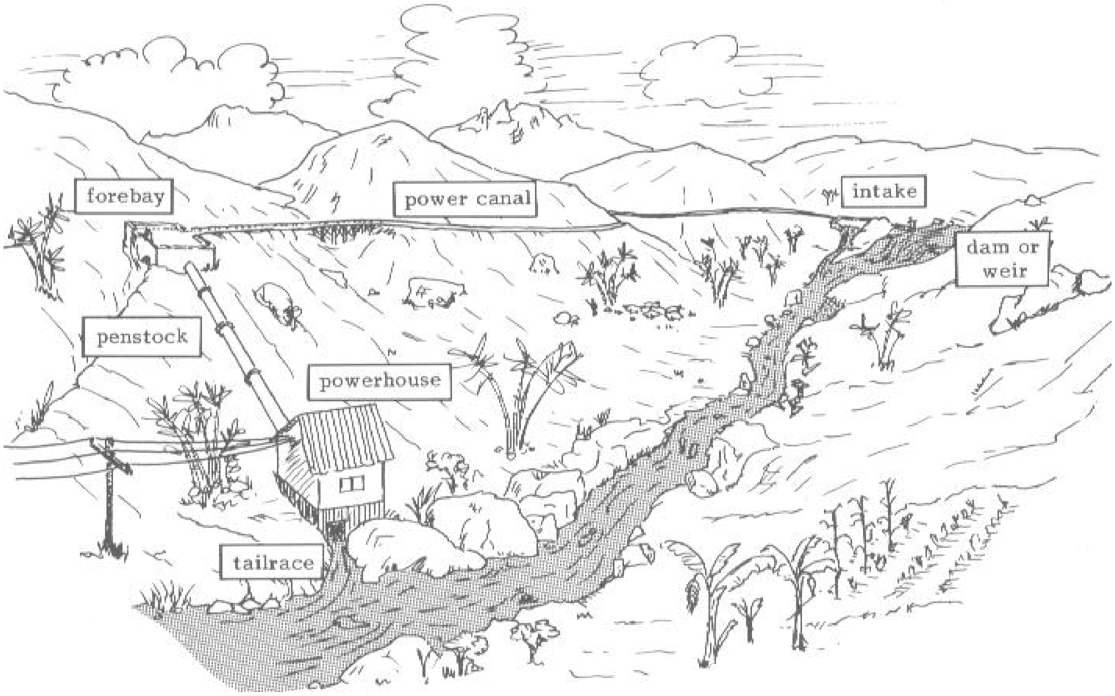

Figure 1: Basic components of a village micro-hydroelectric system. Source: Inversin 1986

Civil engineering components

Water is impounded in a small dam or *weir* made of concrete or rocks placed across the stream to increase the water level so that water can be diverted, by an *intake* structure, into the *headrace* or *power canal*. The headrace can either be an open canal or a low-pressure pipe made of cement or plastic. Upon exiting the power canal water enters the *forebay,* which allows sediment in the water to settle and precipitate before the water enters the *penstock*. A *spillway* is generally provided to safely remove excess water. The *penstock* is a high pressure pipe (generally made of steel) that conveys water from the forebay to the *turbine* located inside a powerhouse. A *tailrace* returns the spent water from the turbine back to the river.

Electrical and mechanical components

Inside the powerhouse, water exits the penstock through a specially designed *nozzle*, and strikes the *turbine*, changing the energy from the falling water into rotational energy to spin the *generator*. For village micro hydroelectric projects in Thailand (as in most of the world) two types of turbines are generally used: crossflow or Pelton. Crossflow turbines look like cylindrical squirrel cages that spin on a horizontal axis. Two side disks are connected by a dozen or more curved blades. In a crossflow turbine, the water flow passes through the blade row twice, first in the upper portion of the wheel and again at the lower portion. Crossflow turbines are the easiest to build, and are more suitable for lower head sites. With a Pelton turbine one or more jets of water impinges on a wheel containing many curved buckets, producing a force on the buckets and resulting in a torque on the shaft. Pelton turbines are more expensive, but also more efficient than crossflow turbines. Pelton turbines are generally used in high head applications.

The generator transforms mechanical rotational energy into electrical energy. All generators have two essential parts: a (1) rotor (the parts that spins) which creates a rotating magnetic field and (2) a stator or armature consisting of sets of wires arranged across the path of the magnetic flux of the rotor. Relative motion between the rotor and the stator induces an electromotive force in the conductors of the stator.

Synchronous generators are used in all stand-alone village-scale micro hydroelectric systems in Thailand. In a synchronous generator the magnetic flux is achieved by applying a direct current across the rotor field coils. This excitation current is provided by a small DC generator mounted on the same shaft as the main ac generator.

When the turbine spins the rotor shaft the rotating magnetic flux induces an alternating voltage in the stator coils.

The generator must be controlled to avoid overspeed. The *controller* or *governor* controls the speed of the generator -- and thus the frequency of the electricity generated -- in one of two ways. An electronic diversion load control allows the generator to generate at full capacity all the time. Excess power not demanded by the village load is diverted to a water heating element. This type of control reacts quickly to changes in village load, and is both simple and relatively robust. The disadvantage is that full water flow is required constantly. An alternative method uses a mechanical governor. When the turbine starts to spin too fast, a mechanical or electro-mechanical control reacts by closing a valve in the penstock restricting water flow. A turbine with this type of governor uses less water, but relies on many (failure prone) moving parts and reacts slowly to rapid changes in load, causing instability in the power supply.

The *automatic voltage regulator (AVR)* is an electronic circuit used with synchronous generators to regulate voltage. The AVR regulates the generator output voltage by increasing or decreasing the DC current provided to the field coils in the rotor. AVRs in Thai installations have been particularly prone to failure.

The *distribution system* brings electricity from the generator to the end-users. The system consists of poles, wires, and meters for measuring electricity consumption. If end-users are particularly far from the generator, transformers are used to increase the voltage, generally up to 3.3 kV, for transmission, and step it back down to 240 volts for customer use.

Village micro-hydroelectric system costs

Micro-hydroelectricity is among the least expensive stand-alone rural electrification options, with typical costs of $1000 to $2000 per kW for community-built projects in developing countries such as Sri Lanka, Peru, or Nepal (Harvey, Brown et al. 1998). In Sri Lanka a typical 10-12 kW installation serves about 100 households and costs about $15,000 including the associated network (Martinot 2001). In exceptional cases, costs as low as $250 to $400 per kW have been reported (1978 dollars, Pakistan) (Inversin 1986). Reported costs for produced electricity vary from as low as US$0.025 per kWh (1978 dollars) (Inversin 1986) to $0.12 per kWh (Jiandong 2003).

As such, micro-hydroelectricity is generally less expensive than diesel generation. Diesel generators have lower capital costs (around $500 per kW for 30 kW generator), but substantially higher operating costs because of the need for diesel fuel. Diesel generators typically produce electricity for $0.20 to $1.50 per kWh (where the high end represents costly transport for diesel fuel to remote sites) (Shanker 1992). Micro-hydroelectricity is often less expensive than grid extension solutions as well (see Appendices 1 and 2). Simple designs and fabrication techniques allow for local manufacture and local reparability.

Micro-hydro for integrated rural development

Village-scale micro-hydroelectricity has useful characteristics that can be exploited in integrated rural development efforts. With careful planning, micro-hydroelectric projects can be integrated with irrigation and water supply projects to provide multiple benefits. In addition to generating electricity, micro-hydropower plants can provide mechanical energy during off-peak times used to directly power agroprocessing machinery or cottage industries. This permits the use of simple, inexpensive, and easily understood mechanical devices.

Because wires in a village mini-grid are all interconnected, village micro-hydro systems inherently allow electricity not consumed by one household to be used by others. In addition, because the marginal cost of additional connections is low, village power systems lend themselves to electrifying an entire clustered community – rich and poor alike.

Some organizations find that the process of working with villages to develop village power projects provides important opportunities to build capacity and skills that are useful for a variety of other rural development activities (Inversin 1986; Lewis 1997; URJA 1998). These groups report significant benefits from a village power project development process that views electrification less as an end in itself, but rather a byproduct of a process in which rural villagers develop the expertise and confidence to take on significant self-initiated development projects. Income generation, education, health care, forestry, and other elements are woven into an integrated package that seeks to derive as much social benefit as possible from village power projects (URJA 1998).

Worldwide village micro-hydroelectricity installations

Micro-hydroelectricity is a well-proven technology for village rural electrification, with installations in Europe, America, and Asia dating back to the last part of the 19th century (Santos 1992). Nepal currently has an estimated 576 village micro-hydroelectric and stand-alone mini-hydroelectric installations serving an estimated 76,500 people (Pandey 2000). By the end of 2001 in China, 18,944 micro-hydroelectric installations have been built, each less than 100 kW but with a total installed capacity of

687 MW. Considering that each village system provides power for hundreds of households, these systems in China alone are currently providing power for several million households (Jiandong 2003).

Micro-hydroelectric systems have also been installed in Bhutan (Arvidson 2000), Borneo, Burma, Cambodia, Cameroon, Guatemala, India (Interview 2000.03), Laos, Mexico, Nicaragua (Lewis 1997), North Korea (Von Hippel 1999), Pakistan, Papua New Guinea, and Peru (Inversin 1986), Philippines, the Solomon Islands, Sri Lanka, Zaire (Thornbloom 1997), and Zimbabwe. Many European countries, Canada, and the USA have village micro-hydropower installations as well (Klunne 2000).

Micro-hydroelectricity in Thailand

Despite lower costs, only 59 community micro-hydroelectric systems were built in Thailand between 1983 and 2001. In comparison, 2002 government figures indicate 69,942 villages served by grid electrification (PEA 2002). Moreover, of the 59 community micro-hydroelectric systems installed, only 25 are still in operation. But many that are operational provide a valuable source of inexpensive, community-managed electricity.

The dearth of functioning installations (or installations at all, for that matter) cannot be explained by lack of suitable terrain or water. With a few regional exceptions, Thailand enjoys abundant rainfall, and there are significant portions of the country in the north, west and south with mountainous terrain suitable for micro-hydro. One DEDE study identified 1136 *mini*-hydro (>200 kW) sites (DEDP 1998). Because of the tributary nature of watersheds, sites for *micro*-hydroelectric projects would be at least several times as plentiful.

What explains why so few projects were built, and why so few are still operating given their apparent cost and community development advantages?

Before discussing these projects in detail (Chapter 3), let us consider theoretical perspectives useful in framing an understanding of these systems in their contexts.

Chapter 2: Theoretical perspectives

With the apparent economic, environmental, and community capacity building advantages of micro-hydropower for village electrification, and the long experience Thailand has had with these projects one might wonder why this technology is not more widespread, why more of the existing installations are not functioning, and why the functioning systems encounter the problems they do.

The existing literature on micro-hydroelectricity offers little by way of explanation. Indeed, relatively little has been written about the adoption of micro-hydroelectricity in the developing country context. The existing literature consists of several texts (Inversin 1986; Smith 1994; Harvey, Brown et al. 1998) that focus on engineering and practical operational issues: hydrology, civil, mechanical, and electrical. The texts are written primarily to prepare the practitioner to make well-informed design, construction, and operation decisions. By way of interpretation of why these systems are rare and/or fail these texts offer little save that some are over-engineered, and others are poorly-engineered or poorly operated.

Yet there is much more at play than simply engineering design. This chapter draws on several literatures that help to create a more sophisticated theoretical framework for exploring the marginalized status of this technology, taking into account multiple factors operating at a variety of scales: from the household and village level (e.g. consumption patterns and community-level management issues), to the level of Thailand as a nation-state (e.g. the historical legacy of nation-level electrification planning and implementation), to the geopolitical level (especially relating to international aid). Possible relevant factors include engineering, economics, politics, and resource management. The chapter works to develop a set of testable research hypotheses that can clarify the causal linkages and interdependencies among outside actors, the recipient community, the micro-hydroelectric equipment, and the local environment in producing the observed outcomes.

Taking a broad view of these micro-hydro systems in their context, it is possible to make a few general observations concerning relationships between technology, environment, and various actors. One observation is that village hydro-electric systems are fixed in capacity, yet provide electricity to a community of users whose population and electrical demands change over time. Another observation is that the complexities and high capital costs of these projects relative to the wages of the community of users generally requires contributions (direct or indirect) from actors outside the village in which the system is installed. The roles of these groups, the reasons for their contributions, and the relationships among various actors are complicated – and self-evidently important. Consideration of these relationships is clearly essential for understanding why projects are built, and under what conditions they exist.

To help interpret events at the local level I draw on common pool resource literature and standard engineering principles to help explain the relationship between the evolution of collective consumption patterns and many of the failure modes and performance shortcomings observed in the field. In a broader perspective that considers Thailand as a whole over the course of several decades time, literature on technological diffusion, social barriers, and the organizational politics of technology adoption suggests ways of seeing localized technology “challenges” in a much richer and broader context that shapes and limits the reach of micro-hydroelectric technology in rural electrification.

Common property perspective

At the village level, one explanation of some of the challenges that Thai micro-hydroelectric projects face is that these systems are strongly affected by the collective action of users. One important aspect of community-scale village power projects is that they have characteristics of common-pool resources (CPR). A CPR is a human-constructed facility or natural resource characterized by two features – (i) exploitation by one user reduces resource availability for others, and (ii) exclusion of beneficiaries through physical and institutional means is especially costly (Gardner 1990; Ostrom 1990).[6] On the one hand, the electricity produced is limited in quantity by the capacity of the power plant and/or by the availability of falling water. On the other hand, once users are connected to the electricity lines, it is difficult to restrict access to consumption of the resource. Anyone with an electricity outlet can plug in appliances. Over-consumption by some individuals pursuing their own short-term interest can degrade the resource for all. In addition to the common property issues in distributing yields from village power systems, an equally important set of issues arises with respect to allocation of maintenance and repair responsibilities and/or collecting funds for these activities.

Common property theories, evolved over the past decade to understand and strengthen village management of traditional village commons such as irrigation canals, forests, fisheries, and grazing areas provide an insightful lens with which to understand collective-action challenges and solutions for village power systems. While village stand-

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[6] The definition of a CPR depends on the physical properties of the resources, and holds regardless of the system of property rights involved (Ostrom 1999).

alone electrification systems have never been studied using common property theories[7], village micro-hydropower systems share important similarities with village irrigation canals, which have received considerable attention from CPR theorists (See, for example: (Lansing 1991; Lam 1994; Joshi 1998)). Both village power systems and village irrigation canals are human-made, inherently community-scaled infrastructure. Both require collective coordination to provide a flow of a resource from which users benefit. In both cases, users experience short-term incentives to appropriate too much of the resource, but the yield of the system as a whole is limited and varies with seasonal and daily resource fluctuations. Both systems require a certain amount of maintenance to ensure yields, and these maintenance efforts require both capital and labor contributions.

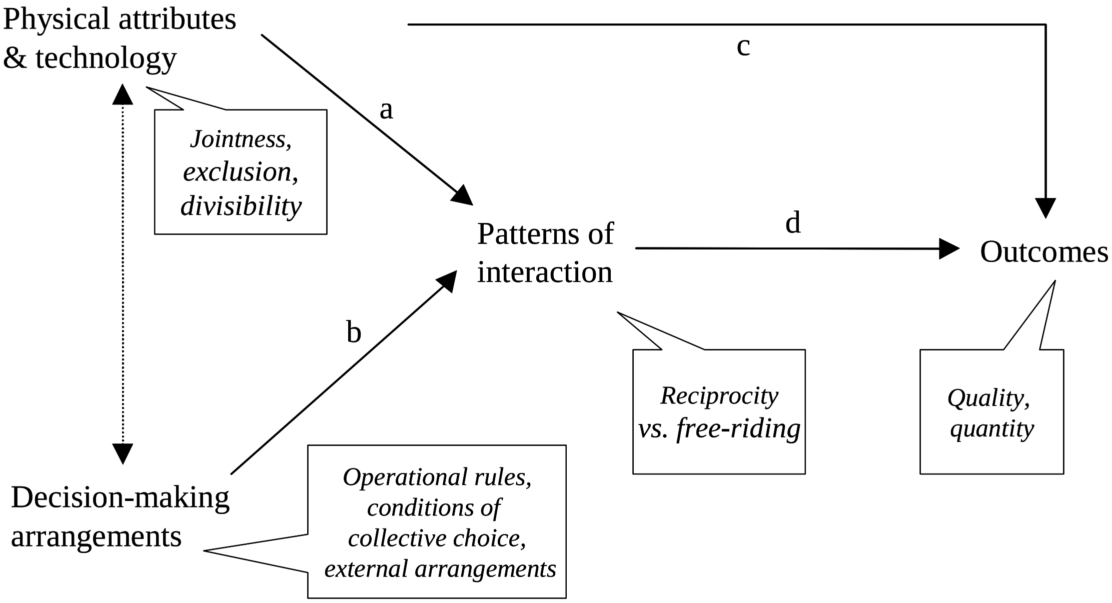

Figure 2: The Oakerson framework for analyzing common pool resources

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[7] A search of over 22,000 entries in the *Comprehensive Bibliography of Common Pool Resources* revealed no relevant articles with keywords “electrification”, “micro-hydro”, “hydroelectricity”, “village power” (Hess 1999).

A framework developed by Oakerson (Oakerson 1992) suggests a useful guide for exploring the CPR characteristics of village micro-hydropower projects. The frame assumes that a commons has four sets of attributes that can be related in specifiable, limited ways: “(1) the physical attributes of the specific resource or facility and the technology used to appropriate its yield; (2) the decision-making arrangements (organization and rules) that govern relationships among users; (3) the mutual choice of strategies and consequent patterns of interaction among decision-makers; and (4) the outcomes or consequences”.

In this model, physical characteristics refer to three attributes of analytical significance. First is the relative capacity of the resource base (in this case the village power system) to support multiple users at the same time without diminishing the total level of benefit available to the group. This is referred to by the microeconomic term *jointness*. Jointness refers to the degree to which use of the resource by one person does not subtract from the use of others. The concept of jointness was originally introduced to define a “pure public good” (Samuelson 1954). An example of a pure public good might be a television or radio broadcast: no matter how many listeners tune in, the broadcast signal is not diminished. In contrast are “private goods” in which an individual fully consumes a good rendering it unavailable for others; for example, a fish caught by one fisherman is not available for other fishermen. “Impure” public goods are those in which jointness is limited by congestion. Beyond a certain threshold, additional consumption by users subtract the quality of the resource for all.

Village micro-hydroelectric systems, like many common property systems, have characteristics of impure public goods. Electricity production is dependent on the amount of water flowing in a stream. If collective consumption is consistently below this level, then the system behaves like a public good – the marginal costs of consumption are zero (electricity not consumed in a stand-alone micro-hydro system is electricity wasted). But if consumption is above the threshold then power quality is degraded for all users. The limited and variable nature of electricity production, combined with the ability of individual users to plug in large or inefficient loads leads to jointness problems.

Second is the degree to which the system permits the *exclusion* of individual users. The concept of "exclusion" was originally developed by economists to clarify differences between private goods and public goods (Musgrave 1959). Broadly defined, the concept refers to the ability to exclude access to any type of good, including the commons. Complete openness, in which all users have unlimited access, is the opposite of exclusion.

In discussing the common property aspects of village micro-hydroelectric systems it is useful to recognize two forms of exclusion: one concerning the entrance of new users, and the other concerning the level of consumption of existing users. In a micro-hydroelectric system, wires carry electricity to individual households connected to a village mini-grid. Those households that are not connected are excluded from consumption. In this sense, access is fairly easily excluded – as long as illegitimate connections can be identified and removed. Among those already connected, however, exclusion must be accomplished by limiting appliance ownership or use – a more sensitive prospect.

The third attribute of the commons is its *divisibility*: the degree to which the commons can be divided. Spatial divisibility is key in processes of converting the commons to private property. If a resource can be partitioned and boundaries established, then individual ownership can be ascribed and the resources in question ceases to be “common”. CPRs have physical characteristics that inherently make physical partitioning difficult or impossible. Because the electricity generation and processing in a village micro-hydroelectric system occurs in a single “powerhouse” it impossible to physically divide the system.

Decision-making arrangements refers to the rules that structure individual and collective choices with respect to the village power system. Of interest here are the relationships that specify *who* has the authority to determine *what* in relation to *whom*. These are nested in three levels. First are *operational rules* that regulate the use of the commons on a day-to-day basis. In the context of a village hydro-power system, for example, rules may exist to curtail or prohibit the use of particularly consumptive appliances such as arc welders or voltage boosting transformers. Operational rules refer as well to the rules that ensure that maintenance is performed and that sufficient funds exist to cover broken parts and other contingencies. Second are rules that establish *conditions of collective choice* -- how the group decides how to make and modify the operational rules. Third are *external arrangements* -- decision-structures outside the community of users that impinge on how the commons is organized and used. Decision making arrangements outside the community play a strong role in shaping the collective choice and operational rules described above. This is particularly true for village power systems that, by necessity, involve a substantial transfer of technology from the outside.[8]

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[8] This level of analysis considers questions such as, what role does the government (at local, provincial, or international levels) play in shaping the design, financing, and operation of the village power project? What national and international

Given the physical and technical characteristics of the commons on the one hand, and the decision-making arrangements available to govern its use on the other, individuals make choices. *Patterns of interaction* arise from these choices. Individuals can decide to cooperate and mutually contribute to one another's welfare through action or through refraining from over-consumption. Or they can free-ride, and look only at their own individual self-interest. If enough free-riding takes place, reciprocity is eroded and the "tragedy of the commons" -- mutually destructive competition or conflict -- occurs. Patterns of behavior also refers to second-order behaviors, such as the ability and interest of individuals to monitor each other's behavior, or apply sanctions.

Finally, patterns of behavior combine with physical characteristics of the resource to create *outcomes*. One way to evaluate outcomes involves assessing the quality and quantity of electricity produced. For village micro-hydroelectric systems, power quality, and overuse patterns are easily recognizable by the use of dataloggers to monitor system voltage and current over the course of days or months.

Under-use can also lead to inefficiencies, particularly since energy cannot economically be stored in village micro-hydroelectric systems, and therefore power generated in excess of loads is wasted. Equity of distribution of yields is also important. Equity can be assessed in village power systems through household consumption and

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forces have shaped rural electrification? How do arrangements for other forms of energy services, for spare parts, and more generally for the goods and services the community consumes and sells establish economic parameters within which management of village power systems operates? In essence, the "external arrangements" described here overlap with the "political economy" perspective addressed later in this chapter. Given the strong role that outside actors play in shaping and limiting the conditions under which village micro-hydroelectric projects exist these issues deserve more weight than their marginal position as a sub-component of the Oakerson framework would imply.

appliance ownership surveys, and through interviews assessing user’s own assessment of the fairness of distribution.

Figure 2 shows the ways in which these attributes interact with each other in the Oakerson framework. Physical attributes and decision-making arrangements influence patterns of interaction. Patterns of interaction, in turn, interact with physical attributes and technology to create outcomes.

With respect to common property my research questions are as follows:

(1) To what extent and in what ways do CPR characteristics of village power projects contribute to project underperformance or conflict? How and why do these problems emerge?

(2) What mechanisms have evolved to cope with CPR challenges in village power? What have been the consequences?

The common property perspective suggests looking for explanations of village micro-hydropower failures in a mismatch between the technical/physical characteristics of village power systems and the decision-making arrangements that govern their use. Similarly, CPR theories suggest a key determinant of successful village power projects is the evolution of rules that are well-matched to the system's technical/physical characteristics. Chapter 3 uses program-wide data (from all 59 projects installed in Thailand) and in-depth case studies of two projects to explore the physical characteristics, rules, patterns of behavior, and outcomes as they evolve at the village level.

Micro-economics

This dissertation draws on common foundations and techniques of micro-economics. One foundation is the normative ideal that the appropriate role of public policy is to maximize public benefits at minimum public expense. The principle has origins in social welfare economics pioneered by Pigou (1920), Marshall (1920), and others, and is a foundation of contemporary public policy analysis (see, for example Friedman 1998). As one basis for evaluating rural electrification technology options this research employs benefit and cost comparisons based on discounted cash flow analysis (Nicholson 1995).

Social barriers perspective and diffusion theory

The common property framework discussed above, combined with micro-economics and engineering common sense can explain a number of outcomes observed in micro-hydro projects in the field. But some scholars have argued that these perspectives still do not go far enough in explaining why the diffusion of a cost-effective and socially and environmentally beneficial technology such as micro-hydroelectricity is so limited relative to its technical and economic potential. Questions of this nature are in the subject of diffusion research, and of a practitioner-oriented literature that identifies “social barriers” to new technology adoption.

Social barriers literature has theoretical roots in an extensive literature on aggregate processes of diffusion of innovations. Diffusion theory observes that adoption of technologies typically follows a sigmoid curve (Bass 1969). The shape of the curve reflects the phenomenon that initially few members of a social system adopt an innovation, but over time the rate of adoption increases, saturates, and ultimately declines. Diffusion research suggests a wide variety of factors to explain differing rates of diffusion. These include risk aversion and communication, attributes of the technology itself (relative competitiveness vis-à-vis other options), and access to the resources necessary to adopt technologies.

One branch of diffusion research invokes psychological explanations that emphasize risk-averse behavior among adopters, and lack of information about advantages and disadvantages of innovations. The seminal work in this area was that of Ryan and Gross (1943) who researched adoption of hybrid corn seeds in Iowa. They explained increasing rates of adoption by concluding that the behavior of early adopters stimulated remaining farmers to adopt as well (Ryan and Gross 1943, page 22). Mathematical models built on this concept proposed that “the probability that an initial purchase will be made [is] a linear function of the number of previous buyers” (Bass 1969, page 216). Other research in the field recognized the importance of spatial and terrestrial barriers that impede or channel information flow (Hagerstand, 1967). These factors appear relevant for micro-hydro given the remote and scattered location of village installation sites.

Other diffusion researchers assume that for the most part adopters make decisions on an economically rational basis, and diffusion depends most significantly on attributes of the technology itself. These researchers observe that new technologies are typically expensive, crude and/or poorly matched to local conditions and therefore offer few advantages over conventional technologies. However, through further refinement to the technology itself, competitiveness improves and diffusion is increased (Rosenberg 1972). Certain technologies have increasing returns to adoption that allow them to lock out other technologies (Bass 1980). These theories relate to micro-hydro power quality and to its relationship with grid extension technology.

Unequal access to resources necessary for technology adoption plays a role in the diffusion research of some development scholars. Access to money features most prominently. In conditions in which resources are scarce, the divisibility of an innovation is critical to adoption and large "lumpy" investments are at a disadvantage (Polak et al 1996). This has bearing on micro-hydro projects which are by nature village-scale, and which require villages to gather collective resources to help build the system.

Some diffusions theorists focus on the observation that the adoption of a technology innovation may be constrained by its availability. This "market infrastructure" perspective (Brown 1981) focuses on aspects of technology supply and notes that bottlenecks can create a stream of "waiting adopters" (Jain et al 1991, page 83). Subsequently, these researchers focus on the behavior of the "diffusion agency" that makes available an innovation to society. Where and how these agencies act, diffusion researchers contend, broadly defines where and when an innovation is made available (Roy 1994, page 33). In a similar vein, other researchers note that certain innovations are *infrastructure constrained* because they require either an existing infrastructure network (cable television), or because they require regular service and access to maintenance and repair. When an innovation is infrastructure constrained, "diffusion will occur in general only where there is the required infrastructure and not elsewhere" (Brown 1981, page 104). These theories suggest investigating the role and performance of state agencies involved in micro-hydro dissemination.

In the context of diffusion research, “barriers” are factors that impede the adoption of an innovation. An extensive, mostly atheoretical literature identifies a variety of barriers to renewable energy dissemination in developing and transitional economy country contexts[9] (Karekezi 1994; Miller 1998; Duke, Jacobson et al. 2002), including in Thailand[10] (Wade 1997; Energy Research Institute 1999).

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[9] Karekezi (1994) finds renewable energy diffusion in Sub-Saharan Africa is obstructed by: limited access to information (particularly for resource assessment), inadequate appreciation of the importance of participation of local manufacturers/assemblers and end-users, and excessive emphasis on welfare dimensions of renewable energy programs at expense of productivity-oriented (battery charging, rural industries functions and entrepreneurial-based approaches). Drawing on case studies of solar electric companies in India and Indonesia, Miller (1998) finds that barriers include lack of entrepreneurial support including both business training and provisions for working capital. Duke, Jacobson and Kammen (2002) find that inadequate product quality information is a significant barrier to solar PV system expansion in Kenya (Duke, Jacobson et al. 2002). Martinot (1995) identifies barriers for renewable energy in Russia including: lack of developed capital markets and long-term capital, uncertainty and lack of information, missing institutional mechanisms; missing or mismatched incentives; weak legal and market institutions; cultural factors; and a lack of experience and training in economic management, finance, law, and marketing. Kammen (1999) cites more systematic problems with the process of research and development, commercialization and dissemination, and follow-up that accompany (or fail to accompany) renewable energy investments in rural areas in developing countries. These include lack of sufficient scholarly attention (particularly on all aspects of these technology systems that lie outside of the narrowly defined and early stage processes of research and development), lack of scholar/practitioner collaboration, and challenges communicating findings across cultural and language barriers.

[10] In Thailand, several workshops, seminars, and papers have discussed barriers to renewable energy dissemination. Wade (1997) found that barriers to PV implementation in Thailand include: inadequate technical design, lack of adequate long term technical support, lack of confidence, the tendency for project developers to prepare only for the short term, and lack of attention to users needs. The Thai Energy Research Institute identified the following barriers to the dissemination of renewable energy in Thailand: high costs, lack of market infrastructure, inability of market actors to capture benefits, lack of user awareness, and commercial immaturity of some technologies (Energy Research Institute 1999). A brainstorming session by the Department of Energy Development and Promotion (DEDP) in 2000 identified: poor co-ordination among government agencies and especially with the private sector; difficult access to finance; no clear government policies; lack of awareness/confidence on available renewable energy technologies and applications; few examples of success; lack of standards; inadequate

Diagnoses vary, but typically conclude that decision-makers lack sufficient information of the right type to make the right kind of rational economic choices (Shove 1998), that institutional capacities to evaluate, finance, and conduct investment are limited, that the technologies and dissemination methods present high initial costs, transaction costs and/or risks (Martinot and McDoom 2000), or that there are insufficient incentives and a policy environment that fails to adequately and fairly address renewable energy (G8 Renewable Energy Task Force 2001). In response, what is needed is better guidance and advice, typically in the form of a set of "best practices" principles offered to address the identified barriers (Cabraal 1996; IIEC-Asia 1998; SGA Energy Limited 1999; Martinot and McDoom 2000).

The barriers literature forms the basis for many of the policy interventions undertaken to support renewables, including large programs by multilateral funding agencies such as the GEF (Martinot and McDoom 2000), the World Bank REF, and the G-8 (G8 Renewable Energy Task Force 2001), as well as a number of NGO programs (IIEC-Asia 1998). Policies and programs within Thailand as well include a substantial "barriers identification" component.

The existing literature on diffusion of innovations and on barriers to clean energy technology adoption yields useful insights. Diffusion research alerts readers to key relationships between technology adoption and a variety of factors internal and external to the social group doing the adopting. Social barriers literature is useful in the sense that

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experts and inefficient means of data collection and information transfer; inadequate renewable energy plans; poor accessibility to existing renewable energy databases; lack of policy information; private sector is not included in planning phase; no forum for public-private discussions; Government focus in economics, not on technical issues (Sajjakulnukit 2000).

there *are* barriers to renewable energy use, and identifying them is a useful initial activity. However, both diffusion and barriers literature are primarily descriptive, and neither provide theoretical tools for understanding how certain barriers arise. In other words, while much of both diffusion research and social barriers literature are adept at identifying problems, they generally provide little explanation of the structural or historical origins of these problems.

Critics of barriers literature complain that the literature is based on an overly simplified and often misleading model of the way that technology adoption works in practice (Shove 1998):

> "the terminology of social barriers presumes pure, asocial technological potential on the one hand, and a confounding set of social obstacles on the other. If we see technology change as an irredeemably social process, the notion of non-technical barriers is instantly as irrelevant as that of pure technical potential."

Shove instead urges a reframing of the issue by noting that all technologies imply a certain set of social relations, which she terms a "sociotechnical regime". Shaped by history and a wide variety of contemporary factors, the sociotechnical regime sets the scene for future development, sometimes allowing and sometimes constraining particular courses of action.

Political economy of technology adoption perspective

The shortcomings of the barriers perspective suggest to some scholars the need for a more nuanced political economy framework (Wolf 1982; Ferguson 1994) sensitive to the web of historical developments and structural factors, including linkages to events and forces far beyond national borders that shape and limit particular socio-technical possibilities. This perspective recognizes the need for an historical analysis of relevant policies, programs, and institutions, and the ways changes in these have shaped current arrangements, both social and technical, for rural electrification infrastructure. The perspective must be sensitive, as well, to a variety of scales of social organization, from the social relations within the village, to wider geographical and social settings in which they are situated, including state bureaucracies, international financial institutions, and global geopolitics.

In this framing of a "political economy of technology choice", considerable emphasis is placed on understanding the trajectories of competing technologies and the dynamics of the organizations that champion them. In this regard, Thomas (1994) provides insight by conceiving of the adoption of technology within large organizations "as *mediated by the exercise of power*, that is, by a system of authority and domination that asserts the primacy of one understanding of the physical world, one prescription for social organization, over others." The organizational faction and associated technology option that becomes dominant is not necessarily "the best" or most logical in an engineering or economic sense. Rather, the choice of particular technologies and the social arrangements that structure them consist of the discovery and application (or attempted application) of rules and conditions that are consistent with particular organizational objectives (Thomas 1994).

Understanding the "organizational objectives" that shape and limit technology choice in the case of Thai rural electrification requires sensitivity to the functioning of the state, state bureaucracies and rural communities. Essential to this analysis is attention to the historical evolution of: the geopolitics of aid (Bryant 1997; Phongpaichit 1998; Dove 2000) Thai rural/urban political and economic transformations (Piriyarangsan 1994;

Phongpaichit 1998), and bureaucratic expansion and competition (Riggs 1966; Ferguson 1994; Scott 1998).

Identifying the interests of various actors and the mechanisms by which they attempt to accomplish those interests is, in itself, insufficient. That is to say, a political economic analysis of technology choice must be sensitive to the pitfall of assuming that it is sufficient to explain technology adoption as simply the product of strategic choice. Whatever interests are at work, and whatever their intentions, attempts to "get things done" in the real world are mediated by complex social and cultural structures that yield unpredictable transformations of original intentions (Ferguson 1994). With this in mind, it is important to ask how technology choices were framed, how the objectives of different actors shape the range of possibilities considered, and most important, how differences in objectives influence the outcomes of change.

In understanding the trajectory of technology adoption, considerable influence must also be attributed to the role of what has been termed "technological intertia" (Thomas 1994) or "technological somnambulance" (Winner 1986). This is to say, while there are clear cases of state agencies and other actors choosing technologies that align well with objectives, the decisions are not always conscious. Thomas observes:

> "the longer a particular coupling of technology and structure is in place and the more deeply held interests and assumptions are about the appropriateness of that coupling, the more likely it is that a given structure and its associated interests and assumptions will become *institutionalized* -- that is, possessed of a measure of legitimacy based as much (if not more) on its longevity as on its consistency for 'fit' with environmental conditions or, for that matter, its economic value." (Thomas 1994)

Once a particular technology solution is adopted, institutional arrangements grow to support, service, and reproduce that particular technological approach. Subsequently the technology is likely to be implemented even in situations where others are more economically rational or make more engineering sense. In the case of rural electrification technologies, technological inertia is the product of the historical coupling of technology and structure discussed above, combined with popular non-participation (leaving the decisions up to the “experts”).

This political economy approach forms the basis of a historical account (chapter 5) of the past 100 years of Thai rural electrification – and the ways in which micro-hydroelectricity interacts with broader rural electrification and rural development patterns. The key questions are: *How and why were key decisions on rural electrification technology choice made? How have organizational structures and social and political-economic forces shaped and constrained opportunities for community managed electricity and village-scale micro-hydroelectricity?*

To answer these questions the account reconstructs the driving factors behind rural electrification with particular attention focused on the administrative arrangements and the choices of technologies used. The account focuses on several important actors or features: Thai leaders, Thai electricity bureaucracies, foreign (especially US) advisors, and trends and concerns of rural populations. The account draws on original archival sources and interviews as well as secondary sources that provide an understanding of the broader historical context.

Towards an integrated understanding of Thai micro-hydroelectricity: hypothetical answers

All of the frameworks presented in this chapter are potentially useful in understanding why micro-hydroelectricity occupies a tenuous position on the margins of rural electrification in Thailand. However, the most complete understanding can only emerge from considering these projects and their challenges from many angles, and using an interdisciplinary perspective that borrows appropriately from the different frameworks to provide research hypotheses that are theoretically robust and can be tested empirically against results in the field. For example, it is necessary to consider how the stage for common pool resource problems or engineering limitations is shaped by forces within and between bureaucracies. Or how responses to engineering and common property challenges are restricted by factors that link back to historical decisions about rural electrification made decades ago.

Taking into account the possibility of multiple causation, I suggest that there are a number of testable hypotheses that can be considered in answering the question, *why is micro-hydroelectricity losing to the grid as the technology of choice for rural electrification in Thailand*. These hypotheses follow from the theoretical perspectives discussed above, and from engineering and economics.

Hypothesis 1: For the Thai public, there are few cases in which micro-hydroelectricity is an optimal investment. The hypothesis derives from the public policy ideal that the state makes decisions in order to optimize collective welfare for citizens. Testing the hypothesis involves benefit cost analysis. Analysis of benefits includes assessments of value of stable power supply, as well as benefit streams from grid-interconnection. Costs include equipment, labor, and fuel. The hypothesis is consistent with beliefs about the relative costs of renewable and conventional energy widely held by energy sector experts in Thailand (see, for example: Energy Research Institute, Center for

Energy Environment Research and Development, et al. 1999; PEA Project Division System Planning Department 1996).

Hypothesis 2: For villagers, there are few cases in which micro-hydroelectricity is an optimal investment. This hypothesis derives the basic micro-economic principles that individuals and groups make economic decisions in self-interest. The hypothesis can be tested using benefit cost analysis as in Hypothesis 1.

Hypothesis 3: Physical circumstances do not favor micro-hydro in Thailand. This hypothesis derives from basic electrical, mechanical, and hydrological engineering principles. Testing the hypothesis requires sensitivity to the fact that hydrological resources are not static, and that activities such as logging and land use change can alter the timing and quantity of flows.

Hypothesis 4: There is a mismatch between village electricity consumption patterns and the production capabilities of village micro-hydro – and this is linked to a mismatch between rules governing user behavior and the technical characteristics of the system. The first part of this hypothesis derives from electrical engineering principles and from the physical law of conservation of energy. The second part draws on Oakerson’s CPR framework discussed earlier in this chapter. In particular, this hypothesis suggests that tariff design does not match the fact that micro-hydropower has limited peak power output. The first part of the hypothesis can be tested using electrical instrumentation, while the second part requires survey research and investigation of tariff structure.

Hypothesis 5: Village management is deficient. This hypothesis derives from barriers literature (in which problems are often attributed to lack of capacity on the part of technology recipients to maintain renewable energy installations) and from ideas in

CPR regarding erosion of reciprocity (Ostrom 1990; Oakerson 1992). The hypothesis is consistent with widely held beliefs among Thai policy makers, and is the defining assumption behind a technology program entitled, “improvement of administration at village micro-hydro” executed by the Chiang Mai University Industrial Engineering Department and supported by the ENCON fund.

Hypothesis 6: The state program charged with supporting community micro-hydro has failed to address key areas for sustainable operation (misallocation at program level). This hypothesis derives from diffusion and barriers literature that relates to capacity building of implementing agencies (Roy 1994; Sajjakulnukit 2000; DEDP 2000; Martinot & McDoom 2000; Cabraal 1996), and to theories about state-village exchange that proposes explanations for mismatch between state responses and local needs (Scott 1998; Ferguson 1994; Dove 2000; Riggs 1966).

Hypothesis 7: The hegemony of the parastatal rural electrification utility and its focus on grid electrification have reduced opportunities for cost-effective deployment and operation of micro-hydroelectricity. This hypothesis argues that cost-effective deployment of village-scale micro-hydroelectricity is thwarted by a politically-determined lack of resources and by a playing field shaped to benefit (and to a certain degree shaped by) the dominant rural electrification utility that works in a variety of ways against community-managed micro-hydroelectricity. The hypothesis operates mostly at national level and international levels, in which rural electrification goals are set and decisions are made to allocate resources in particular ways, but also has local manifestations. This hypothesis draws on theories discussed in the political economy of technology adoption perspective above. The hypothesis draws on concepts of technological inertia (Winner 1986; Tatum 1995), political determinants of technology choice (Thomas 1994), and dynamics of bureaucratic expansion and state power (Riggs 1966; Ferguson 1994; Scott 1998). The hypothesis recognizes that the hegemony of the rural electrification parastatal may not arise only from actions of the parastatal itself. Rather, there may, in fact, be multiple actors with multiple aparati that serve to reproduce a particular technological and administrative approach to rural electricity provision.

Summary and conclusions

Village micro-hydroelectric systems in Thailand can be seen as a set of relationships between an electrical-mechanical system, a changing natural environment, a community of users (and operators), and a variety of outside actors, set within an evolving socio-political context. Several diverse literatures provide perspectives on these systems and the forces that shape and limit their ability to provide long-term sustainable electricity to the communities in which they are installed.

A common property perspective is useful in understanding particular dynamics that emerge at the local village level as a consequence of the collective yet limited nature of micro-hydroelectric systems. The perspective considers physical attributes of the system, decision-making arrangements governing the system’s use, patterns of behavior, and ultimately local outcomes. The common property perspective suggests looking for explanations of village micro-hydropower failures in a mismatch between the technical/physical characteristics of village power systems and the decision-making arrangements that govern their use

Diffusion literature is useful in suggesting a diverse set of factors to investigate in the slow uptake of community micro-hydro including features of the technology, of the implementing agency, factors that hinder exchange of ideas, and perception of risk among adopters of new technology. Social barriers literature, generally employed to explain disappointing clean energy dissemination results, identifies factors such as lack of sufficient information, high costs, insufficient incentives, and misguided policies as key impediments to technology dissemination.

A "political economy of technology choice" perspective considers historical developments and structural factors, including linkages to events and forces far beyond Thai borders that shape and limit particular socio-technical possibilities. This perspective conceives of the adoption of technology within large organizations as mediated by the exercise of political power. It argues that technologies are chosen that are consistent with organizational objectives, and that technology becomes institutionalized in the sense that it is supported, serviced, and reproduced even in cases where other options make more rational economic or engineering sense.

Drawing on the theoretical perspectives discussed above, seven hypotheses are proposed to explain the marginalized role of micro-hydroelectricity in Thailand:

Hypothesis 1: For the Thai public, there are few cases in which micro-hydroelectricity is an optimal investment;

Hypothesis 2: For villagers, there are few cases in which micro-hydroelectricity is an optimal investment;

Hypothesis 3: Physical circumstances do not favor micro-hydro in Thailand;

Hypothesis 4: There is a mismatch between village electricity consumption patterns and the production capabilities of village micro-hydro – and this is linked to a *mismatch between rules governing user behavior and the technical characteristics of the system;*

Hypothesis 5: Village management is deficient;

Hypothesis 6: The state program charged with supporting community micro-hydro has failed to address key areas for sustainable operation (misallocation at program level); and

Hypothesis 7: The hegemony of the parastatal rural electrification utility and its focus on grid electrification have reduced opportunities for cost-effective deployment and operation of micro-hydroelectricity.

The following chapters provide an empirical and historical basis from which to judge the extent to which each of the hypotheses above provides a credible explanation for what initially appears to be a non-rational underemphasis on micro-hydroelectricity in meeting rural electricity needs.

Chapter 3: Seeing the projects; diagnosing the vital signs

It's our power plant. Villagers work together, build a sense of community, and get electricity that saves money.

- Powerhouse operator from Huai Bu village

There is power from the micro-hydro plant 24 hours a day, except during the evening when we want it.

- Woman from Pang Haai village

Introduction

The two quotes above reflect the extremes of villager's experience with community micro-hydroelectricity in Thailand. Some find the experience very rewarding; working together to build and operate a power plant is a source of pride, local income, as well as inexpensive electricity. To others, disappointment with brownouts and blackouts make the whole endeavor seem a waste of time, especially considering the hassles of keeping the equipment operating.

To understand why micro-hydroelectricity appears to the losing to the grid, my research begins in the villages[11] in which the projects are installed. I document the status of systems, and attempt to reconstruct, using interviews, surveys, and measurements, the evolution of factors that lead to outcomes. My field research included site visits to 14 villages, surveys of 18 powerhouse operators, appliance use survey of 65 households in two villages, and extensive computerized datalogging of two generators when they were

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[11] For the cases I visited, villages are geographically well-defined. Houses are clustered, surrounded by farmland and forest. In general, throughout Thailand the category "village" (Mu Baan) is widely accepted by villagers themselves, as well as administrators. Villages are organized with an elected village chief and written records exist for the number of households and other basic demographics.

operating. I also draw on raw data from a survey of all 59 micro-hydro installations conducted by the Industrial Engineering Faculty at Chiang Mai University.[12]

In this chapter I document the positive experiences as well as the challenges reported by users. The key findings are as follows: (1) most of the systems are abandoned at the time of – and because of -- the arrival of the PEA grid; (2) respondents in most villages are (or were before it stopped working) satisfied with micro-hydroelectricity, even though (3) there have been some problems – particularly with low evening time voltages and generator failures; (4) chronic low voltages and generator failures are symptoms of a combination of equipment shortcomings and overloading the generators. (5) Overloads, in turn, are the result of unchecked appliance use, particularly of non-essential electrical heating loads (rice cookers, electric thermoses) by a minority of users.

In short, there are ways in which better local management, better technology, and better technical support could improve the prospects for long-term operation of community micro-hydroelectricity. At the same time, it is clear that in most cases communities with micro-hydroelectric systems are willing and able to make their systems work – unless they have the opportunity to switch to the (heavily subsidized[13], comparatively hassle-free) national grid. In some cases, communities endeavor to

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[12] The surveys covered a variety of topics including village socio-economics and demographics, user perceptions, characteristics of the systems, and failure modes. Respondents were generally village leaders: either the village chiefs or members of village or township-level decision-making committees.

[13] The Thai government national uniform tariff policy, strictly adhered to by Thai utilities for the past four decades, means that remote village households pay the same low price for electricity as counterparts that live near central generating stations, even though PEA provides power to these remote areas at a considerable loss. By 2001, the Metropolitan Electricity Authority (MEA) which serves urban customers was subsidizing PEA at an annual rate of over 8,100 million baht ($209 million) (Electricity Tariff Restructuring Study Steering Committee 2000).

continue operating the system even after arrival of grid power. The field findings suggest that the challenges experienced at the local level fall short of providing a complete and credible explanation of the paucity of installations of micro-hydro in Thailand. Understanding why community micro-hydroelectricity is rare and endangered requires an understanding of the costs of these projects as perceived by various actors (Chapter 4), and a broad investigation of Thai rural electrification policy and practice (Chapter 5).

To explore Thai micro-hydroelectric projects, their challenges and benefits in their local context, I begin with the arrangements under which they are built and operated.

Building and managing the systems

A government agency, the Department of Alternative Energy Development and Efficiency (DEDE) designs the systems, pays for the equipment, oversees project construction, and provides long-term technical assistance. The DEDE also provides 15 days of theoretical training, followed by 15 days of practical training for a locally selected powerhouse operator. Most of the equipment (pipe, turbine, generator assembly) is manufactured in a single private sector metal fabrication shop in the city of Chiang Mai. Labor and local materials such as rock, sand, and wood are provided by the recipient communities.

To initiate a project, residents from a village generally make a request to the governor or the provincial governor. Then DEDE sends one their staff to see if the site meets DEDE criteria (Liumsirijroen 1981):

1. The water source(s) must have enough flow throughout the year.[14]
2. The location of the project must not be further than 10 km from the village
3. The size of the village to be developed must be between 30 to 200 households, located far away enough from PEA's grid or the government's diesel plants that extending the line will not be cost-effective.[15]
4. The location must be suitable so that construction costs can be minimized. For example, if there is already an existing dike the village is more likely to receive support from DEDE.
5. People must be cooperative, have real need, be willing to contribute labor for the construction project, and provide locally available material (rocks, pebbles, sand, etc.)
6. After construction is finished, the villagers must be willing to take on the responsibility for operations, maintenance, and management of generation, distribution and sales by establishing a cooperative of hydropower consumers with an elected committee responsible for the plant.

Projects generally take around one year to build. The DEDE provides a supervisor to oversee construction. Households that wish to receive electricity connections form a queue, and are responsible for providing one worker for the day they are called upon. On average, about 15 villagers labor on the project year round, seven days a week. Those that did not contribute labor to construction, but who later decide to hook up, have to buy into the cooperative at a price determined by the coop committee (Interview 2002.01).

According to a DEDE official, ownership of stand-alone systems is officially divided between the village and DEDE, depending on the value of their contributions. The village typically ends up with a minority share (30 to 40%) (Interview 2001.03). According to 1981 plan cited above, the electricity tariff is to be the same as grid connected electricity (Thailand has a national uniform tariff policy). In practice, however,

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[14] In practice this means that the head and flow must be sufficient for a system of at least 10 kW.

[15] Over the years this has come to be interpreted as “greater than 5 km from PEA lines or PEA's plans for expansion (Interview 2001.03).

the village micro-hydro cooperatives set their own tariffs, which are often lower than PEA rates. The revenues from this tariff, after deduction of maintenance and operations cost were originally "to be divided between the government and the people according to the percentage of shares that each group owns." However, in practice ownership is not emphasized since management and control of the system is vested with the local cooperative, and all of the revenues from electricity sales are deposited into the village micro-hydro cooperative fund. This fund, in turn, is used to pay the operator and tariff collector, to pay for repairs, and as a village fund for projects as deemed appropriate by cooperative committee members.

Micro-hydro location and demographics

Between 1982 and 2001, fifty nine community micro-hydroelectric projects were built. The vast majority are located in Chiang Mai province, with nearly all of the others in surrounding northern mountainous provinces (see Table 1 and Figure 3).

Province	**Total**
Chiang Mai	41
Chiang Rai	8
Kanchananburi	2
Lampang	2
Mae Hong Son	4
Prachuap Kirikan	1
Tak	1

Table 1: Thai micro-hydroelectric installations by province

Figure 3: Approximate locations of 59 Thai micro-hydropower projects.

The installations are located in some of the most remote villages in Thailand, with villages often not on standard topographical maps[16], generally requiring a full day of travel over seasonal roads to reach.

The dominant occupation in nearly all villages with micro-hydro systems is subsistence farming, with villagers growing dryland rice, paddy rice and corn for self consumption. About half of the villages also grow crops for sale, including tea leaves, coffee, ginger, garlic, soybeans, taro, nuts, corn, linchee, pomelo, potatoes, leafy vegetables, and flowers (in declining order of importance). One village is engaged in tourism as its dominant occupation, while another is mostly engaged in extracting forest products and mining. Only one village relies on wage labor earnings during non-agricultural seasons.

Most villages in which projects were built (42 out of 59) self-identified as ethnically Thai or part Thai. Villages with ethnic minorities comprised 22 of the 59 villages. Most common were Karen (9 villages) and H'mong (5 villages) with Musaw, Akha, Ikaw, Lawa, Shan, Lisu, Chinese Haw, and "Burma" constituting one or two villages each.

User satisfaction, effective cooperatives

According to data collected by the Chiang Mai University, micro-hydro systems are popular among respondents, are generally profitable, and provide the basis for a useful village cooperative fund.

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[16] Finding villages with installations is complicated by the non-availability of topographical maps for areas that border on Burma.

Many users satisfied

One important finding is that the systems are quite popular among past and present users. A significant minority, 25 of 59 villages have micro-hydroelectric projects that remain functioning. Of these, respondents from 20 villages would like to continue using the system in the future. Surprisingly, of the 31 responding villages with projects that are currently *not functioning*, representatives from nearly a third (10 villages) stated they would also like to use the micro-hydroelectric system in the future, even though in most cases PEA had arrived. Hence, even though a minority of systems currently function, they are positively perceived by a respondents from a majority (35 out of 59) of villages that have experience with them.

Respondents from 25 villages cited convenience, inexpensive electricity, safety, and feelings of village pride and *esprit de corps* when asked why it was worthwhile to use the project in the future. Answers to the open-ended question are tabulated below in Table 2.

Reason expressed for intending to use system in future	Total number of villages
Because it is convenient and/or worthwhile	13
Provides inexpensive electricity	6
Electricity from micro-hydro is better	2
Feeling it is village accomplishment	1
Need to have in addition to PEA because many villagers not ready to use PEA	1
Probably safer than PEA	1
Villagers work together, build community, and get electricity that saves money	1

Table 2: Reasons for using micro-hydroelectric system in the future

Many of the village micro-hydroelectric cooperatives remain profitable. Out of 50 villages, respondents from 35 claimed that their cooperatives were profitable.

Surprisingly even the cooperatives of projects that were abandoned were profitable while they were operating. Out of 27 abandoned projects, 20 were described as profitable.

Micro-hydro cooperatives and microcredit

Informants in several villages spoke of the importance of the micro-hydroelectric cooperative fund as a source of micro-credit and as a fund for projects that benefited the whole village. Jae Sorn and Mae Kam Pong provide two examples of the role of these funds in local development.

The Jae Sorn village micro-hydro cooperative fund – rice bank

In Jae Sorn village in Lampang (north of Jae Sorn national park) the community micro-hydro fund was started with a contribution of 50 baht ($1.25) from each household, creating a total of 4,000 to 5,000 baht ($100 to $125). The fund grew to 10,000 baht from revenues from the micro-hydro, which the village used to operate a rice-cooperative that allowed purchase of inexpensive bulk rice. Later the road to the village was improved and there was subsequently less need to buy rice collectively. The village fund was transformed into a community bank that allowed locals to avoid loan sharks. As a result the fund grew to 600,000 to 700,000 baht (Interview 2001.03).

The Mae Kam Pong village micro-hydro cooperative fund – ecotourism

The Mae Kam Pong village micro-hydro cooperative used their micro-hydroelectric cooperative fund to launch a successful ecotourism program in December 2000. Visitors who participate in the program enjoy a homestay, traditional dances and other ceremonies, and an opportunity to participate in collecting and processing tea leaves. A nearby waterfall also provides a significant attraction. Visitors pay 1100 baht (US$26) per night for homestay, 120 baht (US$2.80) of which goes to the village -- half for the micro-hydro co-op, and half to cover village expenses such as paying performers who do traditional dances. Eight or nine households serve as homestay hosts, with 15 or 16 spares.

The Mae Kam Pong ecotourism program has won a number of awards, and was featured as one of 11 villages in the Thai government's "One Tambol, One Product" program. As of 2002 there was over 600,000 baht (US$14,000) in the community fund (Interview 2002.02).

Finally, micro-hydro projects can play a role in encouraging sustainable watershed management. The Mae Kam Pong village headman credits the micro-hydro plant with sparking his interest in conservation and ecotourism, "I started being interested in conservation after the micro-hydro came in. I thought, 'were going to need a good watershed in order to have electricity and we will need to conserve the forest.'" (Interview 2002.02)

Reasons micro-hydro systems are abandoned

These successes, unfortunately, are overshadowed by significant causes for concern. Less than half of the systems that were built remain functioning. Wide scale system abandonment is linked to arrival of the grid power, motivated by problems of poor power quality and frequently broken micro-hydro equipment. These factors, in turn, are linked to equipment quality shortcomings, operational procedures, and compounded by over-consumption of electricity relative to the capacity of the plants.

Grid arrival

In the field, one of the most striking findings is that many micro-hydroelectric systems have been abandoned, and furthermore most of these systems are discarded *when* and (in large part) *because* the grid arrives. Of the 59 systems installed, 25 are still in operation (Figure 4). Of the remaining 34 villages with abandoned systems, 31 now have Provincial Electricity Authority (PEA) grid electricity.

When asked why the village abandoned the micro-hydroelectric plant, respondents from 24 of villages with abandoned systems responded “the grid arrived”. Of these, 14 listed grid arrival as the *only* reason for abandoning the plant.

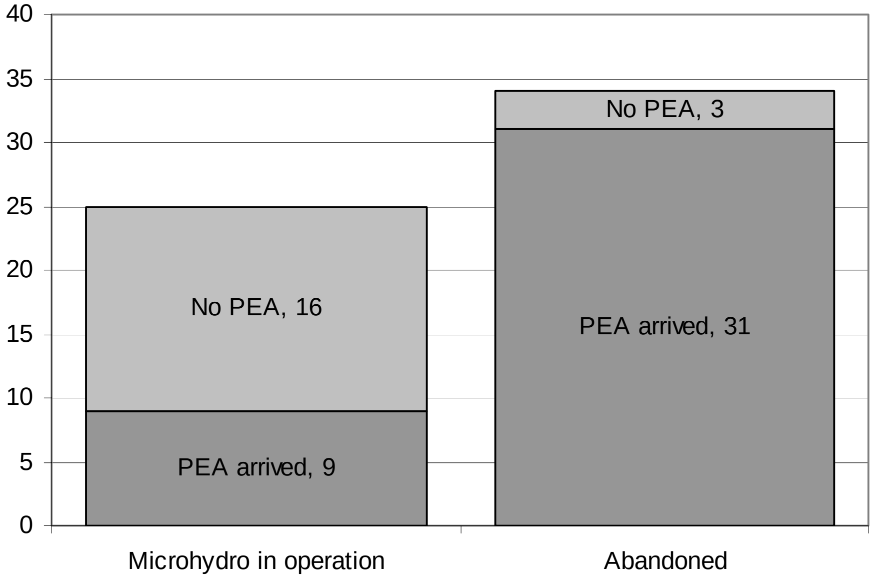

Figure 4: Operational status of micro-hydroelectric systems in Thailand and arrival of PEA grid.

Surprisingly, system age matters little. Figure 5 below shows the pattern of micro-hydroelectric commissioning, operation, and abandonment in 50 projects since the first projects were commissioned in 1982. Each horizontal line on the graph shows the lifetime of a project, in years. One might expect that there would be few older projects as equipment wears out. Many projects remain functioning after over 20 years, while many others are abandoned after only a year or two (generally because PEA arrived).

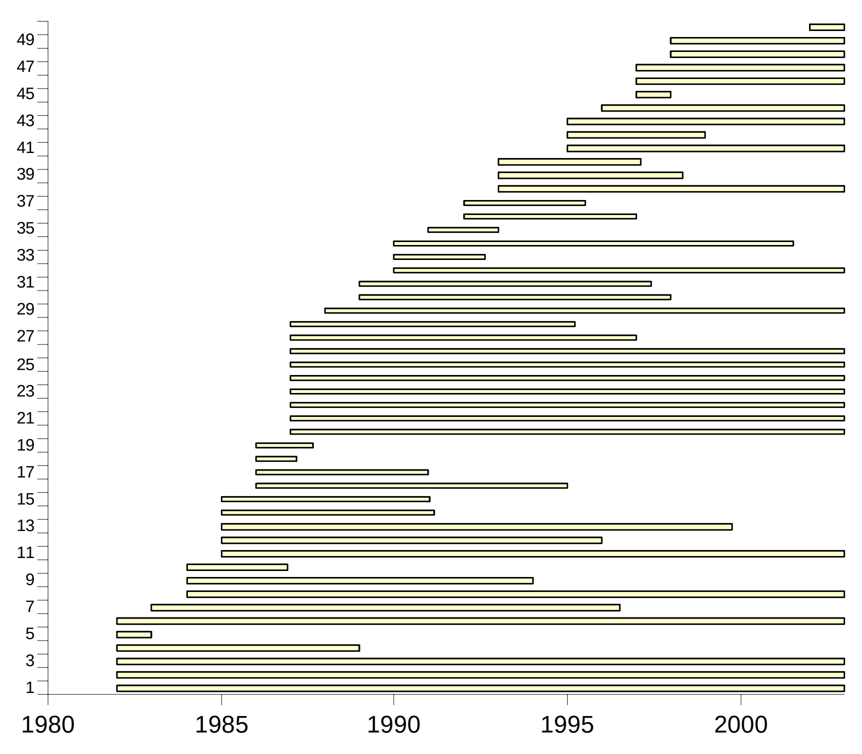

Figure 5: Timeline for micro-hydro projects, showing the years each was operational.

At the same time, respondents indicate that abandonment of the micro-hydro often occurs gradually, sometimes taking months or even years. When the grid power first arrives, a number of homes connect to PEA. If, over time, a certain threshold number of households stop using micro-hydropower, revenues to the micro-hydro fund fall below the cost of continuing to operate and repair the machine. The cooperative operates at a loss, and ultimately collapses. Similarly, if the grid has arrived in the village and the micro-hydroelectric plant suffers a significant breakdown the committee often decides that abandoning the project is the best option (Interview 2003.3).

The location of these villages deep inside forested areas means that if they are connected to grid power, they are at the end of long PEA distribution lines vulnerable to frequent faults from fallen trees and branches, especially in the rainy season. Of the 40 villages with PEA power, 35 complained of blackouts, and another three complained about brownouts. In large part because of the unsatisfactory reliability of PEA, 630 households in nine villages use both micro-hydro and PEA so that there is a backup if one power source is not working. These nine villages appear more intensively wired than many urban areas, with parallel sets of wires running to each household. In several villages, duplicate wiring extends to the level of the household, so that some lights and appliances are connected to PEA while others are wired to the micro-hydro (Interview 2001.06). In other villages, however, the entire house can switch from PEA to micro-hydro and vice-versa with the use of a double-pole, double-throw (DPDT) switch.

Factors other than grid arrival

From the perspective of the villagers, it is not difficult to imagine why the PEA grid is often the preferred option when it becomes available. Repairs to the micro-hydroelectric plant are the responsibility of the village, while repairs to the grid are the responsibility of the PEA. When asked why they no longer looked after the micro-hydro system, respondents from villages with abandoned systems answered, in all but one case[17], that the grid is "more convenient", that they were "tired of fixing the micro-hydro", that "PEA was less troublesome", that the "generator broke frequently", or simply that they "had PEA already".

When micro-hydro equipment failures happen the village powerhouse operator usually travels to the nearest village with a telephone and contacts DEDE. The DEDE sends out the next available a technician to fix the system. The process can take weeks –

or sometimes months before electricity service is restored. Technician reluctance or insufficient funds reportedly hinder travel to the most distant villages (Interview 2004.7).

Typical time required for repair	**Number of projects**
1 Week	15
2 Weeks	18
3 Weeks	2
More than 1 month	7

Table 3: Typical times to repair micro-hydro installation.

Besides the challenge of extended blackouts from equipment failures, many respondents complained about problems with low voltages, especially in the evening time. Of 59 projects, respondents from 48 complained of low voltages. Villagers complain that these low voltages cause a variety of problems: fluorescent lights will not start, television pictures become distorted and motors run hot or stall. Low voltages are blamed for broken televisions, refrigerators, and lights.

I will argue that low voltages and equipment failure are related in a variety of ways, and both are linked to excessive collective consumption and to shortcomings in the quality of the equipment or its installation. The line of reasoning has five arguments and is indicated by numbered arrows in Figure 6: (1) *poor equipment* such as generators that under-perform, or the lack of power factor correcting capacitors are directly responsible for *low voltages*. (2) *poor equipment* – such as AVR circuits that fail to protect themselves from overheating, or misaligned bearings are also directly responsible for certain *equipment failures*. (3) *Over consumption*, especially during evening time hours, overburdens generators, further causing *low voltage* problems. (4) *Over consumption* also

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[17] One village stated that there were water conflicts and the water needed to be used for something else.

directly stresses certain components (shafts, turbines), leading to *equipment failure*. (5) Finally, *low voltages* lead directly to certain types of *equipment failure*. When voltages are low the AVR is forced to operate in a fully saturated mode, increasing the likelihood of generator failure. At the same time low voltages also stress the electrical lights and household appliances, increasing frequency of failure.

Figure 6: Linkages between over-consumption, poor equipment, low voltages, and equipment failures.

I begin with a discussion of types and causes of equipment failures, followed by an analysis of the causes and consequences of low voltages. The analysis combines survey data from all 59 projects with in-depth datalogging and household surveys at 65 households in two villages.

Equipment failure

Equipment failures clearly play a role in the sustainability of installations. When asked why villages abandoned projects, respondents from six villages listed “machine broken often”, and two listed “long repair waits”. These frustrations with failures are not limited to systems that have abandoned micro-hydro projects. Among those villages still using micro-hydropower, six expressed frustration with the equipment – that they were “bored with fixing and maintaining it” or that they found it difficult to care for.

Operators from 51 micro-hydro facilities were asked which part of the system fails most often. The results are shown below in Table 4. By far the most frequent failure mode is the generator, which had failed most often in 61% of all projects.

	Percentage of all projects	**Percentage of operational projects**
Generator	61%	56%
Shaft	17%	20%
Governor	15%	20%
Turbine	5%	4%

Table 4: Responses to the question, “What part of the system fails most frequently?”

Generator failure

In a significant majority of systems, the generator was the most likely part to fail. By far the most common description of failure was that the generator had “burned up”. When a generator “burns up”, the part that burns is generally the field windings or the generator’s automatic voltage regulator (AVR). The AVR adjusts field current in order to control the voltage of the generator. When the generator’s output voltage is low (for whatever reason) the AVR increases field current. The increased field current creates a greater magnetic flux in the rotor, which, in turn, will cause the generator’s output voltage to increase.

If the generator is overloaded, however, the output voltage will remain low even if field current is at its maximum value (an electrical engineer would say that the “field current is saturated”). Sustained operation at maximum current causes the AVR to get hot. Frequently diodes in the AVR or the field windings in the generator burn out.

The burned generators are caused by (at least) five factors. First and foremost, the design of the generator and AVR should be such that it can operate at maximum current continuously. A better self-protection system, and higher capacity diodes are likely solutions. Second, the problem would never happen if peak electricity consumption was not so high. High electricity consumption is discussed in detail later in this chapter. Third, the AVR is most prone to burning out when exceptionally high current loads such as arc welders are used in the village. Some villages have taken steps to restrict these types of loads. Forth, dust sucked into the generator by the cooling fan can accumulate, contributing to overheating. The dust can also attract moisture which can cause shorts when there are defects in the wiring (Harvey, Brown et al. 1998). Fifth, the problem is compounded by the lack of capacitors for power factor correction (this point will be explained in greater detail in the section on blackouts and brownouts).

Shaft and bearing failure

After generators, shafts are the second most likely part to fail, accounting for the most common failures in 17% of the projects. The shaft connects the turbine to the generator, and requires precise alignment to reduce stress and oscillation. Bearings must also be checked and lubricated twice a year. Bearing failure may simply be the result of years of long use. However, the fact that some bearings were broken at installations installed as recently as 1996 suggests failure to properly lubricate the bearings, manufacturing defect or misalignment of the turbine and generator. In the most extreme cases the shaft splits from excessive oscillation and stress. Shaft and bearing failures are compounded by excess consumption because high electrical demand increases shaft torque.

Governor failure

Governors are the third most likely part to fail, accounting 15% of the most common failures, and 20% of most common failures in projects that continue operation.

As described in Chapter 1, Installations use either of two types of governors: electronic diversion controllers, or mechanical governors. About two thirds of the systems (20 out of 32) use electronic diversions controllers. The electronic diversion load control allows the generator to generate at full capacity all the time. Excess power not demanded by the village load is diverted to a water heating element, or ballast load. This type of control reacts quickly to changes in village load, and is both simple and relatively robust. The disadvantage is that full water flow is required constantly.

The remaining third of the systems (12 out of 32) use electro-hydraulic or mechanical governors. When the turbine starts to spin too fast, a servo motor-operated control closes a valve in the penstock, restricting water flow. A turbine with this type of governor uses less water, but is relatively more complicated and reacts slowly to rapid changes in load, causing instability in the power supply if load changes quickly.

Although used in fewer systems, electro-mechanical governors were far more likely to fail. In four out of 12 systems with electromechanical governors the governor was cited as the part most likely to fail. The electronic governor was cited as most likely to fail in only 1 out of 20 systems. The clear lesson is that mechanical governors are problematic and their record of failure should be weighed carefully against their water saving benefits.

Turbine failure

Two villages reported that turbines were the part most likely to fail. In once case the blades were eroded from too much sand in the water. In the second the failure mode was that the blades broke. Possible causes include stones in the water supply, or metal fatigue where the blades are welded to the end plates (a frequent cause of failure in crossflow turbines (Inversin 1986, p. 181)). High electrical demand increases torque on turbine blades, and leads to higher probability of failure.

Low voltages, poor equipment, over consumption, and equipment failure

To the users of village micro-hydroelectric systems, one of the most significant causes of consternation has been “fai dtok” and “fai dap” – low voltages and outages especially in the evenings. Frequent blackouts and brownouts were blamed as a partial cause in the decision to abandon three systems. More significantly, out of 58 systems, 48 reported problems with brownouts, and 41 reported problems with blackouts. I will argue that brownouts are caused by ever-increasing appliance use in the village, exacerbated by equipment that performs below specifications and by failure to install power-factor correction capacitors. Low voltage, besides being a source of frustration in its own right, contributes to a number of system failures.

To better understand voltage patterns and their causes, I surveyed appliance ownership histories and use patterns of electricity users and used a computerized datalogger to measure generator output in two villages: Mae Kam Pong village and Huai Bu village.

Indepth village case studies: Mae Kam Pong and Huai Bu

Mae Kam Pong and Haui Bu represent opposite ends of the socio-eonomic spectrum of villages with micro-hydro projects. But their experiences are similar: electrical consumption increasing year by year to levels that cannot be supported by the micro-hydro plant. Interviews with villagers in other communities indicate these experiences are widespread, if not universal.

Mae Kam Pong is a relatively affluent ethnic Thai village, with a (mostly) paved road, and a long-running micro-hydro project that has received relatively high levels of support. The village is located in Tambol Huay Kaeo, Ging Amphur Mae On, Changwat Chiang Mai. It is approximately 50 km from the city of Chiang Mai, with the last 20km over steep but sealed roads. The micro-hydro project serves 128 households. The catchment area of the micro-project is about 6 square kilometers in mountainous terrain covered with dense forests and steep slopes.

Most Mae Kam Pong residents earn a living from growing chewing tea (miang). The tea leaves are fermented and traditionally chewed as a mild stimulant by residents in northeast Thailand, though currently the market is declining as new generations turn to cigarettes, chewing gum, and amphetamines. The chewing tea orchards occupy hill areas surrounding the villages. Working 30 days, a skilled tea leaf picker can earn 7500 baht (US$175) (Interview 2002.02). Other occupations in Mae Kam Pong include ecotourism, dressmaking, trading, and seasonal labor. There are over a dozen pick-up trucks in the village, and most households have at least one motorcycle.

I chose Mae Kom Pong as a case study because it is Thailand's longest running and arguably most successful village-scale micro-hydroelectric plant. The long-running nature of the project provides the opportunity for more data on long-term load changes. Another key feature of Mae Kam Pong is that while it is no Potemkin village, the micro-hydro project has probably received more support from the DEDE than other villages. The DEDE provides quicker repair service to Mae Kam Pong than for more distant villages. And over the years, the DEDE has expanded Mae Kam Pong micro-hydro generation by two additional generators to accommodate load growth. In addition to the 20 kW installation in 1983, a 20 kW micro-hydroelectric generator was added in the same power house in 1998, followed by the construction of a new 40 kW project downstream from the outlet of the first two projects.

DEDE’s particularly strong support for Mae Kam Pong follows from several factors: (1) the project site is relatively accessible – only 1.5 hours from the DEDE micro-hydro office on paved roads; (2) the project has a successful reputation that DEDE is eager to protect; (3) the wife of the director of the DEDE village micro-hydro program hails from Mae Kam Pong. Problems encountered in Mae Kam Pong’s micro-hydroelectric project are thus likely to be just as bad, if not worse, in other lower-profile communities with fewer resources to draw on.

Huai Bu is a subsistence Karen village, located much further from urban centers, with a relatively more recently built project. Located in Tambol Mae Daed, Amphur Mae Chaem, Changwat Chiang Mai, the drive from Chiang Mai takes over six hours with the last hour over steep seasonal dirt roads accessible only by high-clearance vehicle or by motorcycle.

Ethnic Karen have inhabited the Huai Bu area for 100 years, though in the past few decades some ethnic Thai have married into the community. Most Huai Bu residents are subsistence farmers who grow both flooded and upland rice as well as a variety of vegetables. Men typically find seasonal work in surrounding towns between harvest and planting seasons. There are few vehicles: only one pickup truck in the village and perhaps a dozen motorcycles. The micro-hydroelectric plant at Huai Bu serves three village hamlets: Huai Bu (53 households), Baan Mai (8 households), and Sop Laan (33 households). Out of 94 households in the villages, 74 households receive power from the power plant. Most of the 14 square kilometer watershed appears to be covered with healthy forest. It is unlikely that a second installation will be built to accommodate load growth, as the topography is not suitable and it would conflict with existing agricultural water needs.

Huai Bu thus represents a village on the opposite side of socio-economic spectrum from Mae Kam Pong: remote and inaccessible in wet season, composed of ethnic minorities engaged in subsistence agriculture. Despite the substantial differences between these two communities, the village's experiences -- described below -- of systematic low voltages due to increasing loads and underperforming equipment are similar. Moverover, the patterns appear to be widely experienced in other villages as well: interviews with villagers from 14 randomly selected communities indicated that the dynamic described below occurred in their villages as well.

Datalogging results

Using a datalogger, measurements of voltage and current (on three phases) were taken at the Mae Kam Pong generator. Figure 7 below shows data recorded at 15 minute intervals over 108 days from 7 June to 23 September, 2001. The data shows that about

90% of the time the system was generating power, but with extremely variable voltages from 100 volts to nearly 300 volts.

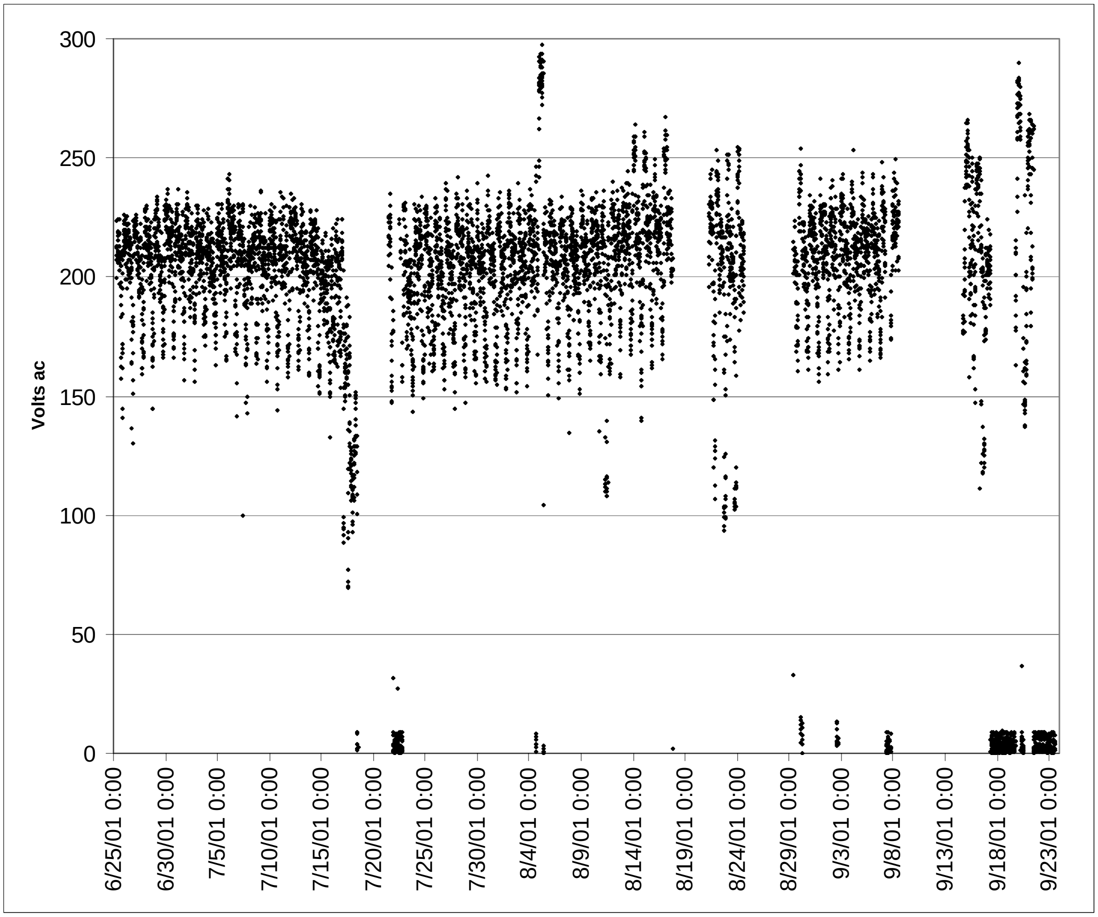

Figure 7: Voltage measured at the generator at Mae Kam Pong

To simplify interpretation, the voltage data from Mae Kam Pong is presented below in Figure 8 as an exceedence curve. The time-series voltage values are ranked from highest to lowest, and then plotted. By way of comparison, PEA's official "standards of maximum and minimum voltage levels" are 240 volts and 200 volts respectively (NEPO 2002). When viewed with respect to these criteria, the voltage at the Mae Kam Pong micro-hydro system is higher than the standard 4% of the time, and lower than the standard 35% of the time. About 9% of the time Mae Kam Pong was blacked out.

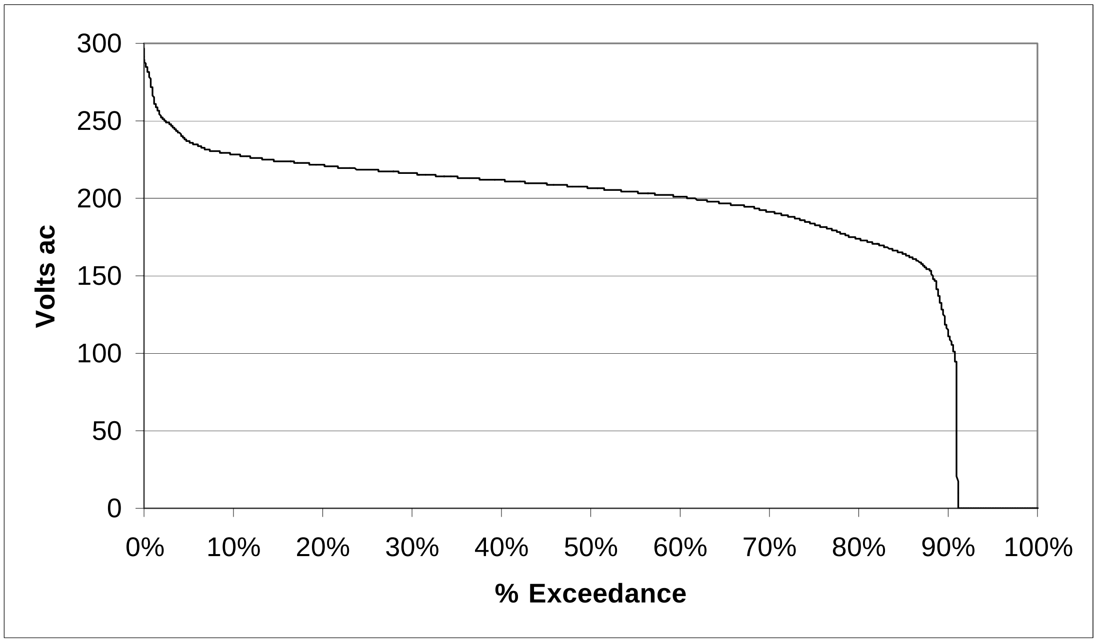

Figure 8: Voltage readings at Mae Kam Pong sorted by voltage value.

Figure 9 and figure Figure 10 show similar voltage measurements taken at Huai Bu village, between 4 April and 15 June, 2002. Voltage is never higher than the PEA standard, and is lower than the standard 53% of the time. About 31% of the time Huai Bu was blacked out.

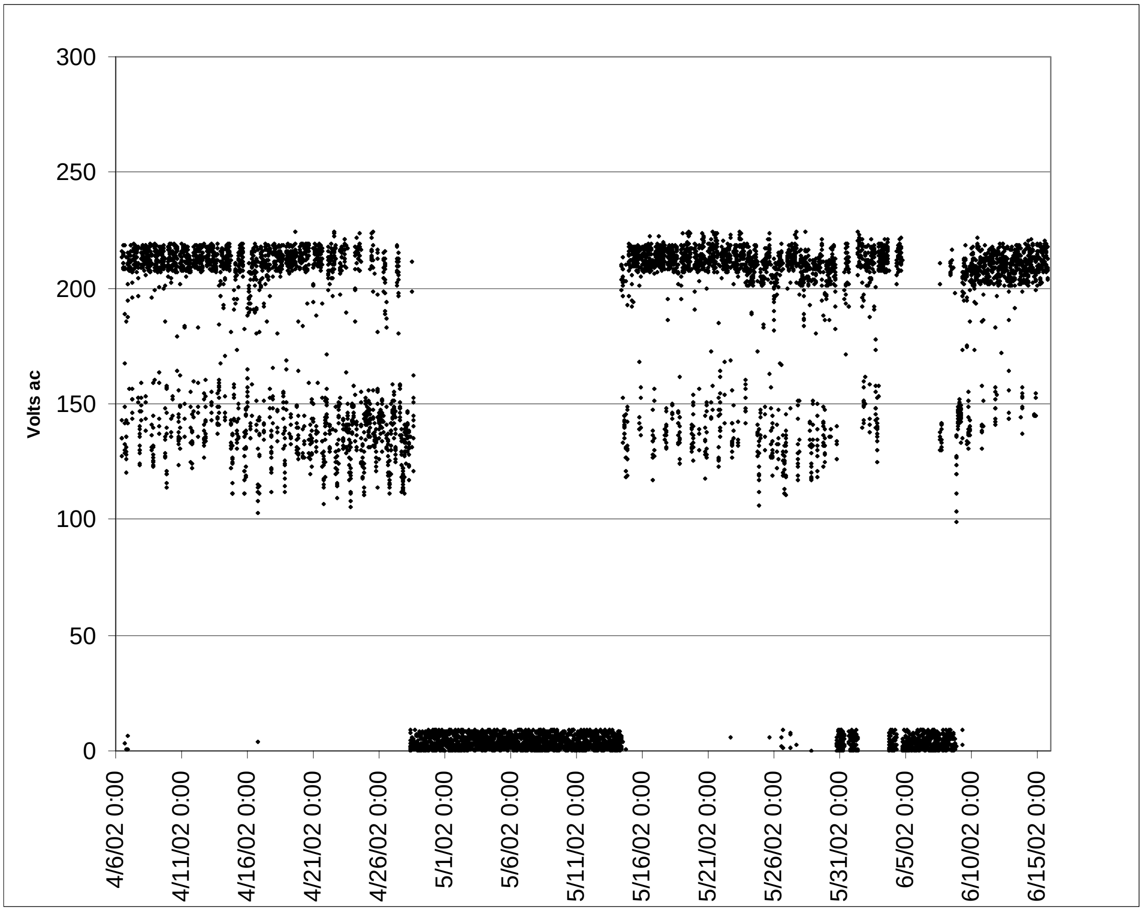

Figure 9: Voltage measured at the generator at Huai Bu.

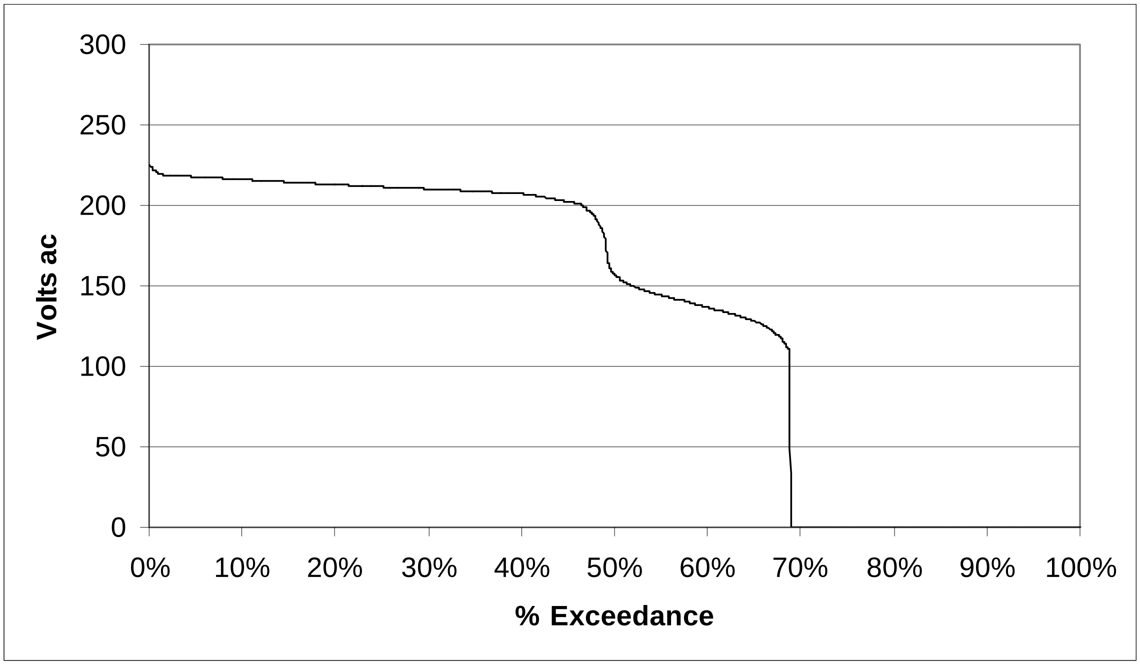

Figure 10: Voltage readings at Huai Bu sorted by voltage value.

Despite their different socioeconomic demographics, both villages suffer from significant blackouts and brownouts. The technical and user-behavior causes of these problems are also more or less the same in each village: the micro-hydro turbine/generators fail to generate their rated power, capacitors to correct for low power factor loads are absent, and in villages there is a pernicious pattern of runaway collective over-consumption.

Generators fail to generate rated power

It is no surprise the lights are dim if generators do not make as much electricity as advertised. The powerplant in Mae Kam Pong produces a maximum of only 70% of rated power, while the power plant at Huai Bu running at full throttle produced only 50% of rated power. Figure 11 shows apparent power (kVA) measured between 25 June and 23 September 2001 at Mae Kam Pong. Although the installation is rated 20 kW, the peak apparent power[18] is less than 14 kVA. Similar measurements in Huai Bu indicate that the 25 kW (rated) power plant never produces more than 12 kVA.

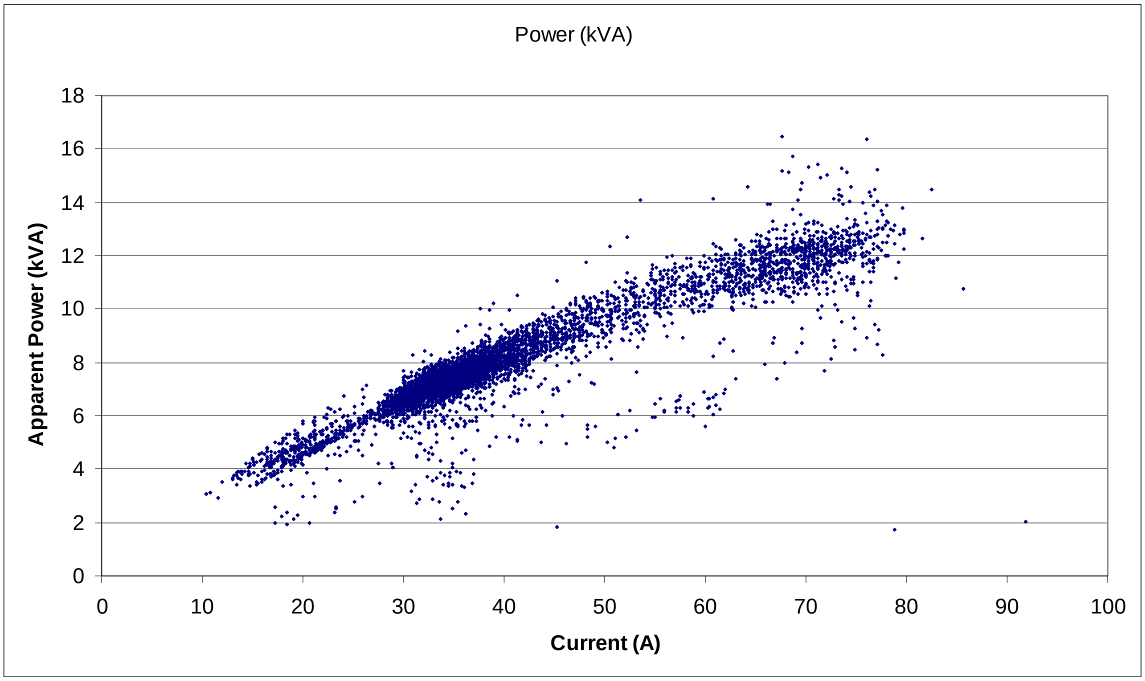

Figure 11: Apparent power as a function of current at Mae Kam Pong.

Low power factor

Low power factor appliances and the omission by DEDE to install power factor correction capacitors in these systems is also a cause of low voltages. Power factor is a measure of the degree to which voltage and current are in phase, with a power factor of 1 meaning current and voltage are completely in phase, and zero power factor meaning 90 degrees out of phase. Low power factor is caused by inductive loads (electrical loads that have coils of wire) such as motors or coil/capacitor fluorescent light ballasts. The ballasts used on most fluorescent lights have a power factor of 0.35 (as indicated on the nameplate of the ballast). Motors used in refrigerators and other equipment also have

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[18] Apparent power (kVA) is always equal to or greater than real power (kW) because it does not take into account power reduction through non-unity power factor.

very low power factor. Appliance surveys in two villages showed that motors and fluorescent lights with low power factor ballasts make up over 50% of a village loads.

Because low power factor loads force AVRs in generating stations to work harder, utilities generally strive to achieve unity power factor[19], and employ banks of capacitors to correct for low power factor loads (Von meier 1999). Unfortunately none of the Thai micro-hydro projects follow this standard utility practice.

Low power factor loads disproportionately reduce line voltage, forcing the AVR to send more field current to the rotor. Up to a point the AVR can compensate for low power factor loads by increasing field current, which produces the reactive power consumed by low power factor loads. But there is only so much the AVR can compensate for. If loads are too high, and/or power factor is too low, then generator output voltage will drop even if the AVR is working at full capacity.

Patterns of over consumption

Engineering shortcomings that lead to low voltages are compounded and exacerbated by user behavior. In the evening time, people simply more demand electricity than the system can produce. In this section I first use datalogging measurements to relate periods of heavy consumption with periods of low voltages at Mae Kam Pong and Huai Bu villages. Second, I analyze surveys from both villages to show how consumption patterns evolve over time.

Datalogging measurements of current and voltage show a clear pattern of evening time high consumption bogging down generators and causing low voltages. Figure 12

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[19] “Unity power factor” means a power factor of 1.0.

shows current and voltage patterns during a typical[20] three day (72-hour) period at Mae Kam Pong when all generation equipment was functioning normally. In the figure the three gray lines indicate current (measured in amperes) consumed by the village. Current in all three phases rises sharply during the evening hours, with peak values above 25 Amperes per phase. A much smaller 15 Ampere peak during the early morning is distinguishable from a "baseline" consumption of about 10 amperes. The black line indicates voltage (measured in volts). Coincident with the evening peaks in current drawn by the loads, voltage at the overloaded generator dips precipitously from a normal value of around 220 volts down to 150 volts or lower.

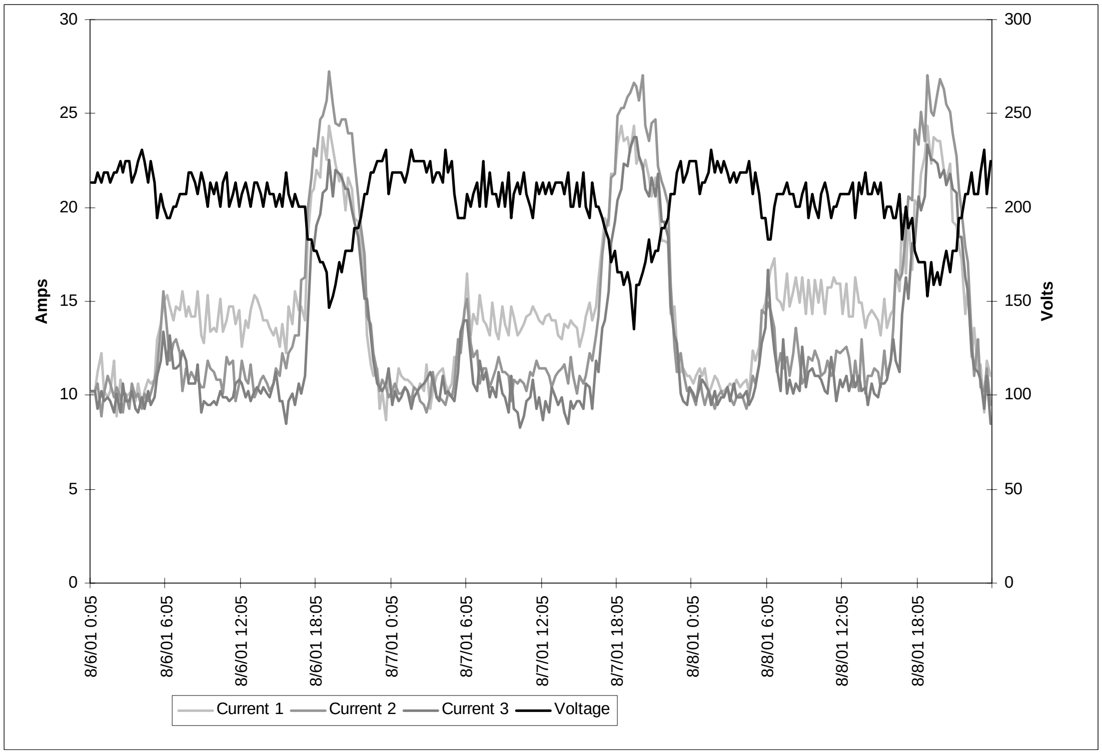

Figure 12: Voltage and current (3 phases) at Mae Kam Pong

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[20] Data shown from 6 August to 8 August, 2001. Data logged for 90 additional days followed a virtually identical pattern.

Figure 13 shows three months worth of data, plotting voltage as a function of current. The relationship between current and voltage is clear. Up to about 30 amps total current the generator is able to produce constant voltage at around 220 volts. But once this threshold is exceeded, increasing consumption drives voltage down linearly with increasing current.

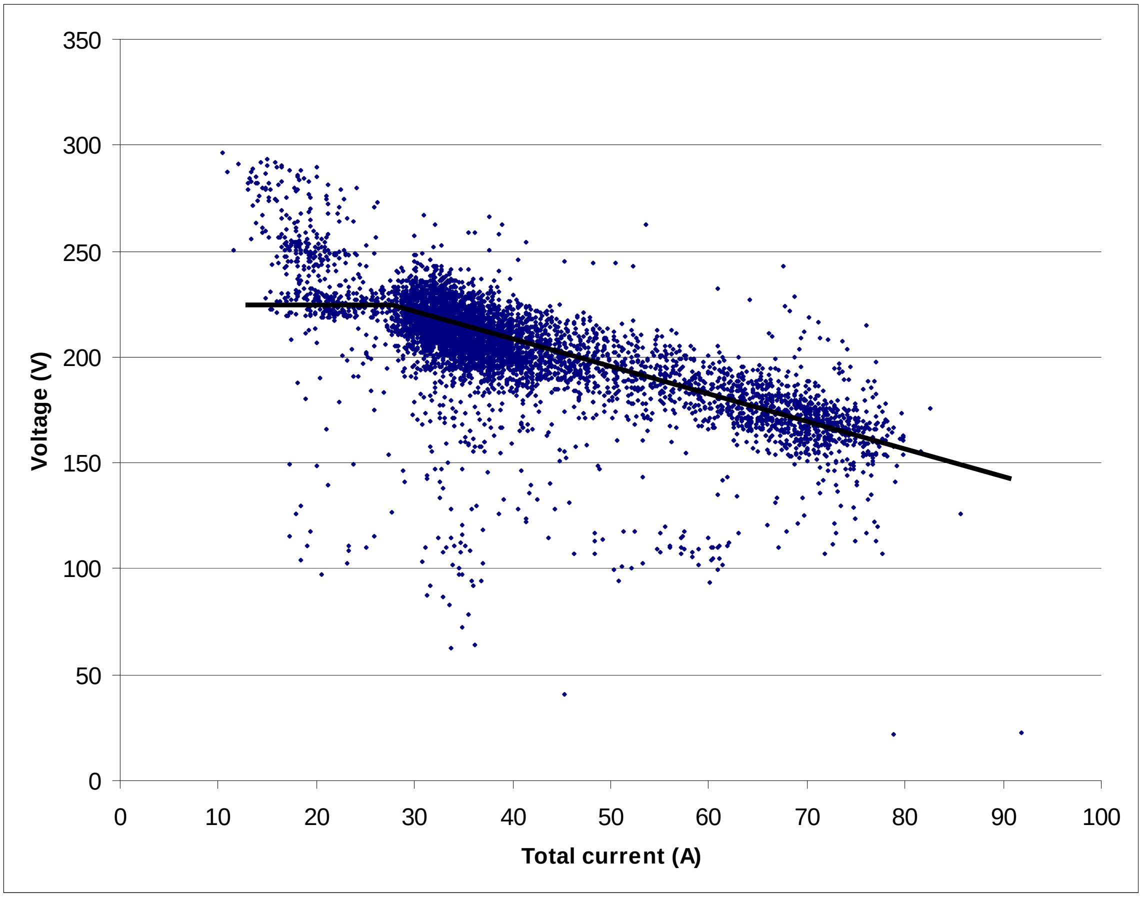

Figure 13: Current vs. voltage in Mae Kam Pong village.

In Huai Bu village (Figure 14) voltage regulation during off-peak times is better (at around 220 volts) but also dips severely as current draw from the loads peak. In Huai Bu low voltages are not confined to evening times: a substantial morning load peak is high enough to bog down the generator and reduce voltage.

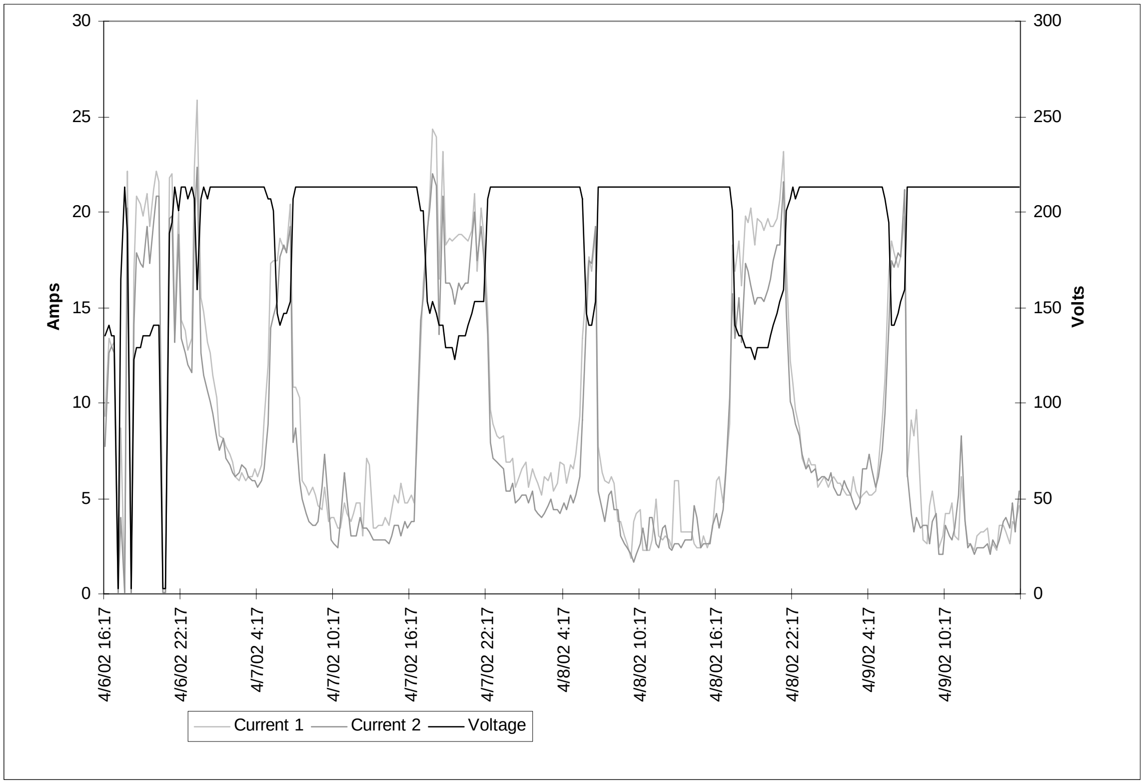

Figure 14: Voltage and current (2 phases) at Huai Bu village

At Mae Kam Pong and Huai Bu, as in all villages visited in the course of this research, households connected to the micro-hydro project have used increasing numbers of ever more consumptive appliances. Figure 15 below shows the trend of growth of electricity demand in Mae Kam Pong from the time the power plant was finished until 2001. The figure represents the results of a survey of 35 randomly selected households conducted during two visits[21] in April and June, 2001. The sample represents approximately 25% of the households in Mae Kam Pong.

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[21] Survey interviews were conducted with the help of a translator. Mae Kom Pong is composed of six hamlets. I distributed interviews so that I spoke with people in 5 or 6 households per hamlet, and randomly chose houses of varying distances from the main road and of varying economic levels. Power consumption for each appliance type was determined either by inspection of the appliance label (for lighting), by published appliance consumption figures (Schaffer 2000), or direct measurement of average current consumption of similar appliances in cases in which the appliance electricity consumption is not constant (eg. refrigerators, water boilers, and washing machines).

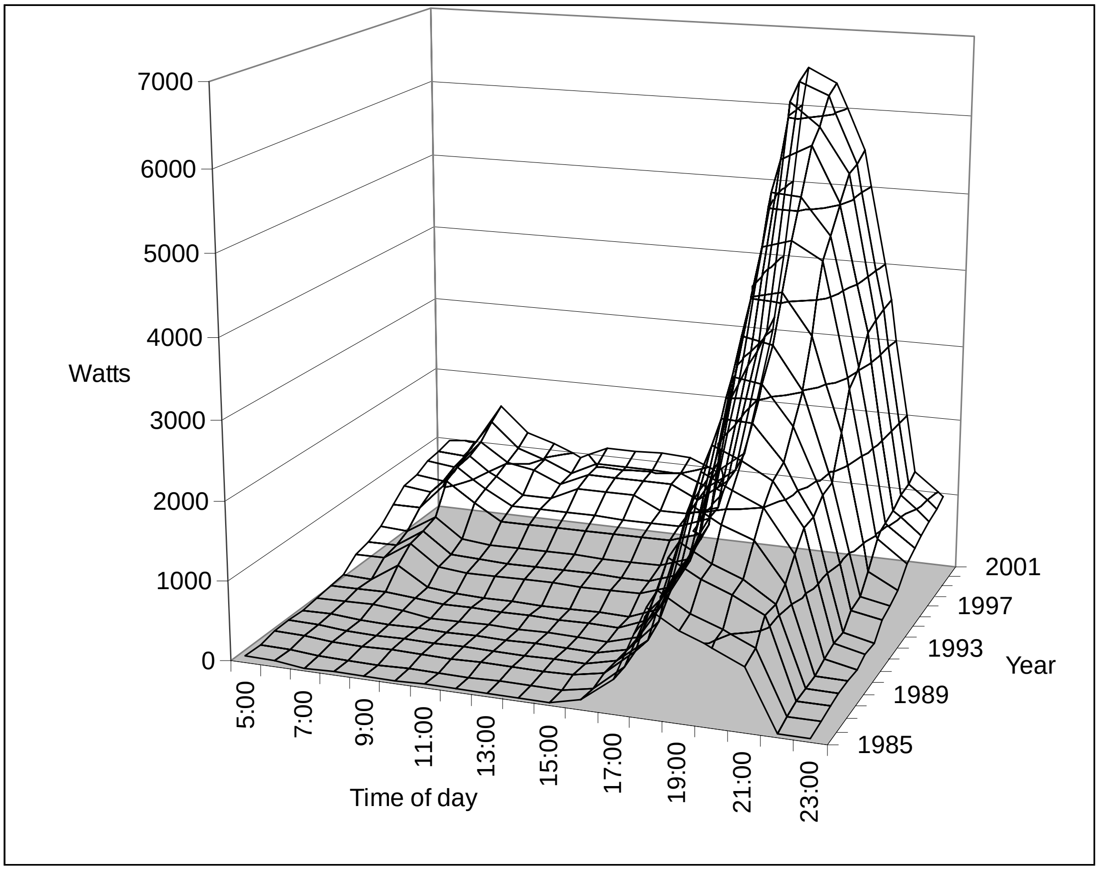

Figure 15: Survey-derived electricity demand (y-axis) vs. time of day (x-axis) and year (z-axis) in Mae Kam Pong village.

Interviewees were asked to specify all appliances that they own. Then for each appliance, respondents were asked how many years the appliance had been in use at the house, and what hours during the week the appliance is typically used. Based on the answers to the survey, electricity consumption of these appliances was calculated on an hourly basis and aggregated.

As Figure 15 shows, in 1985 consumption was negligible until 4 pm, and rose to a small maximum of 1.3 kW by 6pm. Demand then declined to about zero by 10pm. By 2001, consumption had grown strongly. A clearly noticeable morning peak (1.5 kW) had emerged at around 7am. But this was dwarfed by the evening peak that had grown to 6.5

kW – about six times the off-peak load. The pattern, shape, and magnitude of the “small morning peak, followed by much larger evening peak” matches and validates the current and voltage datalogging results (Figure 12).

In Huai Bu load growth was even faster than in Mae Kam Pong. Figure 16 shows the results of appliance use surveys of 30 randomly selected Huai Bu households conducted during a visit in Feb 2002. The sample represents 41% of the households receiving electricity in Haui Bu. In only four years, the peak load grew 59% from 2800 to 4440 watts, or an annual growth rate of 12.2%.

Consumption in the village follows a pattern with two growing peaks, one at 6 am, and the other at 6pm, with a long period of minimal consumption between 7am and 4pm. The vast majority (73%) of the morning peak in year 2002 is attributable to five rice cookers used simultaneously by elementary school teachers. The high simultaneous use of high-wattage rice cookers in the morning also accounts for the strange “S-shape” in datalogged voltage exceedence curve (Figure 10).

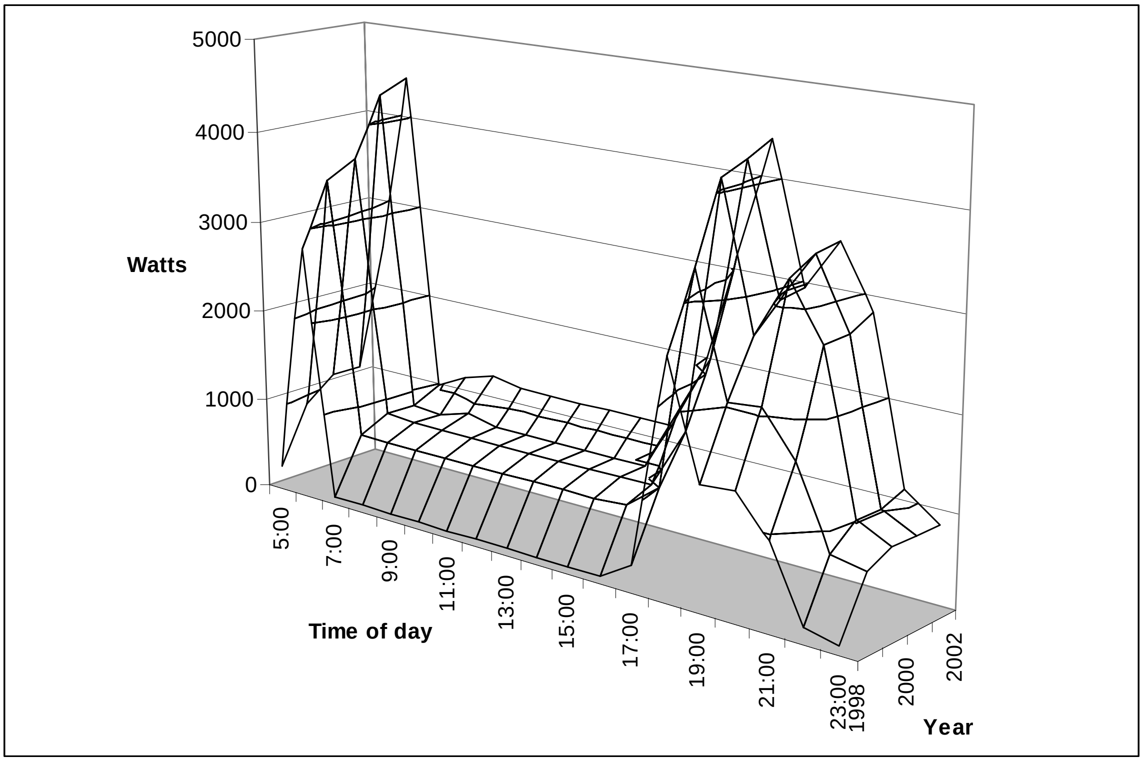

Figure 16: Survey-derived electricity demand (y-axis) vs. time of day (x-axis) and year (z-axis) in Huai Bu village.

Population growth or higher consumption per household?

Where does the increase in peak evening load shown in Figure 15 andFigure 16 come from? There are two contributing factors: growing numbers of households and growing per-household electricity use. Expanding per-household electricity use is by far the most significant factor, as illustrated below in Figure 17. The graph show the change in peak evening load (triangle data points) relative to the number of households connected (circle data points) within the sample of 35 households surveyed in Mae Kam Pong. From 1985 to 2001, the number of homes in the sample rose from 16 to 35, an increase of 119%.[22] Over the same time period, peak load grew from 1.5 kW to over 9.5 kW, an increase of 515%, and an annual growth rate of over 12%. Growth in the number of households thus accounts for 36% of the total load growth, while per household consumption growth accounts for the remaining 64%. The graph indicates that load grew in-step with increasing population until 1991, after which load growth accelerated substantially. Mae Kam Pong was only able to support this sustained increase in consumption through the installation of additional micro-hydro generators in 1988 and 1994.

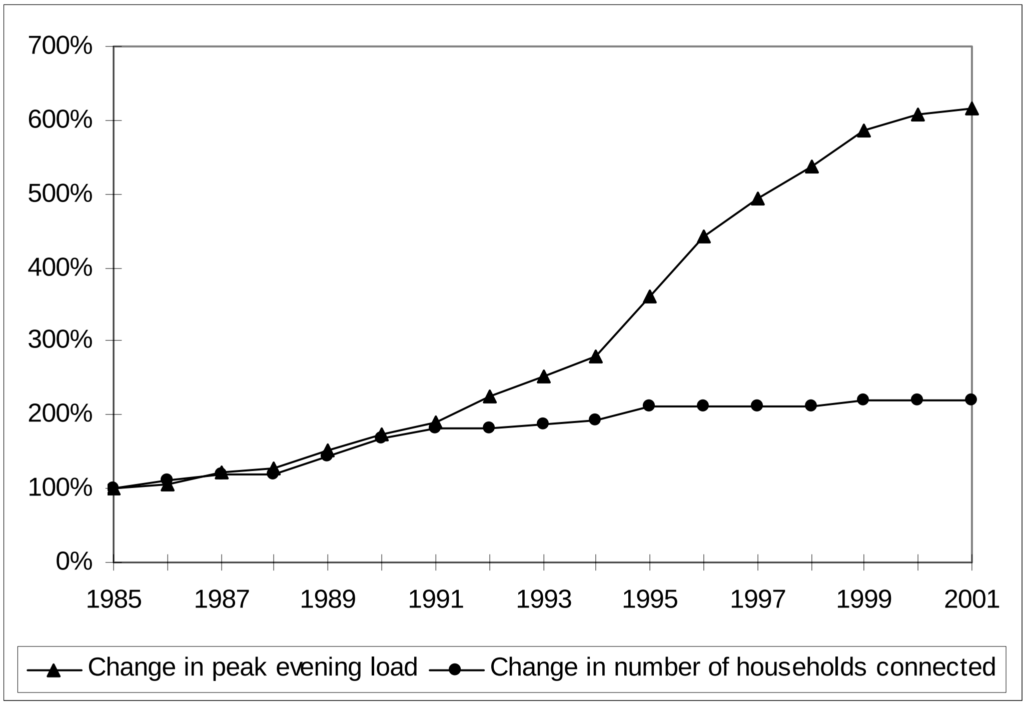

Figure 17: Change in peak evening load and change in number of households using electricity in Mae Kam Pong village relative to 1985 baseline values.

In Haui Bu, increase in consumption tracks increase in connected households more closely (Figure 18). But change in peak consumption still exceeds increases in connected households. Between 1998 and 2002, the number of connected households surveyed rose from 19 to 30, and increase of 58%, but peak consumption over the same period grew from 2480 watts to 4390 watts, an increase of 77%.

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[22] The growth reflected in the sample over exaggerates population growth slightly.

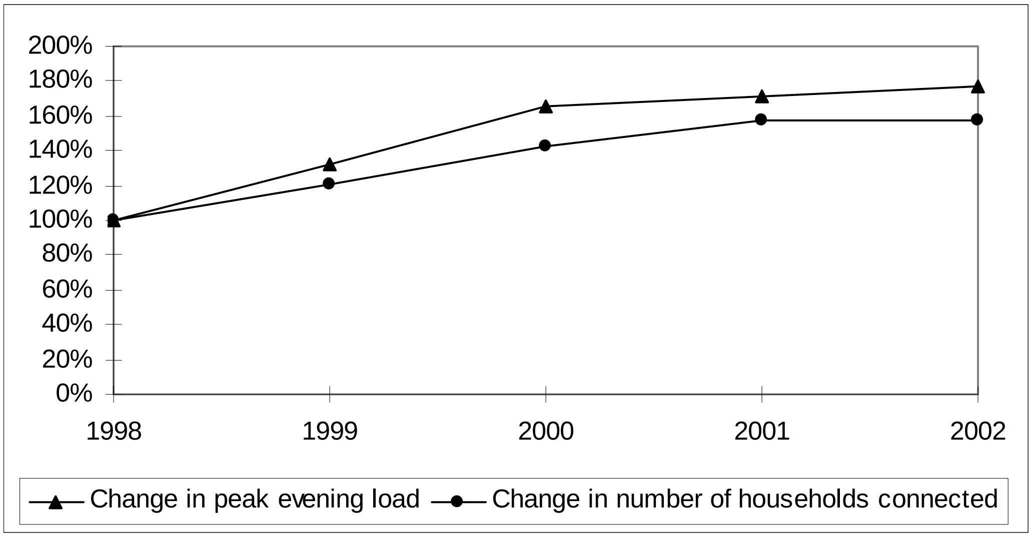

Figure 18: Change in peak evening load and change in number of households using electricity in Huai Bu village.

Evening peak consumption broken down by appliance

The evening peak "ridgeline" in Mae Kam Pong from Figure 15 is shown in Figure 19, broken down by appliance type. The graph dramatically shows that the rapid growth in peak consumption is largely due to growth in non-lighting loads. In the households surveyed electricity was increasingly used for entertainment and electric cooking.

Between 1985 and 2001 lighting grew relatively slowly, increasing an average of 5.5% per year. Other appliance use grew much more rapidly -- for example electricity consumption by televisions increased an annual average of 13.6%, while electricity consumption by refrigerators grew at 21.3%. Consumption by rice cookers and water boilers increased even faster -- from zero in 1985 to 1.5 kW and 1.3 kW respectively by 2001.

The village as a whole grew from 64 to 128 households, an increase of 100%.

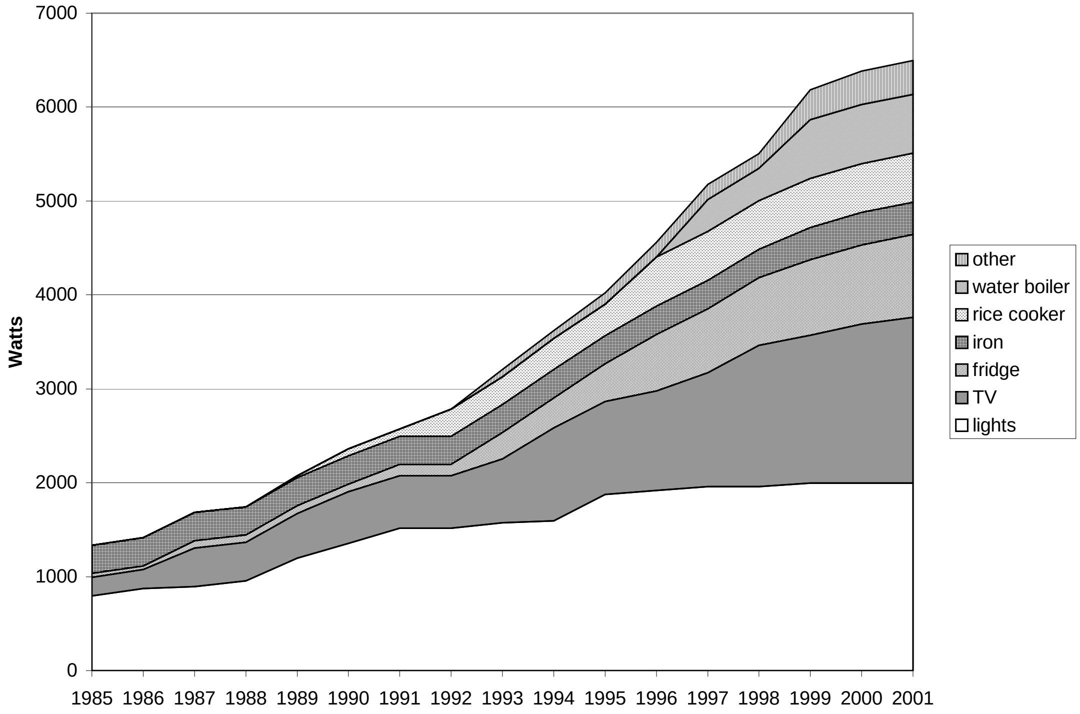

Figure 19: Yearly growth in peak electricity use in households sampled in Mae Kam Pong village, broken down by appliance type.

In 1985 lighting accounted for 59% of peak evening load. By 2001 lighting accounted for less than 24%, slightly less than television (25%). Other appliances, and especially highly consumptive rice cookers and water boilers were responsible for much of the growth in peak evening consumption.

Appliances such as rice cookers and water boilers that use electricity to produce heat have a particularly large impact on aggregate consumption. Even though rice cookers and water boilers are owned by a minority of households (rice cookers are owned by 12 of the 35 households surveyed, water boilers are owned by 10) together they account for over 30 percent of total peak evening consumption in the sample.

Rice cookers represent conspicuous and convenient consumption, and a rather inefficient use of electricity to substitute for a practical and sensible traditional technology. Traditionally the village ate sticky rice (*kaew neaw)* which is steamed over a wood fire and cannot be cooked in a rice cooker. (Deforestation from fuel-wood gathering is not a problem in Mae Kam Pong.) Rice cookers are used to cook plain rice (*kaew suay)* eaten by the dominant ethnic Thai culture. *Kaew suay* is perceived to be higher class and is served to visiting guests. Rice cookers are also used when the household does not want to take the time necessary to prepare sticky rice.

“Water boilers” or electric thermoses keep water hot throughout the day to be used for tea and coffee. They are similar to rice cookers in a sense that they are convenient yet consume considerable amounts of power to substitute for the traditional technology of a kettle on a stove.

In addition to increases in the types of appliances used, villagers also “upgraded” from smaller, less consumptive appliances to larger, more consumptive ones. For example, many households upgraded from black and white televisions to color, and from smaller screens (14" to 17") to larger (20" to 21").

Appliance ownership and use patterns ranged widely in Mae Kam Pong, from one household with only a single lightbulb used two and a half hours a day, to households with washing machines, several color TVs, multiple refrigerators, and a microwave oven. One exceptionally consumptive house (a vacation house used by an American expatriate and his Thai wife a few days a month) had seven electric water heaters for showers, a 25" color TV, and many kitchen appliances including a dishwasher, clothes washer, and coffee machine. Figure 20 shows wide variation among households in contribution to peak evening time consumption. The most prodigious user is responsible for more than 540 watts of peak load – over 25 times more electricity than the three most modest users whose peak evening load consists of a single 20 watt lightbulb.

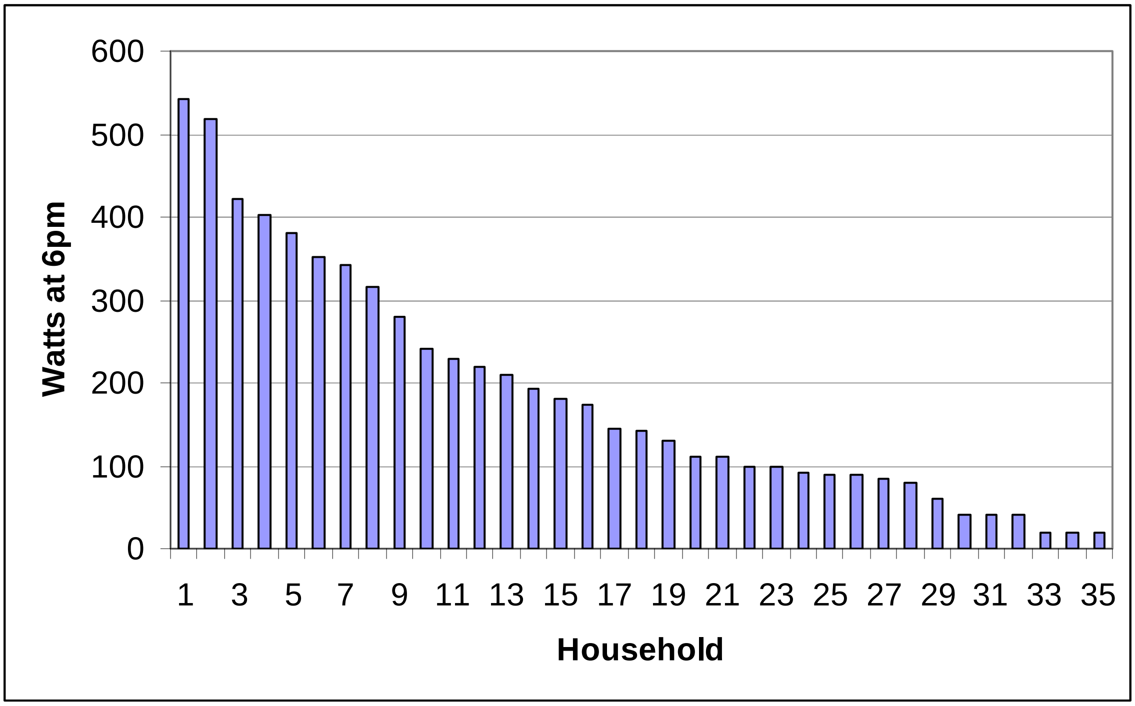

Figure 20: Contribution to peak consumption by each of 35 households surveyed in Mae Kam Pong.

Growth in appliance use during the evening peak in Huai Bu is shown below in Figure 21. As with Mae Kam Pong village, the vast majority of the load growth is in non-lighting loads, especially by two rice cookers and five resistance heating water boilers. In 1998 lighting accounted for 42% of peak evening load. By 2002 lighting accounted for only 31%. Other appliances, especially irons and water boilers in a few households were responsible for much of the growth in peak evening consumption.

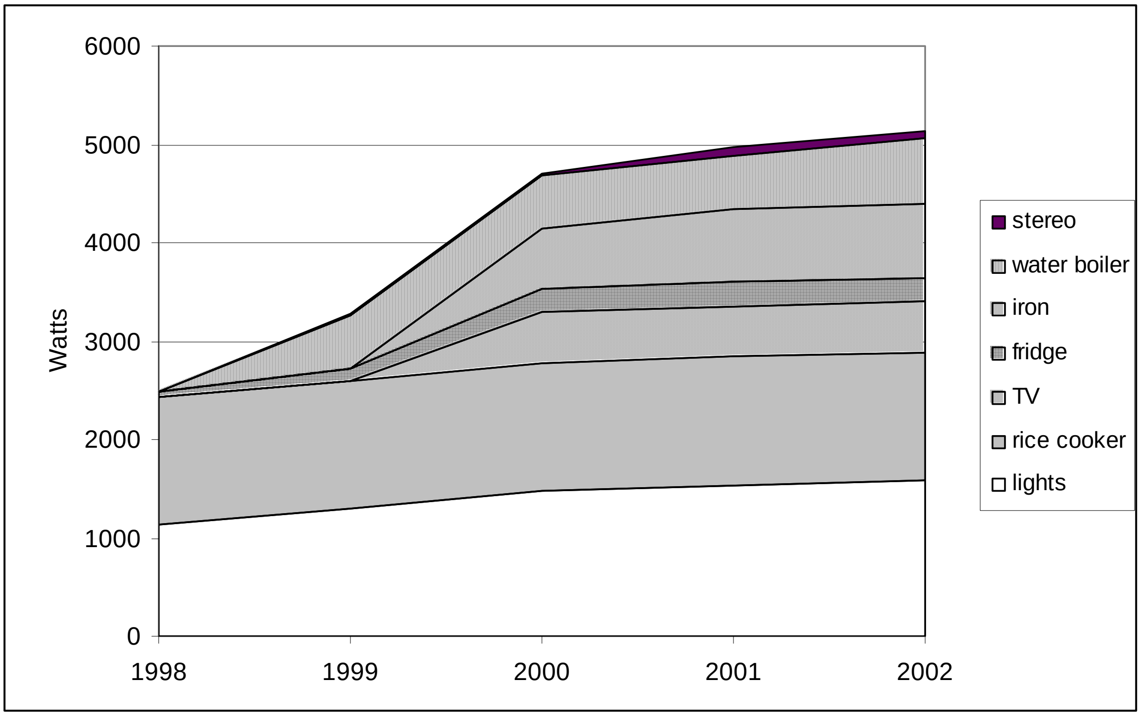

Figure 21: Yearly growth in peak evening time electricity use in households sampled in Huai Bu village, broken down by appliance type.

As in Mae Kam Pong, appliance ownership and use patterns ranged widely, from households with only a single lightbulb used two hours a day, to households with lights, TV and video disk, electric frying pan, rice cooker, and water boiler. Indeed, the spread in the customers surveyed in Huai Bu was even more extreme than at Mae Kam Pong (Figure 22). One single customer, the school including living quarters for several resident teachers, accounts for over 2.7 kW (over 62%) of the total evening peak load -- far exceeding the next highest consumer, a household that used 260 watts. It is worth noting that none of these teachers are not original residents of Huai Bu. In the Thai education system, teachers from regional teacher training institutes are assigned to postings in villages. As is the case in Mae Kam Pong, the highest consumers of electricity are outsiders who brought appliances and expectations from grid-electrified areas. Unfortunately for the Huai Bu micro-hydro cooperative, the school does not have to pay for the electricity. Eight of the lowest consuming customers did not even contribute to the 6pm load, as they stated that they did not turn lights on until 7pm.

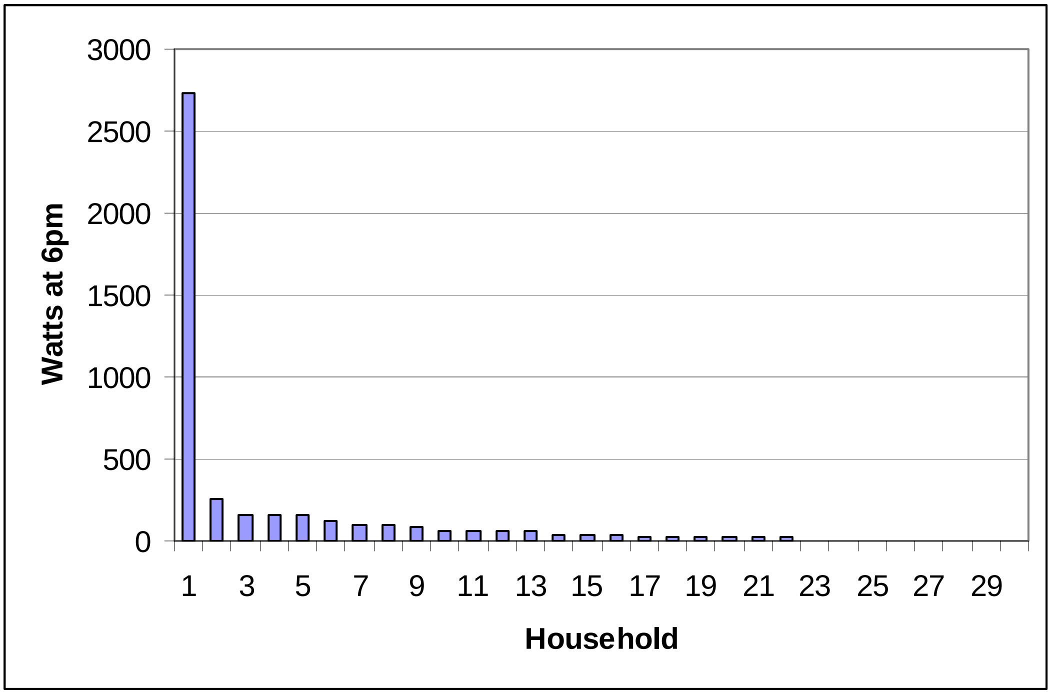

Figure 22: Contribution to peak consumption by each of 30 households surveyed in Huai Bu.

Rules governing behavior

Datalogging and interviews discussed above point to collective over-consumption and ultimately user behavior as a key factor in low voltages. Micro-hydroelectric generators have limited yields, but it is difficult to exclude individual users from using too much at a given time. For systems such as these to be sustainable one of the insights from common pool resource literature is that the rules governing user behavior – such as the tariffs -- have to match the technical characteristics of the system. Tariff arrangements in most micro-hydroelectric systems in Thailand are a perfect example of a mismatch.

Of surveyed villages, 54 provided information about the type of tariff charged. In a majority of cases (38 villages including Mae Kam Pong) households are metered on standard kWh meters (Figure 23) that measure consumption with a dial that spins around and numbers that indicate how many units (kWh) of electricity were consumed by the customer in a month.

But while the micro-hydroelectric plant can generate plenty of energy in a 24 hour period, the plant is peak-limited. In fact, power not consumed is "thrown away" at the powerhouse in an electric ballast load that dissipates excess electricity by heating water. Tariff arrangements in micro-hydro systems should not be concerned with monthly cumulative consumption (kWh) – they should be concerned with maximum rate of consumption (kW) at any instant.

Figure 23: Left: kWh meter used in Thai micro-hydro systems. Right: Miniature circuit breaker used as an over-current cutout.

In nine of the systems (including Huai Bu), an even worse arrangement is or was used. Rather than using meters, each customer[23] is charged a yearly usage fee without restrictions on consumption. This arrangement, like an all-you-can eat buffet, does little to encourage moderation. The results, in the case of Huai Bu, have been severe. Growing at a rate of over 12% per year, within four years, power demand exceeded supply in peak usage times in both morning and evening.

The most appropriate tariff arrangement in Thailand is used in the fewest number of villages. In 8 of the 54 cases, the tariff depends on the number and type of lights and appliances owned by each household. Households pay, for example, 10 baht per month per 20 watt light fixture, and additional amounts for TVs and other appliances. Though difficult to enforce, this method matches the "peak limited" characteristic of micro-hydroelectricity by providing incentives for households to own and use fewer lights and appliances.

Perhaps the best possible arrangement is one not used at all in Thailand, but is common in Nepal and other countries. This arrangement is like the appliance-based tariff mentioned above, but is more enforceable. In this "peak power tariff", electricity service to each house is provided through over-current cutout devices such as mini-circuit breakers (Figure 23) or positive temperature coefficient (PTC) devices. Electricity is offered on a subscription basis. Small customers might get a 1/2 ampere cutout and pay 30 baht per month. Bigger ones pay twice (or more than twice)[24] as much for 1 ampere

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[23] Some customers such as schools or temples are often exempted from any charges.

[24] In Nepal it is common to build in a progressive tariff structure so that a 1 ampere service costs more than twice as much as a ½ amp service. This arrangement provides "lifeline" service to poorer customers, subsidized by wealthier ones.

service. People can use as much electricity as they would like as long as the amount in any instant does not exceed the current limit of the cutout. If they consume too much at any one time the cutout opens and they have to turn off appliances before they can restore power to their house. Though customers pay monthly bills based on the capacity of the overcurrent cutout, the "metering arrangement" has no meters.

By limiting the number of appliances that can be concurrently operated in each household, these devices would decrease the village evening time peak load. Reducing the evening peak load would, in turn, reduce the low voltage problems and over-load related equipment failures that plague most projects.

Installing miniature circuit breakers would be inexpensive. The breakers themselves cost 40 baht ($1) each. By comparison, the low-quality Chinese kilowatt-hour meters that they would replace cost 400 to 500 baht ($10 to $12.50) per unit. More accurate electronic overcurrent cutouts can also be procured cheaply. The CEO of a Thai electronic company, Leonics Ltd. said his company could design and manufacture these for 200 baht (about $5) each in quantities of 100.

Mae Kam Pong and Huai Bu villages illustrate common patterns: with the availability of electricity, customers steadily increase loads, ultimately exceeding generator capacity. The consequences are noticeable every night: dim lights or, all too frequently, no lights at all and a long wait for repairs.

In Huai Bu and Mae Kam Pong, electrical production is limited by the (over-rated) production capability of the generator. But in some cases, *water availability* limits power production even further.

Water availability

Because run of the river micro-hydroelectric systems as built in Thailand have at most only hours of reservoir storage, a consistent year-round water supply is essential. Water availability is an important contributing factor to the decisions of seven communities to give up community micro-hydro plants, and remains a significant issue for communities that still have operational projects.

The majority of villages have water sufficient for micro-hydroelectric generation throughout the year (Table 5). However a significant minority of villages – 12 with abandoned projects and 8 with operational projects – claimed that dry season flows were inadequate to produce required electricity. In addition, three villages (two with abandoned projects, one without) claimed inadequate water year-round.

Installation status	**Water availability**	**Number of projects**
Abandoned	Water is available all year	19
	dry season not enough to generate	12
	Often not enough to generate	2
In operation	Water is available all year	16
	dry season not enough to generate	8
	Often not enough to generate	1

Table 5: Water availability in abandoned and operational micro-hydroelectric sites.

<u>Potential causes of inadequate water supply</u>

Apparent lack of adequate water can be attributed to inadequate surveys and streamflow estimates during project design, changing watershed conditions, water conflicts, or other factors.

Inaccurate streamflow estimates

Project designers may have failed to adequately estimate water flows. Designers of micro-hydroelectric systems in the United States have the luxury of relying on historic streamflow data collected at 19,000 sites by the US Geological Survey – often providing data for the stream in question, or at least a nearby stream allowing fairly reliable correlation techniques to be used (Waanen and Crippen 1977). In contrast, stream gauges are rare in rural Thailand and longterm flow records are generally not available for any of the village locations chosen as installation sites. The DEDE instead relies on a less reliable method based on catchment area, annual rainfall estimates, and assumptions about run-off coefficients (Panya Consultants Co. 1993). Even for large dams in Thailand, predictions of water availability have turned frequently turned out to be wildly optimistic[25] (McCully 1996).

Changes in watershed reduce flows

Assuming that water availability was originally adequate, changes in land-use practices in the watershed above the project may render the streamflow insufficient, particularly during the dry season if the water-holding capacity of the vegetation and soil are reduced by agriculture or logging (Chow, Maidment et al. 1988). Public outcry following drought and a tragic series of flash-floods in 1989 prompted the enactment of a nationwide ban on commercial logging. However, enforcement of this ban has been mixed (Bellow 1998). Hilltribe villagers in northern Thailand have also been encouraged to grow temperate vegetable crops such as cabbages, in an effort to reduce poppy

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[25] Thailand's 25 largest dams held a total of just under half of their combined usable capacity in 1991, and just over one-third in 1992. The reservoirs of Bhumibhol

production and drug trading. These practices require clearing and tilling of steep highland areas, and irrigation, all of which have considerable downstream impacts.

Agricultural uses reduce water available for micro-hydro

Increasing agricultural uses of water, if drawn from the stream at a location above the inlet for the hydropower project, can also contribute to reduced water availability. Although the intake location was not specified, 48 of 59 villages irrigate fields using water from the stream on which the micro-hydroelectric plant was built. And 12 villages used water for domestic purposes.

In many cases, irrigation, domestic water consumption, and micro-hydro co-exist peacefully. The same water is used for both electricity generation and irrigation, passing first through the micro-hydro generator before returning to the stream for subsequent domestic or agricultural use.

There are instances, however, where agriculture and micro-hydro have not existed peacefully. These are discussed below in the section on water conflicts.

Apparent water shortage may be misdiagnosis in some cases

In some cases, the assessment made by power house operators that water supplies are inadequate for electricity generation may, in fact, be wrong. Villagers intuitively associate low voltages (dim lights) with insufficient water, so it may be that in cases when the voltage is low (for reasons other than water supply) villagers naturally assume that the problem is insufficient water. Power generation may appear inadequate because consumption is too high, power factor is too low, pipes are clogged with sand, or a host

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and Sirikit (the second- and third-largest reservoirs in Thailand) contained only 7 percent of their total usable volume in March 1994.

of other reasons that might appear at first glance to be the result of inadequate water. Surprisingly, when asked to characterize the flow of water in the stream, 22 villages reported “very strong”, 26 reported “medium strong” and only 4 reported “weak”. When asked about the abundance of rain in their area, 40 responded “abundant” and 14 responded “medium”. None characterized their area as dry.

Water conflicts

Water conflicts between villages have shut down at least one project, and affected others. One village, Mae La Noi, in Mae Hong Song province, reported the primary reason for abandoning their project was a water conflict between their village and a group that had cleared land and diverted water flows for agriculture. A similar conflict was reported in Huai Bu village, Chiang Mai province where villagers complain that another group cleared land in the upper watershed and pumped from the stream to grow cabbages. These activities caused increased flooding, as well as sediment and branches clogging the intake in the wet season, and lower dry season flows. The water conflict has not yet forced the plant in Huai Bu to cease operation.

In these two cases the conflicts over water have ethnic dimensions. In both cases the micro-hydroelectric project was operated by Karen tribespeople, and those using the watershed above them were Mong. The Mong have participated enthusiastically in Thai government campaigns encouraging commercial production of highland temperate climate vegetables as part of an opium poppy reduction program. Karen complain that the Mong are less concerned about protecting the environment and more interested in business than the Karen (Interview 2002.10).

Intra-village water conflicts involving the micro-hydro plant have also occurred. Sometimes these are relatively minor and easily resolved, as in the village of Huai Bu when an operator error caused a pipe to become uncoupled, damaging fields of one farmer. The conflict was resolved when micro-hydroelectric committee agreed to compensate the farmer for the loss of his crops (Interview 2001.25).

A much more difficult and long-running intra-village water conflict happened in Mae Lan Kam, a Karen village in Samoeng district, Chiang Mai.

Mae Lan Kam: hijacked micro-hydro and the ensuing water conflict

The roots of the Mae Lan Kam water conflict lie in a long-running land-use conflict between the predominantly Karen villagers and the Thai Royal Forestry Department (RFD) which has a Headwater Management Office nearby the village. The villagers are subsistence farmers and have traditionally relied on the forest for a variety of non-timber forest products. Certain areas of the forest have been used as well for rotational agriculture – which involves cutting and burning plots roughly every 10 to 12 years, growing upland rice, and then leaving the land fallow until the forest grows back sufficiently and the soil is rejuvenated.

The RFD has blamed traditional rotational farming as the cause of considerable damage to forests throughout Thailand. The RFD has gone on to designate many areas as “conservation forest”. These areas are closed to all uses including traditional forest uses. Villagers complain that areas which they have traditionally used to practice shifting agriculture are progressively being claimed as "conservation forest" denying them the productive resources that their communities had previously relied on for survival, and forcing a greater frequency of rotation among their existing plots which degrades the soil.

The Mae Lan Kam community responded by erecting their own signs designating various areas as “community forest” and specifying the activities that were allowed and not allowed.

The micro-hydro project in this village, built in 1995 with village labor, originally provided electricity for the whole village as well as the Forestry Department offices. When electricity from PEA arrived in 1998 many of the villagers connected to PEA, but the Royal Forestry Department was not eligible for a subsidized PEA connection. Faced with expensive alternatives of a 100,000 baht ($2,500) PEA hook-up fee[26] on the one hand, and the high price of diesel generation on the other, the RFD determined that the micro-hydroelectric project was their least expensive option. They took possession of the micro-hydro, arguing that this was their right because they had paid to fix the machine at times when it was broken and villagers could not afford to fix it (Interview 2001.22).

Operation of the micro-hydroelectric plant by the RFD added fuel to the existing conflict with the village. Thirty *rai* (about 12 acres or 4.8 hectares) of fields used by nine families are fed by an irrigation ditch with an intake located in the section of river that is bypassed by the micro-hydro pipe. Villagers complained that the Forestry Department operated the micro-hydro in a manner that violated a Forestry Department promise not to affect agricultural uses of water for these fields at the beginning of rice planting season. Villagers further complained that the Forestry Department’s operation of the micro-hydro caused reduction in populations of edible fish, insects, and frogs in the stream.

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[26] PEA’s rural electrification program receives government money to provide rural electrification to remote villagers, and not other uses. The high charge for a RFD hookup may be linked, as well, to conflict between the PEA and the RFD. The RFD has denied PEA right-of -way for distribution line extensions through protected forest.

Villagers from Mae Lan Kam, and nearby villages of Sop Lan, Haui Ya Saai wrote a formal letter asking the Director General of DEDE to “to please remove generator and install it in another village that would like to use it.” The forestry conflict intensified further and several months later the RFD Headwater Management office was burned down.

Flooding and landslides

Because some equipment is located, by necessity, on or near the banks of the streams, flooding and landslides caused by floods are a concern. In three villages substantial damage was attributed to floods or landslides, which broke pipes and in one case caused a short circuit in a transformer. Heavy rain is, of course, the proximate cause of flooding. But human activity plays an important role, especially logging and clearing land for agriculture in the watershed above the generator. Based on systems I have seen in the field, failure may also be attributed to optimistic placement of headrace or penstock pipe on unstable slopes.

Summary and Conclusions

Thailand’s two-decades of micro-hydro experience been mixed. On the one hand, many villages are proud of having built their own clean energy power plant, and see the project as a source of local income as well as inexpensive electricity. The project cooperatives have generally been profitable, and have served as valuable foundation for micro-credit funds as well. On the other hand, many systems are abandoned when the national grid arrives. One of the main frustrations for villages that rely on micro-hydro is endemic low eveningtime voltages, blamed for broken TVs, motors, and other appliances. Micro-hydro equipment breakages cause considerable periods with no electricity. One challenge these projects face is that equipment often fails to meet specifications or to protect itself from overload. Another problem is collective consumption of electricity that exceeds the capability of the power plant, particularly during peak evening hours. Increasing loads are particularly the result of growth in the use of non-essential electrical heating appliances (rice cookers, electric thermoses) by a minority of users. Weak equipment and over-consumption together create a pernicious combination in which sub-standard power quality is the norm rather than the exception, and breakage is common.

Low voltages ultimately reflect a mismatch between the micro-hydroelectric system and the rules governing its use. A change from kWh meters to over-current cutouts and subscription-based electricity service would help align the tariffs with the peak-limited characteristic of the micro-hydro resource. In addition, low water flows or water conflicts are important barriers in several projects.

Overall it is clear that in most cases communities with micro-hydroelectric systems are willing and able to make their systems work – unless they have the opportunity to switch to the (heavily subsidized, comparatively hassle-free) national grid. The next chapter considers the economics of these arrangements from the perspective of costs borne by villagers as well as those borne by the Thai public.

Chapter 4: Microeconomics of rural electrification infrastructure investment: micro-hydro and the grid

This chapter explores the role of micro-hydro in the economic optimization of rural electrification. It investigates benefits and costs of options, with particular focus on two perspectives: costs borne by the Thai public and costs borne by villagers. The chapter begins by framing the rural electrification technology dilemma from the perspective of a social welfare maximizing planner. Subsequently, the chapter discusses and attempts to calculate relative benefits of grid and micro-hydroelectricity, particularly those related to power quality. The chapter then develops a simple formula, based on empirical Thai data, to determine spatial/demographic conditions under which micro-hydroelectricity may be economically optimal. A related analysis considers the relative costs of micro-hydro and the grid in the electrification of 20 villages currently served by micro-hydro. The chapter considers implications of the opportunity to connect micro-hydro generators to the grid, including a basic financial assessment of 27 projects.

The rural electrification dilemma: what villages, when, with what technologies

A social welfare maximizing rural electrification planner facing decisions of what villages to electrify, when, and with what technologies faces a difficult task involving decisions with large consequences. When and where should the grid expand? And where and when should stand-alone options like micro-hydro be employed? Recognizing that village loads grow and micro-hydro may be a stop-gap measure, where and when does it make sense to build micro-hydro to be used first as a stand-alone technology? Where does it make sense to ask a particular village to wait until others are served first? Overall, *what is the economically optimal path for providing electricity to unelectrified villages?*

Social welfare theory suggests the answer can be found through an analysis that considers that net present value of the economic benefits to villagers minus costs of each possible investment alternative and selects the option with the highest value. In practice such a precise analysis of this kind is improbably difficult, as it requires discounted assessments of future benefits and costs that are difficult to predict with precision. More fundamentally, the decision of a planner to electrify a particular village changes the history of that village and of the surrounding area, and with it the trajectory of future demand. The optimization problem is compounded when both the grid and microhydroelectricity options are available, and when the micro-hydro has the characteristic that power quality (and hence benefits to villagers) may decrease substantially over the lifetime of the equipment if consumption grows beyond the limits of the capacity of the facility. A further complicating factor is that distance to the grid may change over time as the distribution network expands.

Faced with these circumstances, rural electrification planners must rely on models that make simplifying assumptions or bracket analyses in ways that allow them to ignore certain variables. The following section develops a model based on empirical Thai data that calculates conditions under which micro-hydroelectricity is likely to be an economically optimal investment compared with grid electrification. To compare the two investment options, it is necessary to consider both benefits and costs. The section below discusses the relative benefits of micro-hydro and grid electrification, followed by cost analysis of the two technology choices.

Valuing relative benefits of grid and micro-hydro: the economics of rural power quality

The micro-economics of power quality in the village context can be addressed in two ways: first, a calculation of the economic losses[27] incurred from low power quality; and second, an assessment of the costs of mitigation measures to address load growth given the options available to micro-hydro villages.

Economic losses from low power quality

There are three types of economic losses from low power quality, all of which may occur in a given village: losses from blackouts, losses from brownouts, and losses from foregone appliance use even when power is functioning.

<u>Losses from blackouts</u>: Power sector economists calculate losses from blackouts by determining the economic Value of Lost Load (VOLL) and multiplying this by the Loss of Load Probability (LOLP) in a given service area. The VOLL represents the economic losses from a power outage, whereas the LOLP represents the probability of a power outage. A study commission by the Thai Government conducted by the Energy Research Institute (2001) at Chulalongkorn University determined economic losses from power outages for Thai commercial, industrial and residential customers. Based on over

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[27] Though these calculations focus on the relative economic losses from absence of power or poor quality power, this should be seen in a seen in light of the economic benefits provided by electrification. The benefits from Thai rural electrification have been assessed in a thorough study conducted by the Thailand Development Research Institute (Poapongsakorn et. al 1995). The study concluded that economic benefits far exceeded economic costs, so that rural electrification had an IRR of 17%. The study found that economic benefits per household were between 55,600 and 67,900 baht ($2200 to $2700 in 1995 dollars). The study focused only on grid electrification and did not include micro-hydro.

2000 responses to a survey, the study calculated that for residential customers, power outages caused damages equal to 38.52 to 73.65 baht per kWh ($0.96 to $1.84 per kWh).

Considering that frequent blackouts were reported by respondents from 41 out of 58 micro-hydro villages, and considering that the LOLP of two villages datalogged over 3 months in chapter 3 were 9% (Mae Kam Pong) and 31% (Huai Bu) respectively, economic losses assessed using the Chulalongkorn results would be considerable. Each household uses roughly 1 kW per day, implying economic damage of approximately $30 to $60 per household per year in the case of 9% LOLP. Considering that the average micro-hydro village has 220 households, this is equal to a damage cost to the village of $6900 to $13,300 per year. Assuming a discount rate of 7% and a 10 year timeframe, the NPV of this damage cost estimate is $49,000 to $93,000. In the case of 31% LOLP, the damage to the village has a NPV of $168,000 to $322,000.

It is not clear what the LOLP for grid electricity is in these remote areas, though as noted in chapter 3, risk of blackouts from PEA is also substantial for these remote villages. Respondents from 35 out of 40 villages (87.5%) with PEA power complained of frequent blackouts on the PEA grid. Given high reports of blackouts from PEA power, it is possible that economic loss from blackouts on the PEA grid is comparable with those from micro-hydropower.

Outage criteria for cost assessment included damages from lost salary, lost profit opportunity, lost overtime payments, lost raw material, damaged equipment and costs of restarting processes. While the criteria for outages cost assessment makes sense for commercial and industrial customers, it is not clear from the study how these are applied in the residential case.

Arguments could also be made that since most households connected to micro-hydro projects (or most remote households for that matter (MacDonald 1984)) do not use electricity for productive uses, economic losses from blackouts are considerably smaller than the Energy Research Institute study would suggest.

Losses from brownouts: Economic losses from brownouts (low voltages) can be assessed through equipment damage costs. In appliance use surveys of micro-hydro villages, questions about appliance breakage from low voltages were not asked. However, the fact that few people volunteered information about the problem in the course of the survey or in informal discussions suggests that in many cases villagers have adapted to low voltages.

Losses from foregone appliance use: even in cases in which power appears to be functioning well, users may forego purchase or use of certain appliances at certain times because of social norms or other factors. This cost could be assessed through willingness-to-accept or willingness-to-pay surveys, but at this time data is not available.

Cost of restoring low power quality

Several options are available to mitigate power quality problems in micro-hydro villages:

Over current cutouts: as described in Chapter 3, these devices limit the peak consumption of each customer. If villagers are willing to allow them to be installed, the price is quite inexpensive: miniature circuit breakers cost $1 each, while accurate electronic overcurrent cutouts cost $5 each in quantities of 100. Adding $2 for installation materials and labor, and total cost per household would be $3 to $7. The cost for a typical micro-hydro village of 220 households would be $660 to $1540. Operations and maintenance costs are expected to be negligible. The option imposes an additional cost on villagers in the form of a cost of foregone appliance use: using a rice cooker, watch TV, and using lights all at the same time may no longer be possible. However, indications from one village in Uganda in which this approach has been tried indicates that villagers were very satisfied with the change overall, suggesting that that the improved power quality experienced by all is worth the costs imposed by shifting appliance use (N P A Smith et al 2003).

Generator-interactive inverter/charger: This technology allows electricity to be stored during batteries during off-peak periods for use to complement micro-hydro output during peak periods. The installed technology cost is approximately $3,000 to $5,000 per kilowatt capacity, and is a lumpy investment in the sense that investments must be made in large increments (Interview 2004.07). A 20 kW inverter/charger to supplement a 35 kW microhydro system might cost $60,000 to $100,000 – an amount comparable to the original installation cost of the micro-hydro facility.

Other options of a similar nature include building another micro-hydro generator on the same stream (if a site is available), or a diesel-generator (likely to be more expensive than inverter in the long run because of fuel costs) (Interview 2004.07). Another attractive option is synchronization and interconnection with the grid, addressed at the end of this chapter.

Comparing damages and mitigation costs

Results from the various methods of calculating economic losses from low power quality are summarized in Table 6 below. In comparing the results, the most noticeable factor is the extreme variability in costs. Estimations of the net economic damage, as estimated either from damages or from mitigation costs, vary from negligible to $100,000 per village. Moreover the LOLP for remote grid service is not known, though it is suspected to be significant but smaller than the LOLP for micro-hydro.

The high variability in these assessments of relative benefits suggests that in developing a pragmatic assessment of optimal investment in micro-hydro it is more meaningful to find other ways to control for variations in power quality, such as limiting the analysis to a timeframe in which power quality of micro-hydro and the grid are expected to be comparable. Comparisons can then be made on the basis of comparative costs to provide electricity service, and can be adjusted to incorporate benefits (especially the value of power quality) afterwards if necessary.

Assessment type	**Power quality issue**	**Method**	**Value**	**10 year NPV village cost**
Damage cost	Blackouts	EOLL / VOLL	Negligible to $1.84/kWh	Small to $100,000s
	Brownouts	Appliance damage	Unknown but presumed small	Unknown but presumed small
	Foregone appliance use	Willingness to pay or accept	Unknown but presumed small	Unknown but presumed small
Mitigation cost	Blackouts, brownouts	Overcurrent cutouts	$5 to $7 per household + foregone appliance use	$660 to $1540 + foregone appliance use
		Inverter	$3000 to $5000 per kW	$60,000 to $100,000

Table 6: Summary of estimations of economic losses from low power quality.

Distance vs. number of households

In what circumstances is micro-hydroelectricity likely to be an economic investment? Given the fixed cost per kilometer to extend the grid, one would expect that the grid would be most viable for large communities close to the existing network, whereas micro-hydro would tend to be more economically viable for smaller villages, far from the grid. This section uses empirical data from Thailand to develop a mathematical relationship between distance from the grid and numbers of households economically served with micro-hydro.

Averaging over cost variations due to site conditions, costs for micro-hydroelectricity are primarily a function of capacity of the generator. Capacity of the generator, in turn, determines the number of households served. Thus the present value of micro-hydro cost (on average) can be reduced to a function of the number of households served.

The present value of the cost of serving customers with the grid is primarily a function of two variables: the distance the grid must be extended and the present value of the capital, labor and fuel requirements to generate electricity and deliver it to the rural area.

By setting present value of micro-hydro costs equal to present value of grid-extension costs, the two cost calculations represent two linear equations in two unknowns, and thus can be solved algebraically to express households served as a function of distance from the grid.

Recognizing that power quality problems do evolve (and thus relative benefits between grid and micro-hydro diverge) in many projects as consumption ultimately exceeds generation capacity, this analysis is bracketed by considering a time-span over which power quality between the two technologies can be considered equal. In practical terms, this means calculating present value of costs over 10 years. Justification for 10 years is offered by considering that average age of 25 micro-hydro projects that remain in operation is 14.8 years, and one project has been operating 23 years, suggesting that in many cases load growth may not overwhelm generation within a decade, or at least that villagers do not experience power quality problems as sufficient cause to abandon the unit. Equipment life, however, is assumed to be 25 years (as is the convention in both PEA and government documents). Thus the analysis uses a linear depreciation method, and calculates the present worth as the capital cost minus the discounted salvage value (Swisher et al 1997).

Grid electrification costs are derived from grid extension cost estimates used by PEA for the north region (Interview 2004.8), costs commonly used by government and utility planners for marginal generation addition (Interview 2004.10), and estimates of transmission and fuel costs calculated in a comprehensive study commissioned by the Thai National Energy Policy Office (PriceWaterhouseCoopers 2000). Micro-hydro costs are based on project cost data for each of the 20 villages analyzed (Panya Consultants Co. 1993), interviews with village chiefs (for labor and O&M costs), and government studies. All estimates involving past costs use inflation-adjusted exchange rates. Present and future costs assume an exchange rate of 40 baht per $US. Present value calculations of annual expenditures assume a real discount rate of 7%, as assumed in contemporary power sector studies commissioned by NEPO (PriceWaterhouseCoopers 2000, Annex J, page 7).

Model inputs: grid extension costs

Providing rural electrification through grid extension can be broken down into five cost categories:

- Capital costs of increasing generation capacity in order to meet increased demand caused by the grid extension.
- Operation and maintenance costs for the increased generation capacity.
- Fuel costs of generating electricity for the new customers served by the grid extension.
- Capital costs of extending the transmission and distribution system.
- Operation and maintenance of the newly expanded transmission and distribution system.

Costs for providing 10 years of electricity to one typical household via grid extension are detailed in Table 7 below.

Item	*Amount*	*Cost*
Peak load per household (kW) [28]	0.2	
Cost per peak kW in increased generation[29]	$ 600	
Contribution of household to system peak (kW) [30]	.085	
% loss (peak, from generation to LV in PEA north region) [31]	17.9%	
Peak load from household (kW) observed at generator	.103	
Present value of increase in generation capacity		$62
Annual generation maintenance cost[32]	1%	
Present value of maintenance cost of generation over project life		$4
Electricity consumption (kWh/day) [33]	1.16	
Fuel cost per kWh ($)[34]	$0.033	
% loss (average of peak and off-peak from generation to LV in PEA north region) [35]	15.0%	
Average electricity use (kWh/day) including losses	1.4	
Present value of fuel costs over project life		$114
Present value of generation costs		**$180**

Table 7: Present value of generation costs per household in case of grid extension

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[28] Remote households have an average peak demand of 0.2 kW, according to a PEA division chief who works on remote electrification (Interview 2001.05). Average rural residential customers use 0.3 kW peak. This data is consistent with average rated capacity per household for micro-hydroelectric projects of 0.23 kW (averaged over 42 projects). Average peak demand per household in Mae Kam Pong village is 0.185 kW.

[29] For planning purposes at both EPPO and EGAT, the marginal cost of generation capacity is $600 per kW. This represents the current costs of combined cycle gas turbines, including a planned reserve margin of 20% (Interview 2004.10)

[30] Rural peak occurs in the evening and is not coincident with the system peak, which occurs at 2pm. Using the ratio of 2pm consumption (1230 kW) to peak consumption (2901 kW) from the PEA (2003) Residential Load Curve implies that contribution of 0.085 kW to the generation system peak load.

[31] Average losses in PEA north region (PriceWaterhouseCoopers 2000, page 54 table 6.3 and page 56 table 6.5). Losses are likely considerably higher for remote villages.

[32] (PriceWaterhouseCoopers 2000 page 57. Table 6.6.)

[33] 2.9 million of PEA's 10.2 million residential customers use 35 kWh per month or less of power. This corresponds to a daily use of 1.16 kWh. It is expected that the average remote village user would fit into this category (PEA 2000). This is commensurate with the 1.16 kWh/day average consumption in 2001 from Mae Kam Pong village survey.

[34] Estimate from NEPO for 2002 (Interview 2002.11). To simplify the analysis, future fuel costs are assumed to remain constant. Increases are likely, however, and would shift economics in favor of micro-hydro.

[35] Average losses in PEA north region (PriceWaterhouseCoopers 2000) page 54 table 6.3 and page 56 Table 6.5. Losses are likely considerably higher for remote villages.

Item	*Amount*	*Cost*
Cost per kW per year for transmission capacity (from generator to exit of 115/69 kV system) [36]	$ 706	
% loss (peak, from exit of 500:230 kV system to LV in PEA north region) [37]	14.4%	
Peak load (kW) per household observed at transmission system	0.10	
Present value of transmission costs		**$70**

Table 8: Present value of transmission costs per household in case of grid extension

Item	*Amount*	*Cost*
Distribution extension capital cost (per km)[38]	$7593	
Annual distribution maintenance cost (as % of capital cost) [39]	1%	
Present value of distribution maintenance over project life (per km)	$533	
Discounted salvage value of distribution extension (per km)	$(2316)	
Present value of distribution system extension cost (per km)		**$5810**

Table 9: Present value of distribution (grid) extension costs per household in case of grid extension

Item	*Cost per household*	*Cost per km*
Present value of generation costs	**$180**	
Present value of transmission costs	**$70**	
Present value of distribution extension cost		**$5810**

Table 10: Summary table of present value of distribution (grid) extension costs per household and per km in case of grid extension

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[36] (PriceWaterhouseCoopers 2000, Annex K, page 27 Table K-14). This table presents annualized costs, which were converted to their present value using assumptions listed in the study (evaluated over 10 years with discount rate = 7%).

[37] Average losses in PEA north region (PriceWaterhouseCoopers 2000, page 54 table 6.1)

[38] (Interview 2004.08)

[39] (McDonald 1984)

Model inputs: Micro-hydro costs

The cost of electrification using village scale micro-hydroelectricity comprises:

- Capital costs of building the micro-hydro project (including the local distribution system)
- Labor costs of building the micro-hydro project
- Operation and maintenance costs of the micro-hydro project

Capital cost data for micro-hydro projects as a function of generator size was derived from cost estimates for six different sizes of generators ranging from 20 kW to 100 kW presented in a study on renewable energy by Energy for Environment (2004). The capital cost estimates for micro-hydro were adjusted by a factor of 1.4 to reflect the over-rated capacity of micro-hydro generators observed in the field (Chapter 3). Present value of the six micro-hydro generators were then calculated using linear depreciation and incorporating labor and O&M costs based on project size. As was assumed in the grid cost calculations, each rural household consumes 0.2 kW peak power.

This data was then plotted and a least squares linear fit was calculated, as shown below in Figure 24.

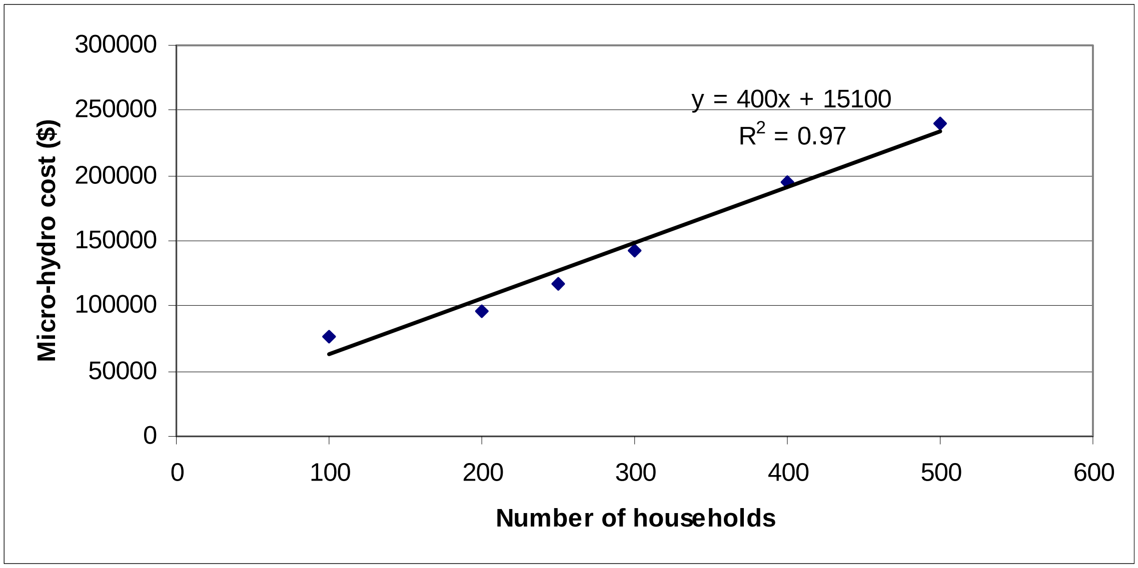

Figure 24: Graph of micro-hydro cost as a function of number of households.

Model results

Final derivation of the relationship between households economically served by microhydro and distance from the grid is as follows:

$$\text{Cost of microhydro} = 400H + 15100 \qquad (4\text{-}1)$$

$$\text{Cost of grid} = 5810D + (180+70)H \qquad (4\text{-}2)$$

Where H is the number of households and D is the distance in km. The numerical values in (4-1) are the equation for the linear fit line in Figure 24, while the numerical values in (4-2) are from Table 10. Setting *Cost of micro-hydro* < *Cost of grid* and solving for H, we have:

$$H < 39\,D - 100 \qquad (4\text{-}3)$$

The equation is presented in graphical form in Figure 25. The interpretation is straightforward: micro-hydro power makes sense for a village of about 100 households at distances above 5 km, and for a village of 300 households at distances exceeding 10 km.

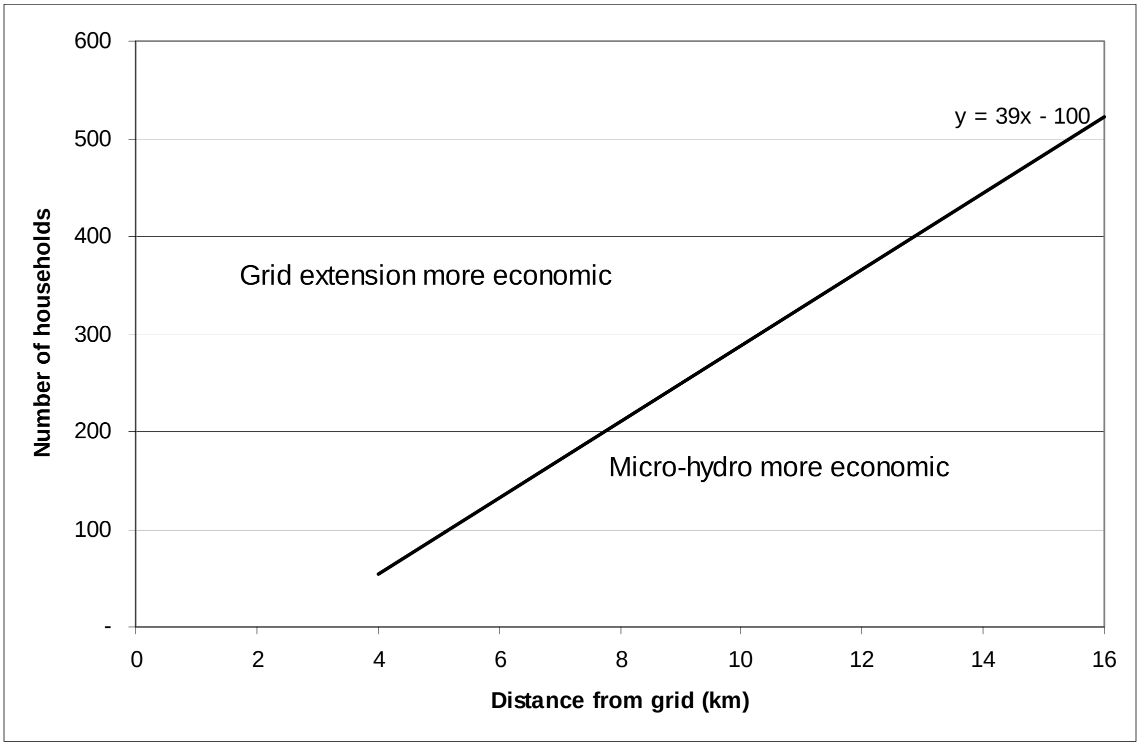

Figure 25: Number of households economically served by micro-hydro as a function of distance from the grid

A sensitivity analysis on the timeframe of the analysis (Figure 26) indicates that using NPV calculations of 25 years makes micro-hydro appear more viable, especially for larger projects. But the effect is not huge: a project for 200 villages that was viable at 7.5 km under a 10 year analysis becomes viable at 6 km when the analysis is extended to 25 years. Reducing the timeframe of the analysis to 5 years has little effect.

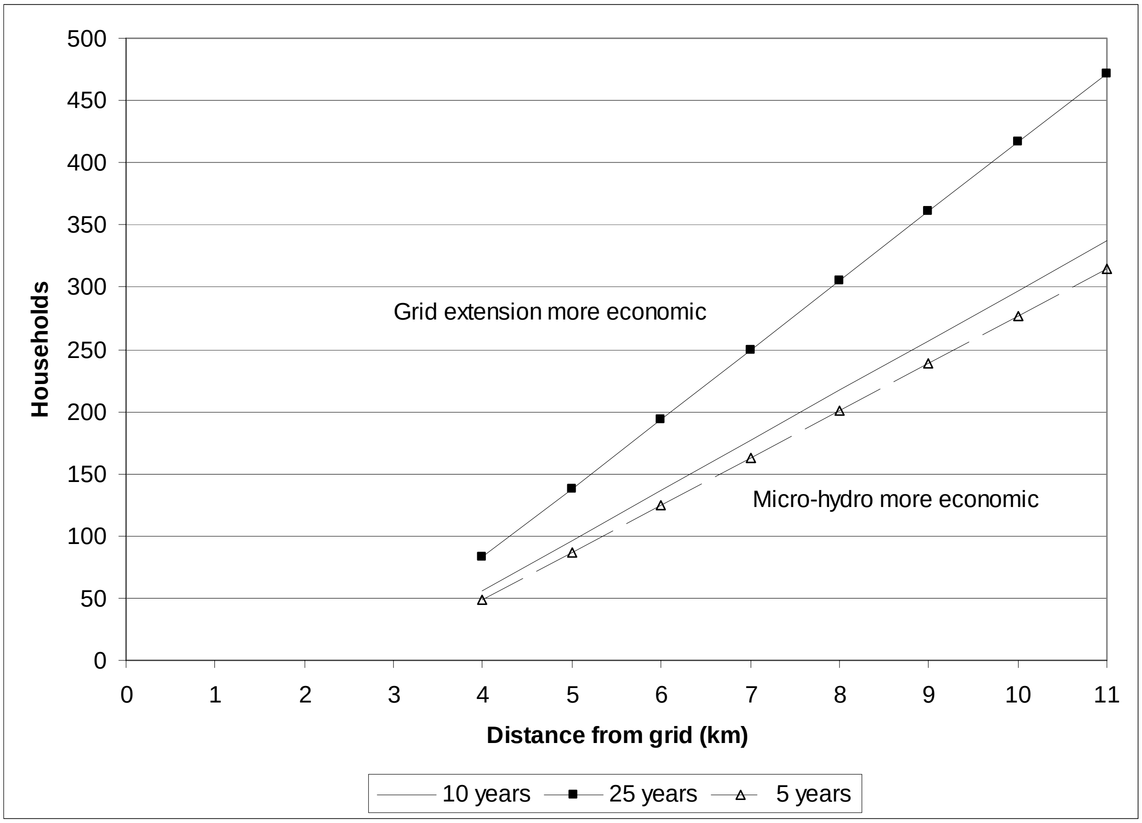

Figure 26: Sensitivity analysis on evaluation period.

Sensitivity to discount rates is shown below in Figure 27. Decreasing the discount rate to 5% increases the relative viability of micro-hydro: a microhydro project for 200 households that was economic at 7.5 km becomes economic at about 6 km. But at 9% a village with 200 households is only suitable for micro-hydropower if it is 9 km or further from the grid.

This result reflects the relatively higher proportion of fixed costs relative to variable costs in micro-hydro projects. Whereas variable costs in a micro-hydro facility consist of only O&M costs, grid extension annual variable costs include both fuel costs and O&M. By discounting future payments, higher discount rates favor the technology with a higher portion of variable costs.[40]

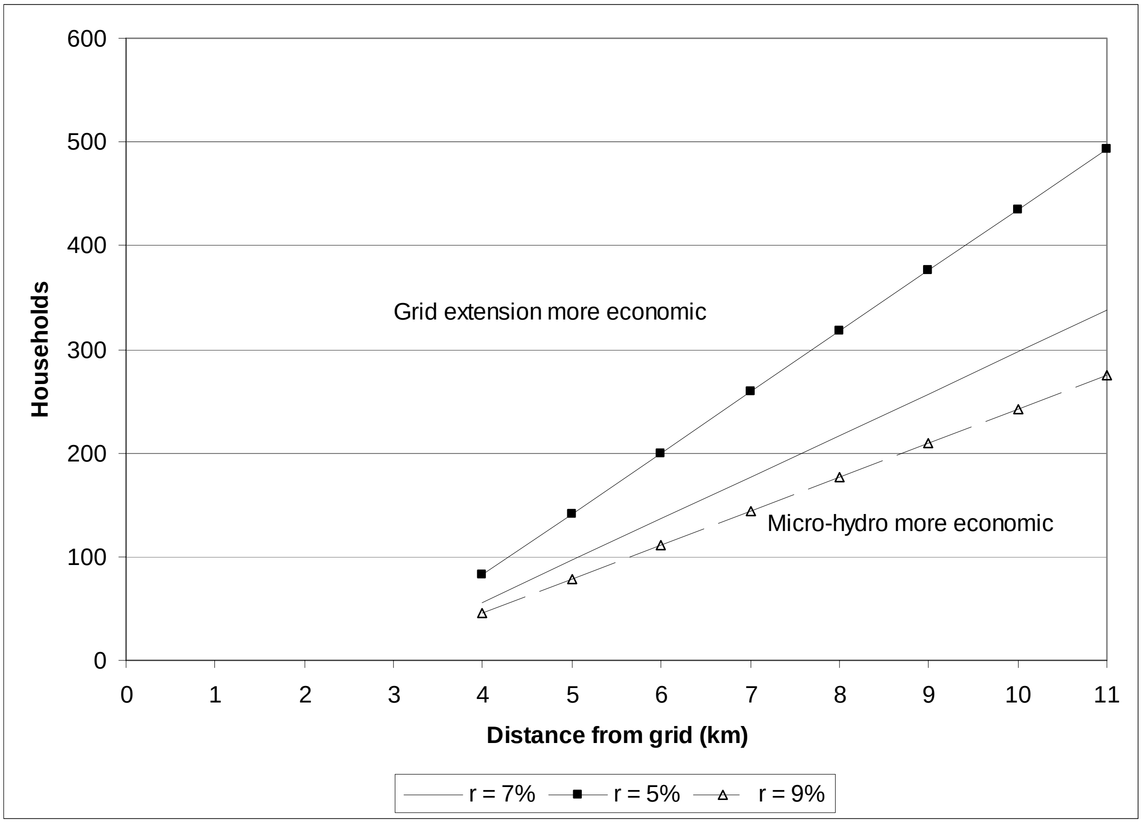

Figure 27: Sensitivity to discount rate

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[40] The situation is complicated by the fact that whereas the ratio of fixed to variable costs of micro-hydro is *constant*, the same is not true for grid extension. Extending the grid a greater distance to a village means a higher portion of upfront capital cost. This suggests that the sensitivity to discount rates is, in turn, sensitive to a variety of other factors that influence whether or not the micro-hydro option always has a higher ratio of fixed to variable costs. These factors include the relative O&M costs for transmission, generation, grid extension, and micro-hydro as well as relative fuel costs. If one assumes that all O&M costs are the same constant percentage of capital costs then micro-hydro will always have higher ratio of fixed to variable costs because micro-hydro does not make fuel payments. In this case, higher discount rates will favor the grid.

As a planning tool, equation (4-3) should be used with care. Clearly, micro-hydro only makes sense in communities that have suitable water resources. The model assumes a linear relationship between micro-hydro cost and number of households served. In practice, economies of scale as well as variations in terrain and other factors introduce wide variability in the cost of building a micro-hydro project in a particular location. Similarly, grid extension in the model is assumed to be directly proportional to distance. In practice actual costs are complicated by factors including terrain characteristics, choice of transformer, single or three phase wire, as well as medium voltage and low voltage segments.

Characteristics of the villages are important. Communities expected to grow slowly are also likely to be more favorable, or communities may be distant but along the route of expansion to a larger load center. Finally, the analysis assumes that electricity from micro-hydro has the same value to users as grid electricity. Consideration of the possible long-term prospect of lower quality power from micro-hydro would tend to shift the graph to the right, favoring the grid.

Cost comparison of micro-hydro versus the grid in 20 micro-hydro villages

In practice, how do micro-hydro projects compare with grid electrification in terms of long term costs of providing electrification to villages? This section calculates the net present cost of 10 years of electricity production at 20 different villages for which data were available, and compares it with the cost had the village been served by the grid instead.

Calculations use measurements of distances from the grid taken by government micro-hydro technicians at the time of micro-hydro installation (Interview 2004.9). The calculations also include the inflation and currency-conversion adjusted cost of building the micro-hydro, as recorded in an engineering list of projects commissioned by the DEDE (Panya Consultants Co. 1993).

Calculations rely on system-wide costs of impacts of new rural loads presented above in Table 7 through Table 9, and in many respects are identical to the calculation in the section above. The key differences are that the unit of analysis in the previous calculation was a typical household while in these case study calculations the village is the unit of analysis. There are separate calculations for each village.

The other key difference is that in this case, costs are calculated from two perspectives: costs borne by villagers and costs borne by the public. Costs borne by the village are the net present value of the tariff value of the village's collective tariff payments over the timeframe of the analysis, as well as the in-kind contribution of labor to build the project.

Costs borne by the public are equal to the overall costs minus the village costs. This reflects that fact that in both grid extension and micro-hydro, the Thai public – whether ratepayers or taxpayers – ultimately pays for everything that the villagers do not pay for.

Village name	Grid extension cost borne by public	Micro-hydro cost borne by public	km to grid	Village load (kW)
E Tong	$ 624,109	$ 61,519	67	60
Pang Bong	$ 353,138	$ 128,121	40	15
Muang Kong (2)	$ 376,510	$ 121,123	40	40
Pha Moun	$ 381,184	$ 36,323	40	45
Mae Khun Wang	$ 263,685	$ 71,085	30	10
Baan Kud Chang	$ 291,731	$ 172,323	30	40
Chae Sorn	$ 329,126	$ 63,948	30	80
Mae Sai Noi	$ 225,970	$ 85,223	25	15
Huai Pui	$ 216,301	$ 362,047	20	50
Naam Mae Sa	$ 192,929	$ 59,985	20	25
Baan Long Khord	$ 263,046	$ 285,106	20	100
Ban Pox	$ 188,255	$ 111,531	20	20
Pong Nam Ron	$ 216,301	$ 183,760	20	50
Pang Khum	$ 188,255	$ 134,470	20	20
Pha Pung	$ 192,929	$ 104,781	20	25
Muang Kong (1)	$ 145,866	$ 271,914	15	20
Pang Hai	$ 164,563	$ 250,045	15	40
Nam Klun	$ 151,411	$ 117,171	14	35
Mae Kom Pong 1	$ 103,476	$ 351,365	10	20
Huai Nam Rin	$ 98,802	$ 111,945	10	15

Table 11: Comparison of present value of costs to public of grid versus micro-hydro electrification for 20 villages

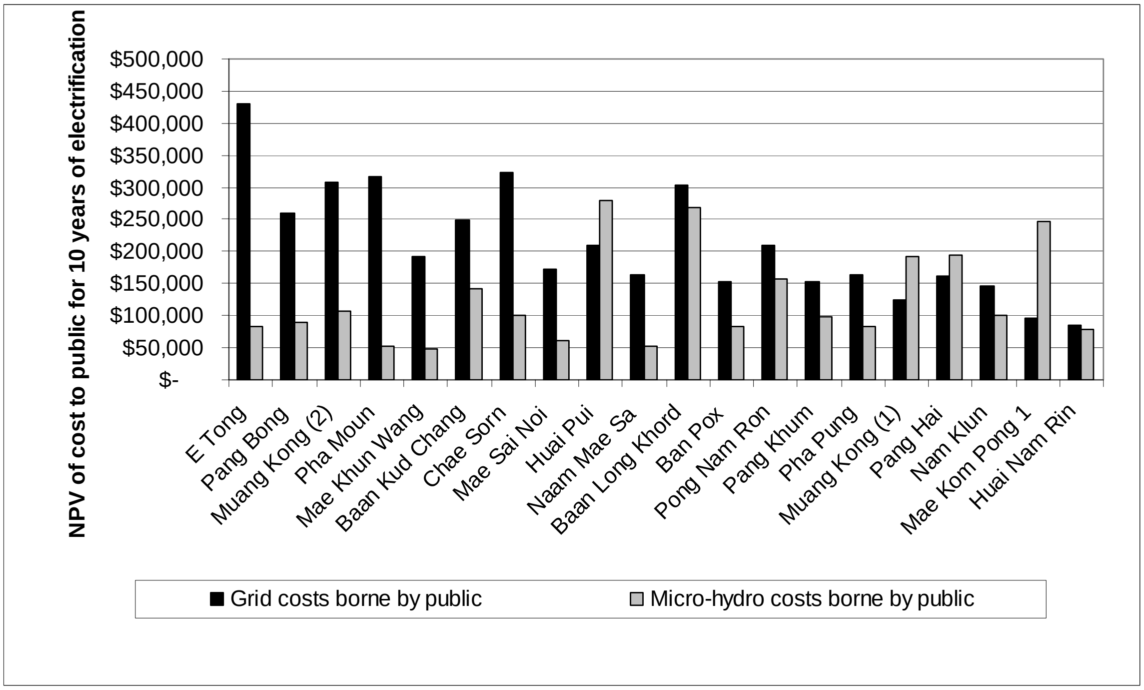

Figure 28: Comparison of present value of costs to public of grid versus micro-hydro electrification for 20 villages

In comparing the results in Table 11 and Figure 28, several points arise. First, micro-hydro was less expensive in 14 out of 20 cases. The average cost of micro-hydro electrification to the public was $108,467, while that of grid electrification was $178,577 – about 65% higher.

The results show huge variation in relative costs, and in absolute costs in the case of micro-hydro costs. Regarding the extreme variations in micro-hydro cost, looking at some of the highest cases (Huai Pui village, Mae Kam Pong 1) the specific characteristics of the project offer explanations: both Huai Pui and Mae Kam Pong had expensive civil works with very long headraces (Panya Consultants Co. 1993). Similarly, the lowest cost cases did not include costs for weirs or headraces, presumably because they made use of existing infrastructure built for irrigation. These results emphasize the caution with which

Eq (4-3) should be used in assessing suitability based only on distance to the grid and number of households.

Micro-hydro projects with extremely low costs to the public were low in part because capital costs were offset by payment of tariffs. The graph below considers the situation from the side of those paying the tariffs.

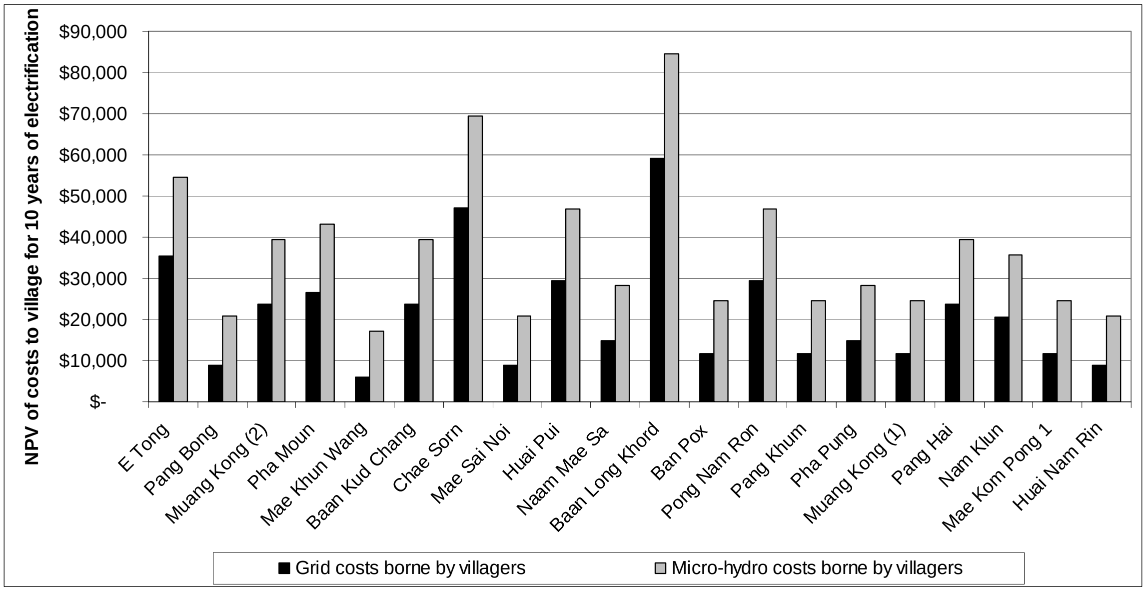

Figure 29: Comparison of present value of costs to villagers of grid versus micro-hydro electrification for 20 villages

Even though micro-hydro has lower over-all costs and lower costs borne by the public in 14 out of 20 cases, from the perspective of villagers the relative attractiveness the two technologies is completely reversed. Figure 29 above indicates that in all 20 cases electricity from micro-hydro was *more* expensive than the grid to villagers. On average, the cost of micro-hydro to villagers was 71% higher than grid power. The answer to this apparent economic paradox lies in the setting of tariffs. A strong majority (37 out of 50) micro-hydro systems use an electricity tariff set at 2 baht ($0.05) per kWh. In contrast, PEA subsidizes small customers by charging 1.76 baht ($0.0394) per kWh. In addition, villagers bear the cost of in-kind labor contributions which are not required in the case of electricity from PEA.

Average cost of electrifying households: micro-hydro vs. grid electrification

Though comparing average costs over large numbers of households masks important details, it is also interesting to consider how the cost of electrifying the average "micro-hydro household" compares with the projected average per-household cost of electrifying Thailand's remaining as-yet-unelectrified households. In this case, grid extension costs are derived from the budget for PEA's Rural Household Electrification Project, 2nd Stage (2001-5). The budget provided 4 billion baht ($100,000,000) to extend the grid to 150,000 homes, implying an average hookup cost of $667 per household (PEA 2002b). Generation and transmission costs are as calculated in Table 7 and Table 8. Micro-hydro capital costs are based on an average of capital costs of 42 systems built by the DEDE (Panya Consultants Co. 1993), while O&M costs were based on actual O&M costs over a 20-year period documented at Mae Kam Pong village. Results of the calculations are shown below in Figure 30.

In terms of over-all costs, micro-hydro is about $300 less costly. However, because micro-hydro tariffs are higher and villagers bear the cost of in-kind labor contributions, micro-hydro is the less cost-effective option (given a choice) for villagers.

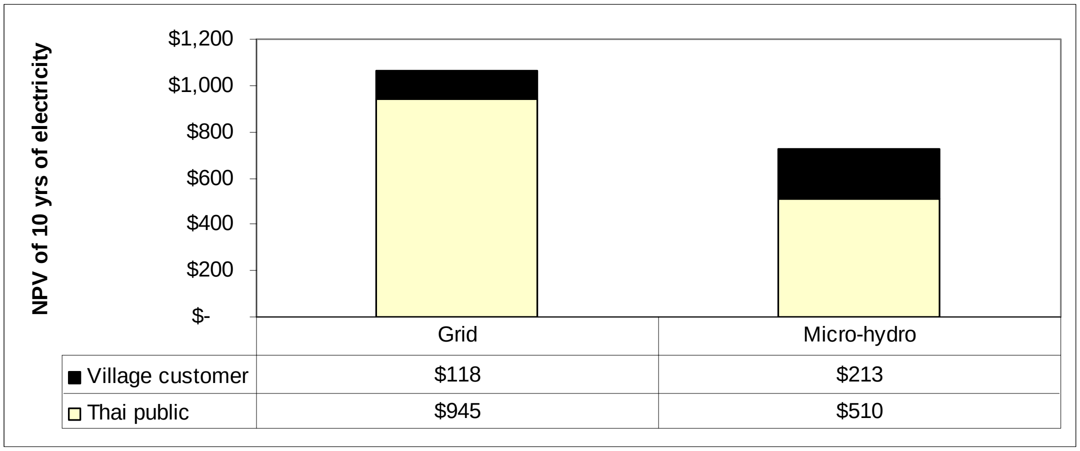

Figure 30: Average cost of electrifying micro-hydro village compared with electrifying average village.

Economics of the arrival of the grid into a micro-hydro village

As discussed in Chapter 3, respondents from 24 of the 34 villages with abandoned micro-hydro systems listed the arrival of the grid as a key reason for giving up the plant. With the arrival of the grid, substantial assets (weir, headrace, pipes, powerhouse) representing considerable state investment as well as a year of village labor are scrapped. The irony is that the arrival of the grid also offers a potent opportunity to solve power quality problems and continue deriving economic benefit from micro-hydro.

With the arrival of the grid, the cooperative governing the micro-hydro faces three options: (1) continue operating the plant normally, separate from the grid; (2) synchronize and sell electricity back to the grid; and (3) abandon the micro-hydro and use PEA grid power.

<u>Option 1: business as usual</u> can produce overall benefits in the short term, but carries substantial risk of long-term economic losses. With the arrival of the grid, some customers may choose to migrate to PEA. This is economically beneficial to all

customers to the extent that excessive village consumption is a problem and reducing load will decrease brownouts and blackouts of remaining micro-hydro customers. But if too many migrate to PEA, micro-hydro electricity is under-utilized. Electricity is generated but diverted to the load controller. Revenues for the micro-hydro cooperative decline, as does the labor pool to make repairs that require manual tasks. Indeed, mass migration by customers acting as economically rational individuals attracted by the subsidized tariffs and higher quality power of PEA apparently plays a significant role in the collapse of many systems (Interview 2002.05).

Option 2: interconnection has short term costs – requiring (at least) interconnection equipment that costs approximately $10,000, and approval from PEA. But it also has long-term benefits both in terms of revenue streams as well as improvements in power quality. Regarding power quality, if a micro-hydro is synchronized with the grid, then the grid will inherently provide the voltage stability that overburdened generators now lack in the evening time. This is a significant benefit, as it brings power quality up to the level of the grid. From a power quality perspective, the grid may also notice power quality improvements. Indeed, installing distributed generation is sometimes used by utilities to reduce voltage drop at the end of long distribution lines.

The option also has significant revenue generating potential, due in part to the fact that all electricity production can be utilized (24 hours a day). It has been estimated that the micro-hydro cooperative at Mae Kam Pong village, for example, can earn 188,400 baht ($4,700) per year selling to the grid, whereas their 2002 revenues were only 112,500 baht ($2,810) (Prasand 2004).

Finally, option 2 “locks in” micro-hydro as part of the system, rather than leaving it orphaned and suffering from attrition (option 1). This provides assurance that economic benefits in terms of local employment and revenues flowing from utilities to the village will continue.

Option 3: abandoning the micro-hydro offers the least benefits to either the village or the Thai public. Despite sunk costs, resources are unutilized while expenditures must be made elsewhere in the system to generate and transmit electricity that the micro-hydro could have generated.

Table 12 below considers the financial viability of interconnection for 27 villages that have micro-hydro installations (working or not working) and receive electricity from the national grid. Based on data from site visits, the condition of equipment in each village is assessed and a determination is made of the cost of renovations required to return the project to functioning condition. The calculation also notes whether villagers reported “seasonal” or “year round” water availability. If water is available year round, the capacity factor is assumed to be 50%. In the case of seasonal water availability, a capacity factor of 30% is assumed. Operator salaries are fixed at $2,400 per year (Interview 2003.04), and the electricity buy-back rate is set at $0.05375/kWh according to tariffs applicable under VSPP regulations that allow interconnection of small renewable energy generators. Discount rate and O&M costs are the same as other calculations in this chapter: 7% and 1.5% of initial investment, respectively.

Project Name	kW	Capacity Factor	Required Renovation			Total Initial Investment (US$)	IRR 25 years
			New Gen	Power Plant	Weir		
Mae Kom Pong 3	40	50%		Y		18,000	59.96%
Mae Tun Noi	200	50%	Y			115,000	59.63%
Baan Long Khord	100	50%	Y			63,000	47.18%
Mae Na Jon	80	50%	Y			57,500	37.12%
Doi Laang	60	50%	Y			44,500	33.03%
Pa Pae	25	50%		Y		15,000	27.70%
Pha Moun	50	50%	Y			41,500	26.62%
Huai Pui	50	50%	Y			41,500	26.62%
Mae Wak	40	50%	Y			37,250	20.75%
Pong Nam Ron	50	50%	Y		Y	52,750	19.13%
Huai Sat Yai	120	30%	Y			87,250	17.52%
Mae Kom Pong 1	20	50%		Y		15,000	15.64%
Mae Kom Pong 2	20	50%		Y		15,000	15.64%
Mae Ton Luang	17	50%		Y		15,000	8.76%
Muang Kong 2	40	30%	Y			37,250	5.75%
Pang Hai	40	30%	Y			37,250	5.75%
Pang Bong	15	50%		Y		15,000	3.81%
Mae Khun Wang	20	50%	Y			33,750	2.58%
Pang An	20	50%	Y		Y	42,656	<0
Huai Kang	20	50%	Y		Y	42,656	<0
Kun Lao	20	50%	Y		Y	42,656	<0
Huai Moh	20	30%		Y		15,000	<0
Ban Pox	20	30%		Y		15,000	<0
Muang Kong 1	20	30%	Y			33,750	<0
Tung Lakorn	20	30%	Y			33,750	<0
Huai Nam Khun 2	20	30%	Y			33,750	<0
Huai Nam Rin	20	30%	Y			33,750	<0

Table 12: Internal rate of return for renovating and interconnecting micro-hydro to the grid.

The analysis suggests that at least 5 of these projects are potentially very profitable, and 13 of these 27 installations are worth interconnecting on the basis of financial criteria.

Summary and conclusions

Micro-hydro and grid power are assessed from the overall objective of economically optimized electrification, including decisions of where to employ what technologies, when. Power quality issues are important in assessing relative benefits of each technology, especially in the long term as village loads exceed supply. However, evaluations of the damage cost and cost of mitigation show wide variability in economic value of high power quality, making quantitative analysis of benefits difficult given existing data.

This chapter develops a linear mathematical model for determining conditions under which micro-hydro may be economically optimal. For villages of 50 households or more, micro-hydro becomes cost effective when grid power at least 4 km away. A village of 300 households becomes economically served at about 8 km. Using a similar analytical framework, costs are compared between micro-hydro and the grid for 20 villages from the perspective of costs borne by the public as well as those borne by villagers. For 14 of these villages, micro-hydro is a less expensive way of providing 10 years of electricity from the public perspective, but in all 20 micro-hydro was considerably more costly from the villager perspective. Analyses using large averages of villages show the same uneven economic perspectives, reflecting high subsidies for grid electrification relative to micro-hydro.

In cases in which the grid arrives in a village already served by micro-hydro, three options are available for the micro-hydro cooperative. While a business-as-usual approach offers short-term benefits, it carries significant long-term risks of economic losses. Grid interconnection, with higher short-term costs, has significant long-term benefits for both villagers and the broader public. Abandoning the micro-hydro is the least economically optimal choice. Financial analysis of grid-interconnection for 27 micro-hydro villages shows five installations have IRR potential exceeding 30%.

The phenomenon that projects are abandoned rather than interconnected, and the lack of micro-hydro installations in general given their favorable economics, suggests the need to consider the broader historical context of rural electrification technology choice in the country. The structural arrangements discussed in the next chapter help explain why few public resources have been directed towards micro-hydro, and comparatively much more directed towards expansion of the (considerably more expensive, centrally controlled) national grid electricity.

Chapter 5: Micro-hydroelectricity in the context of Thai rural electrification

PEA consolidates heart and soul for the prosperity of Thailand.
-<u>1999 PEA Annual Report</u>

Micro-hydroelectricity and the grid in Thailand

In a country where the government and rural villagers are often at odds over resource management and infrastructure provision (conflicts in which the Thai government is often accused of being overly patronizing, top-down, and insensitive to local needs (Piriyarangsan 1994; Hirsch and Warren 1998; Phongpaichit 1998)), Thailand's government-run micro-hydro program has been a notable exception. Villagers and government employees work collaboratively to build each project, and ultimately operations and management responsibilities rest with the village. As discussed in the previous chapters, this arrangement, though not without problems, has proven to be cost-effective and well-received by rural villagers. However, micro-hydro cooperatives are an endangered entity, with an extremely small and declining presence compared with the dominant centralized alternative.

How did this particular mode of government / village collaboration on rural infrastructure evolve? What are the limits to the continued expansion, or continued existence of Thai village cooperative micro-hydroelectricity? How were key decisions about rural electrification technology made? How did centralized grid-based technology become institutionalized and achieve dominance while village-scale solutions became marginalized?

Answers to these questions require considering micro-hydroelectricity as a subplot – or even a footnote – in a broad history of rural electrification. In this telling of

Thailand’s rural electrification history, I focus on two points of contention. Would the electrical system be centralized or decentralized? And would the system be a state-owned monopoly, or would ownership take some other form such as municipal utilities or cooperatives?

The evolution of rural electrification in Thailand can be broken into several important stages. The initial era involved diverse approaches in which rural electrification was limited in scope, but rich in administrative diversity, with service provided by cooperative, private, and municipal utilities. The late 1950s, however, began a new era with the formation and growth of large parastatal electricity monopolies. Centralized arrangements for provision of rural electrification were subsequently guided by bureaucratic intertia and domestic political prerogatives fueled by the availability of bilateral and multilateral concessionary financing. Through planning procedures and program design, rural electrification came to be defined as grid extension, with virtually no consideration of alternatives. In the 1980s the country flirted with “Small is Beautiful” approaches but these never challenged the growing hegemony of PEA and the grid extension model. By the 1990s and 2000s several vicious circles of marginalization were well established. On the one hand, few installed projects led to a lower profile for DEDE micro-hydro program, which in turn meant lower budgets allocated, and therefore fewer projects. A related vicious cycle is that low demand for micro-hydro equipment provides sufficient market for only one monopoly small equipment supplier. Lack of competition means high prices and low quality equipment, in turn, contributes to lower demand.

1880s to 1960s – Diverse electrification strategies

In 1884, just two years after Thomas Edison created the first electric light power plant in New York City, an ambitious Siamese army general acquired a generator and lights and electrified an army building. When news spread to the King Rama V, the general was requested to light up the Royal Grand Palace in Bangkok. Subsequently the homes of the Royal Family were electrified (Chullakesa 1992; Nye 1995). A few years later, a Danish company gained a concession to run an electric trolley from Bang Kaw Laem to the Royal Palace. In 1897, the company then expanded into generation of electricity for lighting and set up a permanent generation system using wood fuel (Chatikavanij 1994; PEA 2000). For decades, electricity was available only to the wealthiest of families as an expensive substitute for lamp oil, and to power household fans (PEA 2000).

Rural electrification efforts began when the government set up a rural electricity division in the Interior Department that built a diesel powered generating system in the town center of Nakhon Phanom on the Laos border. The system began generating in 1930.

In 1932 the absolute monarchy was challenged by a successful coup led by a small group of mid-ranking military officials and foreign-educated civilians. The next half-century was dominated by military governments and a series of coups, interspersed with brief flirtations with democracy. World War two brought economic and identity crises to Siam as the country was occupied by Japanese troops intent on using it as a base to attack British India. Thai people suffered heavily from essential commodity shortages, increased taxation, high inflation, and by the middle of the war, Allied air raids (Wyatt

1982). As the war progressed, rural electrification was halted, and rural electric power plants fell short of spare parts and fuel (PEA 2000).

Through the 1950s and even the 1960s it was not yet clear what form bureaucratic arrangements for Thailand's electricity industry would take, administratively or technically. By the early 1960s only 2% of Thai communities had electricity. There was no consensus on the form of ownership: whether it would be investor owned utilities, the state, or some other model such as cooperatives as was the case in rural America. Indeed, forms of ownership of electric utilities were diverse: there were over 200 separate small cooperative, municipal or privately owned utilities (PEA 2000). The technologies to be used were also undecided – especially the extent to which electricity would be generated in large power plants or by smaller decentralized systems ultimately linked together by an expanding grid.

But brewing on the horizon were events outside Thai borders that would set the stage for significant US involvement in Thailand. In 1948 increasing Communist control in Eastern Europe and the prospect of Mao winning the civil war in China raised U.S. concerns over a variety of anti-colonial insurgencies in the region. As the Cold War expanded, pro-US military governments in Thailand received over a billion dollars in economic and military assistance from the U.S., which saw Thailand as a regional power to be courted in containing communism (Wyatt 1982).

Starting in the 1950s American economic planning advisors drew up plans for substantial regional infrastructure development in Thailand, Laos, Cambodia, and Vietnam. The planners envisioned Thailand as the launching pad for a Mekong development plan modeled after the US Tennessee Valley Authority (TVA). The plan would have harnessed the Mekong River for electrical production to provide plentiful cheap electricity to drive industry and mechanized agriculture. Seven huge hydroelectric dams were planned which would have carved the Mekong River into a series of reservoirs over 2000 kilometers long (Hirsch and Warren 1998). One dam alone, the Pa Mong project was investigated for 30 years, with US$50 million spent on studies by 1984. Construction of the dam and reservoir would have required the permanent resettlement of at least 100,000 people. The projected electricity generation capacity of the Pa Mong and three other related dams was estimated at almost four times the 1980 electric consumption of all of Thailand. The expansion of electrification during the 1960s and 1970s rested in large part on the promise of virtually limitless supplies of cheap electricity from these dams (McDonald 1984).

As part and parcel of this development process, the National Energy Authority (NEA) was created under the National Energy Authority Act on January 6, 1953. Reporting directly to the Office of the Prime Minister, the NEA was to be “responsible for the planning and coordination of schemes for development and utilization of all energy resources in the country” (United Nations 1963). Among other tasks, the NEA regulated hundreds of small utilities spread across Thailand, and built many of the country’s early power plants (McDonald 1984).

One of the early main projects of the NEA was to serve as the Thai Secretariat to the Committee for Coordination of Investigations of the Lower Mekong Basin (Mekong Committee) (United Nations 1963). The Mekong Committee, founded under the auspices of the United Nations in 1957, was an intergovernmental agency consisting of government representatives from the Lao People's Democratic Republic, Thailand, Cambodia, and the socialist Republic of Vietnam. The mission of the Committee was the comprehensive development of the water resources of the lower Mekong Basin, including the main stream and its tributaries.

Disagreements among Mekong Commission countries over water management, and the economic non-viability of the proposed hydroelectric projects thwarted efforts to build any dams along the Mekong River. Increasing Communist activity in Laos, Vietnam, and Cambodia also forced the US government to fall back and concentrate its infrastructure development efforts on Thailand. After 1978, the Committee functioned under an interim status, with only the government of Laos, Thailand, and Vietnam participating. During the 1980s, most of the long-range aspects of the Mekong scheme and its key basin-wide projects were abandoned (Hirsch and Warren 1998).

Thus, with advice and concessionary financing from the World Bank, USAID, and other multilateral funding agencies, a number of large hydroelectric dams and large thermal plants were constructed in Thailand starting in the early 1960s.

1960s – Formative period of parastatal utilities

In the 1960s the basic institutional arrangements were put in place that continue to shape and limit rural electrification possibilities today. The role of the state in developing centralized power plants and a national grid received strong support under the martial law administration of Field Marshall Sarit Thanarat (1959-63). Under the advice of the World Bank, Sarit initiated centralized economic planning under the National Economic and Social Development Board (NESDB) with five year plans starting in 1961(Wyatt 1982). The first five-year National Economic and Social Development Plan (NESDP) (1961-5) emphasized construction of large electrical generating systems together with other infrastructure such as rural electrification, roads, reservoirs and canals.

In the early 1960s work began on a number of large generating stations, including the Yunhee (also called Bhumipol[41]) hydroelectric dam[42] and several thermal (lignite coal) power plants in North, Central Thailand, and southern Thailand. Administrative arrangements for these power generation projects were originally fragmented – each was under the responsibility of different regional electricity authorities set up as "independent" state-owned enterprises at the behest of the World Bank in order to ensure that World Bank loans would not be deposited directly into the Thai national Treasury (Chatikavanij 1994, p. 29).

These projects included the beginnings of the Thai transmission grid, which allowed electricity generated from resources extracted from rural areas to be transmitted to industrial, commercial, and residential customers in Bangkok and the surrounding metropolitan area.

In 1968, the Yanhee Electricity Authority, Northeast Electricity Authority, and the Lignite Authority merged to form the Electricity Generating Authority of Thailand (EGAT), a state-owned enterprise under the Office of the Prime Minister. EGAT also

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[41] Bhumipol is the first name of the current king of Thailand. Most major hydroelectric projects are named after royal family members. Eventually there were more dams than royal family members, and the King came up with other royal words to bestow upon major hydroelectric projects. In part, because of the high regard for the royal family held by most Thai people, these projects long enjoyed unquestioning acceptance as key building blocks for Thailand's development. In a somewhat similar vein, the common village name for electrification – *fai luang* is etymologically linked to the word for king, *nai luang*.

took over hydroelectric power plants that had been built by the NEA and the Royal Irrigation Department.

Electricity distribution inside and outside the Bangkok metropolitan area was the responsibility of separate state-owned utilities. In 1958 the Metropolitan Electricity Authority (MEA) was established to distribute electric power to the Bangkok Metropolitan area and its adjoining provinces Northaburi and Samut Prakarn. In 1960 the Sarit Government established the Provincial Electricity Authority (PEA) to distribute electricity to the remainder of the country. The MEA and PEA were created under the Ministry of Interior, a competing ministry with the Office of the Prime Minister that housed the NEA. Whereas as the Office of the Prime Minister is largely concerned with long-range economic and social planning, the Ministry of Interior has a focus on infrastructure provision such as roads and water supply, as well as internal security.

Kasame Chatikavanij, the first and longest-running General Manager of EGAT, reports in his autobiography that while the country's electrification efforts received attention from the highest levels of Thai government, it was US advisors who played key roles in informing and coaching early Thai power sector decision-makers on the details of a variety of early electrification projects (Chatikavanij 1994, p 26-33).

In 1966 a reconnaissance team[43] from the United States Agency for International Development (USAID) arrived to help with systematic rural electrification expansion

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[42] The 100 MW Yanhee dam was financed by a $69 million World Bank loan arranged in 1957. The loan was nearly three times larger than any Thailand had previously secured (Chatikavanij 1994, p 33).

[43] The text of the reconnaissance team report reflects the philosophy of the U.S. advisers that in the face of Communist threats, abundant electricity was a key tool in building a wealthy, capitalist-friendly Thailand:

(USAID 1966; Voravate 1997). A report by these early US advisors addresses the possibility of micro-hydroelectricity as a potential technology option for rural electrification, but quickly dismisses the idea on the basis of security concerns:

> “The view has been advanced by some that the construction and operation of hydroelectric plants... is necessary in order to demonstrate the interest of the Government in the welfare of the people, particularly in the so-called "sensitive areas" where the very low income status of the population makes them susceptible to the propaganda of Asian Communism. Others believe that … the funds available can be put to better use by building transmission and rural distribution facilities to bring power from large, centrally located generation stations which are …less exposed to damage or destruction by subversive or enemy action. The team endorses the later option.” (USAID 1966).

Though the notion that an electrical infrastructure based on centralized power plants and large transmission networks is less susceptible to terrorism is questionable, it indicates that counter-insurgency concerns may have also played a role in favoring a centralized grid electrification.

> The Electric Power Supply Team believes that its greatest contribution to the future of Thailand -- “Land of Freedom” -- will be to establish firmly the PHILOSOPHY OF PLENTY as a basic premise for planning the expansion of is electricity supply system. *(emphasis in original)*
>
> Attention is called to the fact that nations in which internal strife is minimal or nonexistent, and in which people are immune to revolutionary propaganda, have many small industrial communities spread throughout the land… This chapter calls attention to the unchallenged fact that the level of wealth of nations is remarkably close to being in direct proportion to the per-capita use of electric energy (USAID 1966).

Besides hopes that rural electrification would help spur the growth of rural capitalism, rural electrification had specific, practical benefits for Cold War planners. One USAID document from this era noted, “Lighting serves a particular counter-subversion need by reducing the psychological isolation of villagers, facilitating police surveillance, and inhibiting clandestine infiltration” (USOM 1965). A further justification for electricity was that it would provide 24-hour power for two-way radios for tactical or security traffic (USOM 1965).

In stark contrast, starting in 1953 China had begun an extensive program urging "self-construction, self-management and self-consumption" of village-scale hydroelectricity. By 2001 there were 18,944 micro-hydro installations in China, the vast majority of which were community owned (Jiandong 2003). The total capacity of small (<1 MW) micro-hydro in China exceeds than 26 GW – more than 160% of the peak load of Thailand in 2002 (Jiandong 2003).

Following the 1966 reconnaissance team, USAID funded a pre-feasibility study, called the Accelerated Rural Electrification National Plan Study, which was completed by the US Middle West Service Company in 1972. The plan included specifications for equipment, procedures for determining which areas and villages to electrify in what order, rules governing tariffs, and recommendations for administrative structure.

In August 1973, the Royal Thai Government officially adopted verbatim the USAID pre-feasibility study as *the rural electrification master plan* for the country. The document was renamed, “The National Plan for Thailand Accelerated Rural Electrification” (Chullakesa 1992; PEA 2001). This plan called for the electrification of the entire country in a 25 year time frame, giving priorities to “economically and politically backward and unstable areas” (Chullakesa 1992). The Communist-threatened Northeast was ranked highest priority, followed by South (which had substantial insurgent activity), North, and Central Zones of the country (Table 13).

Short-Range Program		Project Villages		Region
Stage	Fiscal Year	In Program	Accumulated	
Stage I	FY 1977-81	5,200	5,200	Northeast
Stage II	FY 1980-84	8,000	13,200	South
Stage III	FY 1983-87	13,500	26,700	North
Stage IV	FY 1986-90	14,500	41,200	Central
Stage V	FY 1989-91	5,800	47,000	Countrywide

Table 13: Timetable for Thailand’s National Rural Electrification Plan.

PEA planning and the entrenchment of grid extension

PEA’s system planning was organized into three interrelated projects: the Power Distribution System Reinforcement Project (PSR), Power Distribution Line Extension to Small Diesel Power Plant Project (EDE), and the Village Electrification Project (VEP). The PSR emphasized systematic strengthening and expansion of the medium voltage (11 to 33 kV) backbone of the grid. The EDE emphasized nationwide replacement of autonomous diesel generation with the centralized grid in order to reduce generation and operation costs. The VEP focused on extending the distribution system to unelectrified villages.

One result of organizing system planning within these three parallel grid-extension programs was to elevate grid extension to the defacto universal rural electrification solution, applied in virtually all circumstances. The EDE in particular, by defining grid extension in opposition to decentralized generation, established a dynamic in which decentralized generators as a category were targeted for replacement with grid extension. With respect to diesel generation, the goal of replacement may have made sense on long-term system planning and economics grounds, but as a spillover effect these projects contributed to the creation of an environment that would be hostile to decentralized micro-hydro, which as shown in Chapter 4, can be more cost-effective than the centralized grid in many circumstances.

1960s – Cooperative or state-owned rural electrification?

As grid extension emerged as the chosen technology, a debate arose over ownership and control. At one point in the mid-1960s, it appeared that widespread cooperative ownership of rural distribution was a serious possibility, but one that was defeated by PEA by 1967. Correspondence and meeting notes regarding these events are archived in a number of mid-1960s mimeographs (Davies 1966; Porter 1966; Smith 1966). The unfolding of this lost opportunity is summarized (with a brief introduction to rural electricity and the American model of rural electricity cooperatives) below.

Much rural electrification in the U.S. was accomplished using a cooperative model in which distribution lines are owned and operated by a local non-profit cooperative and power is purchased in bulk from federal power supply agencies or private power companies. This model arose during the 1930s as American farmers grew tired of waiting for electricity that was enjoyed by urban citizens, and organized among themselves to build and manage their own distribution lines. These farmers' cooperatives were supported by long-term low interest loans made possible by the New Deal-era Rural Electrification Administration (REA), and were often given preferential access to electricity from federal power projects (REA 1936). The National Rural Electrification Cooperatives Association (NRECA) is a US national non-profit federation of these rural electrification cooperatives (NRECA 2002). Sponsored by the United States Operations Mission (USOM) and USAID, NRECA sent a team to Thailand in 1964-6 to study the feasibility of setting up rural electrification cooperatives in three North East *amphurs* to support Thailand's rural electrification efforts.

In initial discussions between NRECA and the Thai government in June 1965 over where a rural electrification cooperative program might be hosted, PEA indicated that they were not interested in including cooperatives in their bureaucracy. The general manager of PEA at the time, Mr. Sai Widhinandana, stated that "PEA is losing money on the small village operation" which "do not need power, they will not use it and cannot afford it." PEA's rural electrification work at the time focused on electrifying towns where load density was highest and profitability was ensured. The visiting NRECA representatives noted that "this language sounds like the same language we heard from private power companies in the States in 1937 and 1938 when RE Coops were being established" (Davies 1966).

The National Energy Authority (NEA), which operated a number of hydroelectric plants, responded enthusiastically, and pledged to supply electricity to the rural cooperatives as well as provide engineering assistance. Other sections of the government responded enthusiastically as well. In a memo dated June 10, 1965 Mr. J. K. Smith of NRECA endorsed the Department of Credit and Cooperatives Marketing (DCCM), under the Thai Ministry of National Development as the best agency to sponsor a pilot rural electric cooperative. The DCCM had previously played a role in supporting rural credit cooperatives.

Four additional phases for NRECA involvement were proposed: Phase II -- organizing and surveying local interest in coop formation (90 – 120 days); Phase III -- preliminary engineering, feasibility, and financing criteria (90 – 120 days at same time as

Phase II); Phase IV – construction (9 months to one year); and Phase V – operation guidance (4 years).

The phase I study was completed on 23 June 1965 (Smith 1965). The study was scornfully dismissed in August by Mr. Belford Seabrook, a senior American advisor to the PEA. Mr. Seabrook's memo begins:

> I read the report by Mr. J. K. Smith of NRECA... I have considerable doubts that in an underdeveloped country such as Thailand, that a co-op organization would be the best or the least expensive way in which to solve the problem. Before any steps are taken to secure an adviser from the REA, I would think that it would be desirable to examine the matter objectively without the emotional handicap of an REA missionary. It seems to me that our objective should be rural electrification and not to sell the cooperative way of accomplishing it (Davies 1966).

Despite these criticisms, USOM allocated funds for further study, and in November 1965 a second NRECA team arrived to complete Phase II (organizing and surveying) and Phase III (preliminary engineering, feasibility, and financing criteria) studies. In meetings with NRECA, PEA raised objections that the project interfered with their own rural electrification work, would confuse villagers, and that farmer credit cooperatives had been tried earlier in Thailand and had failed, and that organizing villagers to manage a cooperative is a waste of time. PEA said that providing electricity to villages would lead to economic loss, and that precious state resources should be used instead to support PEA's own efforts that concentrated on rural towns. Displaying lack of concern about the importance of the distinction between "participatory ownership and decision-making" and "voluntary material and labor contributions", PEA argued that their own efforts at rural electrification were "already participatory" in that they required prospective users to contribute wooden poles, crossarms, and labor for the projects, and therefore the cooperative was redundant. Finally, PEA pointed out that a comprehensive power survey was soon to be conducted, and that the rural coop program should await completing this survey.

The NRECA and the DCCM began their survey work. Villagers in the cooperative pilot study area responded with enthusiasm to the prospect of cooperatively owning and managing their own distribution system. In the course of ten days of meetings, 8,141 villagers signed membership applications, with additional applications received later. On this basis, NRECA selected an area of 99 villages, consisting of 14,815 households. The signup response far exceeded NRECA's 20% preconstruction signup goal. A noteworthy aspect of the signed membership applications was that they required a future commitment to pay a 20 baht cooperative membership fee, as well as a 7 baht per month minimum charge. These charges were substantially higher than the official PEA rates for rural electrification (minimum charge 4 baht per month, and no membership fee) (PEA 1966). Faced with uncertainty about when PEA might arrive, rural villagers were apparently willing to commit substantial resources for cooperative electrification.

Sometime in the winter of 1965 PEA General Manager, Mr. Sai, traveled to Washington D.C. and met with NRECA and AID, presumably to lobby for the cancellation of the NRECA/AID cooperative rural electrification program (Davies 1966).

On 1 February, 1966, NRECA team member Alex Porter wrote a memo in response to questions posed by one of the strongest critics of the project, PEA advisor Mr. Seabrook (Porter 1966). The questions and their responses reveal vast differences in conceptions of rural development goals of rural electrification and visions of appropriate administrative structures and implementation strategies. Key excerpts from the 10-page mimeograph record of the exchange are quoted below:

Question: what does a cooperative rural electrification program have that a rural electrification program administered through one of the existing RTG (*Royal Thai Government)* agencies such as PEA does not have?

Response:

We would hope that the first result would be a success – which PEA frankly lays no claim at the present time...

We have noted in villages to which PEA has extended service in the area around Udorn that a minor share of the homes have taken electric service. We have asked the villagers themselves why they were not using PEA service. Their answer was that be TEA *(corruption)* money was too high. Many of the people from the villages came to the sign-up meetings and were interested in receiving electric service from the cooperative...

The cooperative method of operation has a byproduct development of the people such as is most urgently needed. An example of the need for this development is the above case of individuals submitting to the collection of TEA money or denying themselves the electric service that they anxiously want.

In a cooperative venture, people:

1) learn to work together as a means to achieve common goals – they can do together that which cannot be done individually;
2) learn the value of self-help to improve their lot through investing time and resources. Government cannot do everything that is required without the help of the people themselves.
3) People develop a pride of ownership through membership in the cooperative.
4) A valuable lesson in democracy is learned through one vote process of electing representatives to run the cooperatives. This is a valuable lesson which may add to the future stability of this threatened land.

Question: in view of the failure of many cooperatives in Thailand, what makes this proposal an exception?

Response:

If this cooperative is instituted in the manner of other cooperatives which have failed, this will fail. The condition of being an electric cooperative instead of a credit or other cooperatives is not a guarantee of success. We are not unmindful of the pattern of failure referred to in the question. Neither are we unmindful of the success that has inventoried by those cooperatives that have been properly instituted and supervised. The USOM experience in joint effort which has these requirements for cooperatives has been good:

1) sufficient size and funding;

2) adequate arrangement for training;
3) responsible auditing and management services;
4) reached by lots with policymaking powers assigned to responsible local people;
5) sound financial forecasting

You may judge the report to be submitted in mid-February in light of your own opinions.

<u>Question: how are the villagers really going to pay for the electricity? Are they really prepared for a cooperative project like this or should it be a grant program?</u>

Response:

No grant funds are necessary in the Nong Harn area of this program. Wider area coverage at some future date may require different financing. The villagers with enthusiasm have signed up to pay a rather high minimum (high for Thailand). They have expressed their preparedness.

<u>Question: If this is a grant program, why go through the agony of a cooperative program of this sort?</u>

Response:

This is not a grant program.

The agonies of dealing with people; of organizing the people for self-help; the enlisting of men and women in the ownership and promotion of their own country, are exactly WHY we are here. Even if this were a grant program, it would be a sad loss is any other vehicle but cooperatives were used.

The PEA side seemed unwilling to believe that a rural electrification project of this nature could be built without using substantial grants. NRECA team was confident it could be built with no grants. The PEA side believed villagers would be unwilling and unable to manage electricity cooperatives. The NRECA team felt otherwise, based on their own experiences with rural electrification cooperatives in the US and the response of thousands of Thai villagers. The PEA side focused on rural electrification as the only end product. NRECA saw electrification as both a process and an end product. The process itself, NRECA believed, is useful in building technical and managerial capacity, self-sufficiency, cooperation, and democracy.

In mid-February, The NRECA team submitted a 136 page Phase III study, with initial cost estimates, financial projections, engineering specifications, and a charter for the cooperative. The study suggested forming a US$1.68 million pilot rural electrification cooperative in an area consisting of most of Nong Harn Amphur[44], Udorn Thani Changwat and two eastern Tambols of Udorn Amphur. The Nong Harn site was expected be profitable after its first year, while the others would take 6 to 9 years to achieve profitability. The Department DCCM was to help administer loans to the cooperative and provide organizational assistance, while the NEA was to provide technical assistance.

The Phase III study recommended that loans be arranged from domestic and foreign sources, that a board of directors for a cooperative be elected and trained in the service area, that wiring of homes commence as soon as possible, and that at least two Thai participants travel to the United Sates in March 1967 for four months of NRECA training.

I have found no records that detail exactly how the program was cut, but Phase IV and V were never authorized. It appears that PEA was successful in stopping the rural electrification cooperative threat. Prospects for rural electrification cooperatives in Thailand were never heard of again, with the small exception of the community-managed micro-hydro systems studied in this research.

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[44] Thailand is organized into a system of hierarchical administrative units similar to be United States. The units (and their English translation) are changwat (province), amphur (district), tambon (commune), and mu baan (village). A district is approximately equivalent to a county in the United States, and a commune which is usually comprised of 6 to 12 villages, corresponds to a township in the United States. The capital of a province and the province itself share the provincial name. For example, Muang Chaing Mai (the city of Chiang Mai) is the capital of the province of Chiang Mai. This pattern holds true for districts and communes as well.

1970s-80s – PEA expands

Though much of Thailand’s electrification bureaucratic structure was determined under military dictatorships, it thrived under democratic governments as well. In 1973 massive student protests ushered in a democratically elected government. Though this new government repealed anti-Communist laws and ejected US forces from Thailand, it upheld the earlier electrification policies, and indeed further accelerated rural electrification. The revised National Plan for rural electrification compressed the 25-year timetable into 15 years (Voravate 1997).

In addition, under democratic regimes Thai demographics played a role in the hastening of rural electrification. The political center of gravity in the country lies in rural areas (in 1974, the rural population was 89% of Thailand’s total population (PEA 2000)). The rise of the power of Parliament and the principle of “one person, one vote” shifted the geographical locus of power from Bangkok towards rural areas, reinforcing the prioritization of rural electrification.

The PEA also received considerable support from the Royal Family. The King issued a decree calling for public support of rural electrification throughout the country, helping to ameliorate issues of right-of-way and minimize political pressures. The Royal Family also provided helicopter fuel for army helicopters that were used for reconnaissance and planning in remote areas (Interview 2002.05).

As was common with regulated monopolies, the Thai electricity utilities’ profits were set according to a “cost plus” structure with a fixed rate of return. That is, profits were set by the government to be equal to a certain percentage of expenditures: the more that utilities spent, the more profits they were allowed to collect. These arrangements provided strong incentives for rapid expansion of the electricity system at a rate that was able to keep up, more or less, with Thailand's periods of significant economic growth during the 1980s and early 1990s.

PEA's financial viability was strongly aided by an arrangement in which EGAT charged PEA a lower tariff for bulk power purchases.[45] By this mechanism urban electricity consumers effectively subsidized rural consumers. The lower tariff was designed to compensate for the higher costs of rural electrification and to help ensure PEA's financial viability. In addition, PEA customers in large and medium-sized provincial cities provided strong revenues to help finance electrification in rural areas (Voravate 1997).

PEA's early rural electrification successes combined with the geo-political significance of the country during the Cold War were sufficient justification for the World Bank and others to provide generous development assistance. PEA secured over US$130 million in loans from the World Bank between 1978 and 1983 (PEA 2000), and Thailand was the sixth highest recipient of power sector lending by the World Bank. As a lead funding agency, the World Bank loans provided confidence to other lenders including the Canadian International Development Assistance[46] (CIDA), the Organization of Petroleum Exporting Countries (OPEC) Special Fund, the Saudi fund for

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[45] In October, 2000 this practice was changed to a direct cash payment from MEA to PEA to increase transparency. The year 2000 agreement required cash payment between 8.5 and 9 billion baht (US$220 million to $230 million) per year (Praiwan 2003).

[46] CIDA's funding (0% interest, 10-year grace period, and 50-year repayment period) was tied to the purchase of Canadian aluminum, which was used to make the wires that carried Thailand's electricity (McDonald 1984).

Development, the Kuwaiti Fund for Economic Development[47], the Japanese Overseas Economic Cooperation Fund (OECF), and the German KfW (PEA 2000). All of these funders lent at exceptionally low interest rates (from 0 percent to a maximum of 4%), with long repayment periods (varying from 20 to 40 years). Repayment of these funds from international development agencies was guaranteed by the Thai government, and the loans were complemented by internal government budget expenditures. By 1980, over US$1 billion had been committed to PEA (McDonald 1984). By the late 1980s, EGAT was spending over $1 billion per year for new generation and transmission facilities (Ryder 1999).

By the mid-1980s, more than 75% of Thai villages had electricity. By 2000, basically the entire country was covered, with over 99% of Thailand's villages (around 80% of households[48]) electrified (Kruangpradit 1999; PEA 2000).

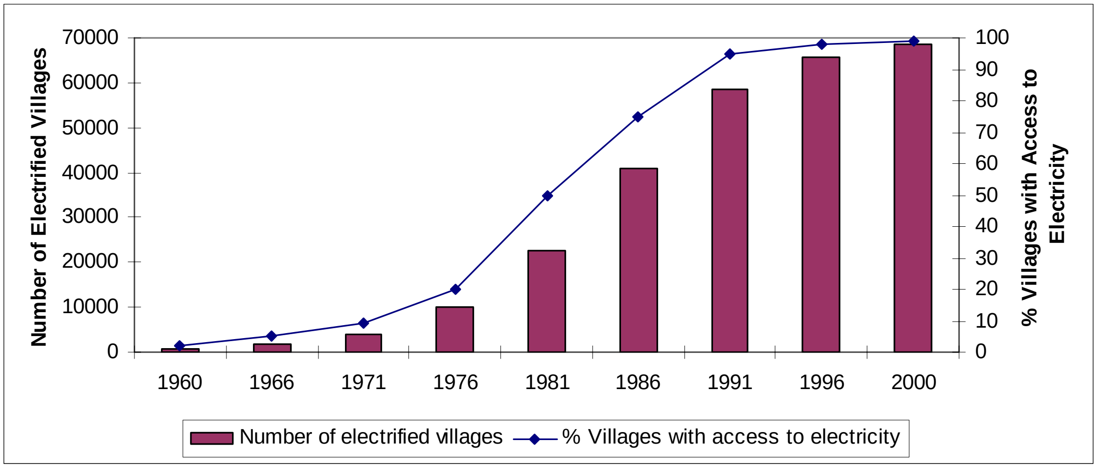

Figure 31: Number of electrified villages and percentage of villages with access to electricity.

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[47] The OPEC, Saudi, and Kuwaiti funds concentrated on electrifying Muslim areas in Thailand.

[48] A village is considered electrified when at least one household has electricity. Because some households in electrified villages do not have electricity, the percentage of electrified households is lower than the percentage of electrified villages.

The material successes of Thailand's electrification sent the message to Thai people that electricity is a privilege to which Thai citizens, whether city dwellers or rural villagers, were entitled. The convenience provided by this infrastructure, combined with the stark lack of these facilities across the border in Laos, Cambodia and Burma, provided a certain legitimacy to the Thai government, countering, to some extent, frustrations over unfair land distribution, low prices for agriculture produce[49], and endemic corruption (Phongpaichit 1998).

With expansion of rural electrification coverage came expansion of bureaucracy, assets, and debt. PEA's workforce grew rapidly from 2,116 in 1960 to peak at over 31,000 employees in 1994 – and failed to decline substantially as PEA's job of electrifying the country neared completion (upper line in Figure 32). Investment cost per additional customer served rose substantially as PEA's more profitable targets were reached and they extended their reach further into remote areas (lower line in Figure 32).

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[49] Thailand's economic development model from the 1950s through the mid-1980s followed a strategy of agricultural-export-led growth. Government investments in roads, irrigation, and green revolution crop varieties were coupled with rice export taxes which drove down rice prices for producers and pulled surplus out of the countryside to build up the urban economy and fund government. The gap in distribution of income between rural and urban areas grew steadily wider under these policies. By 1981 average per capita urban income was 2.5 times the rural level. Rural people resented this exploitation, and expressed their dissatisfaction through protests over debt, high rents, and low crop prices and (in some cases) through support for the communist insurgency (Phongpaichit 1998).

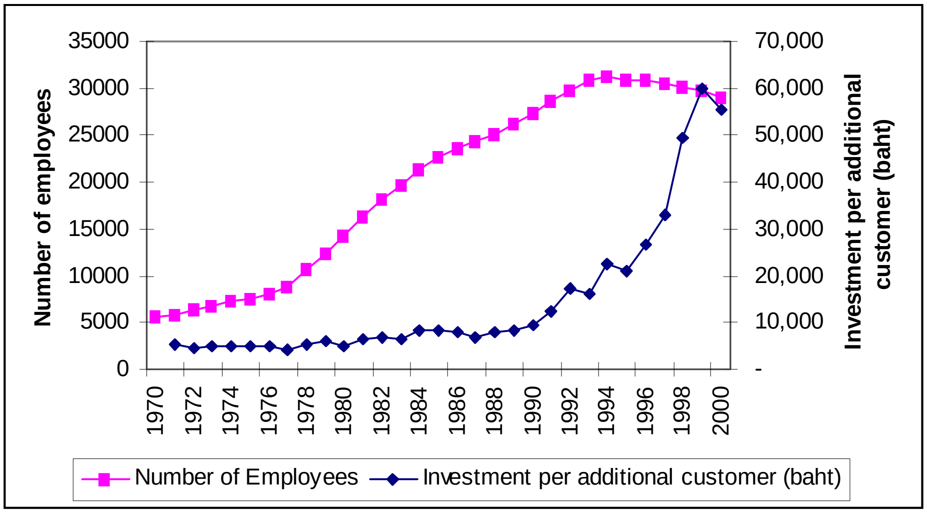

Figure 32: Number of PEA employees and investment per additional customer, from 1970 to 2000.

Net assets grew from 1,401 million baht in 1960 to 157,314 million baht in 2000 (a 112 fold increase). Net debt increased even more -- from 280 million baht to over 57 billion baht, an increase of over 204 times.

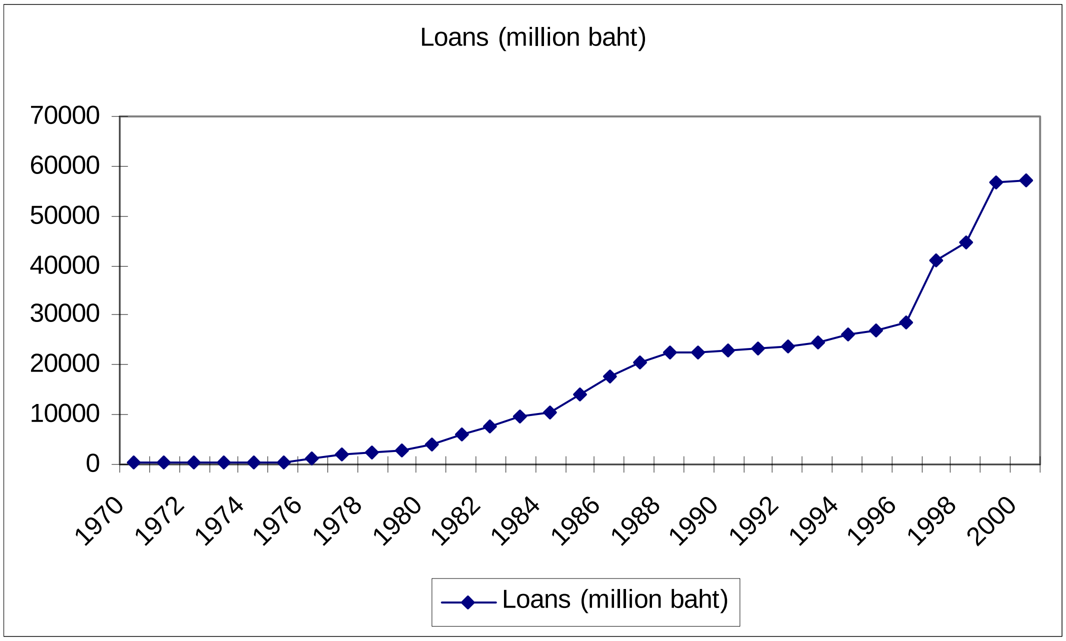

Figure 33: PEA outstanding loans

The continued availability of concessionary financing, the importance of electricity to its rural constituency, and the organization’s sheer size allowed PEA to gain political power (McDonald 1984). As its power increased, PEA concentrated less on profitability, agility and efficiency. These trends were enabled, if not encouraged, by the cross-subsidy policy. As of 2003, more profitable MEA transfers approximately US$15 million every month to the PEA (Praiwan 2003).

By the 1990s PEA was increasingly recognized as inefficient. As early as 1983 The International Bank for Reconstruction and Development (IBRD) chastised the PEA for spending too much for electrifying rural areas and warned PEA that steps were necessary to "prevent serious deterioration of PEA's financial viability" as a precondition of a $30 million loan (IBRD 1983).

A study conducted by the international consulting team Arthur Anderson in 2000 quantified a number of ways in which PEA was overstaffed and inefficient compared with international benchmarks. On the basis of energy sold per employee, and customers per employee, the study found that the productivity of PEA utility employees was 219% lower than international averages. The same study also found that PEA had more than twice as many managers per general staff as benchmark utilities, yet produced monthly management reports that "lack detail and rigour in analysis." The study faulted PEA for promotion based on seniority rather than merit, and also leveled criticisms regarding quality of service, citing poor performance on the System Average Interruption Duration Index (SAIDI), a measure of the duration of power outages. PEA's SAIDI was more 14 times worse than international benchmark of 111 minutes (Arthur Andersen, National Economic Research Associates et al. 2000).

Even with the evaporation of the Communist threat, non-economic projects were justified as important for nation building. One report justified a recent, expensive electrification project on islands as an effort to "expand civilization to rural areas… create a good viewpoint of villagers towards the government… help the villagers to not feel abandoned even though they live in remote islands and feel patriotic; and increase understanding between villagers and government using media on TV." (PEA Project Division System Planning Department 1996)

1960s-1990s – NEA declines

As PEA rose in power, NEA shrank. In theory it was the responsibility of the NEA to regulate the utilities. But by the 1970s in practice key decisions about where to build generators and wires and how to operate the system were made by utilities themselves. The utilities refused to share key information with the NEA which would have allowed the NEA to effectively serve as a regulatory body. As it became clear that the NEA lacked data, analytical capability, and enforcement authority, the NEA became simply a energy data-collection agency and also the agency entrusted with energy efficiency and renewable energy (McDonald 1984). The three utilities (EGAT, MEA and PEA) were essentially allowed to self-regulate – with the exception of basic financial requirements set by the Ministry of Finance.[50]

The NEA's power was also eroded, vis-à-vis PEA, because its primary responsibility had been regulation of cooperatives and private franchises, which were eliminated through PEA's expansion. In addition, the PEA was in a better position than the NEA to build clientele. PEA's provision of electricity service could be seen to benefit

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[50] Utilities must have a self-financing ratio of at least 25% and a debt-service coverage ratio of 1.5. In essence, these requirements are simply prescriptions for the setting of tariffs so that the utilities remain solvent.

consumers and politicians, whose concerns, in turn, could be called upon to obtain resources (McDonald 1984, p. 467).

NEA lost political power as well because it lacked a clear area of responsibility. Besides competing with PEA on rural electrification, the NEA competed with EGAT on power generation, with the Royal Irrigation Department on irrigation, and with both EGAT and later NEPO on energy efficiency (Interview 2001.10).

Rural electrification planning was complicated by the situation that EGAT, NEA, and PEA all undertook significant planning activities that had bearing on rural electrification, and each reported to a different ministry. EGAT reported to the Office of the Prime Minister, while PEA reported to the Ministry of Interior and the NEA reported to the Ministry of Science, Technology, and Energy. This, combined with the fact that most administrative decisions of any import are made the top of the Thai bureaucracy, meant that coordination of units had to take place at the highest levels of government.

Over the years, the NEA was transferred from ministry to ministry and suffered several name changes reflecting its declining status. In 1963 the NEA was transferred from the Office of the Prime Minister to be under the Ministry of National Development. In 1971 it was returned back to the office of the Prime Minister, and the name was changed from “National Energy Authority” to “National Energy Administration”. In 1979, it was transferred to be under the Ministry of Science, Technology and Energy. In 1992, the name was changed to be “Department of Energy Development and Promotion” (DEDP), reflecting its narrower role (DEDP 2001). In 2002 the name was changed again to the “Department of Alternative Energy Development and Efficiency” (DEDE), reflecting further marginalization as an agency focusing predominantly on alternative or non-conventional energy. In contrast, the PEA has remained throughout at the Ministry of Interior, one of the strongest ministries within the government.

Besides the obvious downgrading that these transitions entailed, they also denied the NEA the opportunity to form strong ties to ministries, and these, in turn, had negative implications for jurisdictional disputes.

1980s – NEA tries "Small is Beautiful"

In the midst of its decline, the NEA flirted with "Small is Beautiful" by initiating the Renewable Nonconventional Energy Project (RNEP) in 1984. The project enjoyed support from USAID, based on policies that had been shaped under the relatively progressive administration of US President Jimmy Carter, and received a total of 8 million baht (US$320,000) from the Thai government under the Fifth National 5-year (1982-86) plan. PEA over the same period was allocated 1100 million baht (US$44 million) (McDonald 1984).

The RNEP responded to growing concerns about rural/urban inequality and high prices of imported OPEC oil and especially diesel fuel. In 1981, electricity production used 83% of all fuel oil imported into Thailand. In the same year, an estimated 276 diesel generating plants throughout the country provided 90 MW of electricity and consumed 33 million liters of oil per year (NEA 1984).

The RNEP was designed with strong involvement of social scientists and included a substantial community participation component. A variety of renewable energy technologies were included: biogas digestors, solar water pumping, as well as the micro-hydroelectricity projects that are the focus of this research. A network of "rural energy centers" to facilitate the use of renewable energy was planned and funded.

The micro-hydro component called for local people to participate in construction, operation and maintenance, and for villages to manage the systems using community cooperatives – which harkened back to NEA's interest in supporting cooperatives almost 20 years earlier.

Three community micro-hydroelectric projects were built before USAID ceased funding the program under US President Ronald Reagan. However, the Thai government continued to provide funding for five or six projects per year through the 1980s (Figure 34). In the 1990s, funding was decreased and the DEDE currently has a plan to complete 10 additional projects between 2002 and 2012 (Interview 2002.04).

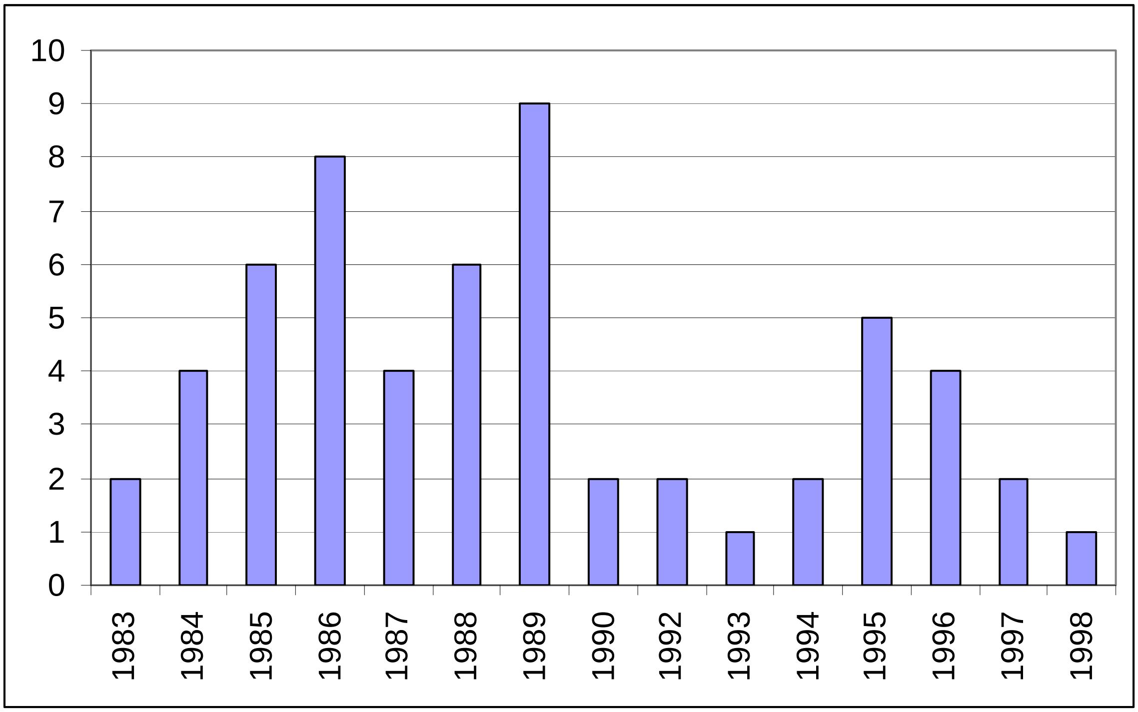

Figure 34: Micro-hydro projects completed per year through 1998.

These numbers hardly register compared with the hundreds or even thousands of villages electrified per year by the PEA. Access to funds plays a large role in the disparity. PEA has enjoyed a long legacy of concessionary financing with government-guaranteed loans from bilateral and multilateral funding agencies. Furthermore, PEA receives hundreds of millions of dollars in supplemental funding through the cross subsidy from MEA. Micro-hydro, in contrast, has used government budgets which tap largely internally generated capital. These funds compete with other government priorities, or require the government to borrow capital at commercial rates, usually with no grace period (McDonald 1984, p. 470). This disparity distorted the comparative costs of PEA electrification relative to micro-hydro, leading to grid-based rural electrification costs that are unrealistically low – even if they remain higher than community-based micro-hydro (McDonald 1984, p 469).

Village micro-hydro: the current situation

As discussed in Chapter 3, micro-hydroelectric systems continue to be both the source of electricity and village pride for thousands of remote households. Some of the systems have operated for as long as 18 years. There are unresolved challenges stemming from the common pool nature of the resource, and from some engineering shortcomings in the equipment. These challenges are significant, though (in many cases) probably resolvable.[51]

Contrary to what PEA officers said in the 1960s about rural Thai people being unable to manage cooperatives, electrical cooperatives can and do work in Thailand. To the extent that the systems have remained operating, it is because rural people value electricity and have the ability and desire to collectively put in the necessary work to make village micro-hydro cooperatives function. In doing so, they build upon on

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[51] Specific suggestions based on approaches that have worked in other countries are discussed in Chapter 7.

community strengths and generally report that they are proud of “their powerplant” and happy with the ways it brings the community together.

Barring extreme technical catastrophes or conflicts, it is generally only the arrival of the PEA grid that spells the death knell for a microhdyro system in a village. It is no surprise that when presented with the opportunity most villagers would choose PEA. From the villager’s perspective, subsidized electricity from PEA is a great deal: it is essentially maintenance-free, and has voltage that is generally stable – even if it also has considerable problems with power outages, especially caused by falling branches during storms in the rainy season.

The bureaucratic history of rural electrification suggests that PEA electrifies remote micro-hydro villages because it fits with PEA’s organizational objectives of “electrifying the whole country” and providing work for its overgrown staff. With the cross subsidy from MEA, the cost-plus based system in which profits are based on expenditures, and government-guarantees for concessionary loans it has had the means to fulfill these objectives.

Indeed, community micro-hydro villages make particularly attractive targets for PEA grid extension because these so-called “unelectrified households” make easy and good customers. Extending lines to these areas counts towards PEA’s quota of 150,000 households electrified under the “Rural Household Electrification Project 2nd Stage”, a project for which 4 billion baht (approximately $100 million) was allocated under the 8th National Economic and Social Development Plan (PEA 2002b). Not only does electrifying these villages fulfill the quota, but it does so for lower cost and promising higher revenues than electrifying truly unelectrified areas. Distribution costs within the village are lower because villages served by micro-hydro projects tend to be clustered, with generally at least 100 families in a radius of several kilometers. Revenues are higher because these “unelectrified” villages have already started on the process of accumulating and using electrical appliances, and are used to paying monthly bills.

Another factor that slows down micro-hydro development is a requirement that micro-hydro be built in locations which PEA determines will not receive grid service in the near future. The DEDE village micro-hydro division director complained that in some cases DEDE requested that villagers obtain a letter from PEA confirming that they would bring in electricity. Instead, the PEA wrote a letter saying they would electrify the village, so DEDE was not allowed to build a project. But it has been 10 years and PEA still has not brought in the lines. In other cases, PEA confirmed that they would not bring in the lines, and DEDE proceeded to built project, only to have PEA lines arrive two or three years later (Interview 2001.03). Ironically, at one point in time the DEDE (when it was still called the NEA) had the authority to regulate all electricity utilities and plan all energy projects within the country (United Nations 1963). By the beginning of the micro-hydro program in the 1980s, the roles had reversed and PEA was vested with the authority to deny service territory to NEA micro-hydro projects.

PEA’s power to determine where DEDE can or cannot build reflects a potential conflict of interest as both are ultimately in the business of providing rural electricity. Moreover, PEA has, since the late 1980s, become involved in renewable energy projects. This involvement has not come about through the result of systematic consideration of grid-extension vs. decentralized renewable energy as part of PEA’s general rural electrification activities. Rather, it is in response to specific opportunities to tap into external sources of funds, generally using turn-key technology packages from donor countries. Thus PEA has set up three experimental solar electric systems with Japanese turn-key technology funded 87% by a US$2 million grant from the Japanese government, a wind/PV/diesel hybrid system using Australian equipment largely funded by the Australian government, and initiated wind studies using mostly funding from the Thai National Energy Policy Office and the US Department of Energy.

PEA's renewable energy investments include one micro-hydroelectric/solar/diesel hybrid project. The project, Khun Pae, is a 90 kW (rated) hydro project installed in 1997 at a Royal Project near Hang Dong in Chiang Mai province. The project cost, at over 7 million baht, was several times more expensive than DEDE's Thai-built technology and requires a full-time PEA staff to be stationed full time to operate the plant. The project has proven to be costly for PEA. The predicted annual power output of the project was 100 MWh, but actual output has been only 65 MWh. Operating cost has ranged from 400,000 to 700,000 baht per year, with annual income 80,000 to 150,000 baht per year.

PEA is currently working on designs for several other stand-alone micro-hydro projects – two on islands in Trat Province, and two projects in Loei Province. The projects will also be turn-key projects using foreign technology. PEA takes little interest in the work already done by DEDE in micro-hydro, instead preferring turnkey solutions from foreign suppliers. As of 2002 none of PEA's several engineers that work on micro-hydroelectricity had ever visited a DEDE micro-hydro project, nor had PEA micro-hydro engineers talked to DEDE micro-hydro staff. Never the less, they said the DEDE technology was "low tech", and appeared surprised but not particularly interested that the turbines and generators used in DEDE installations were made in Thailand by Thai companies (Interview 2001.26). They said that DEDE turbines were poor quality and quickly abraded from sand within a year.

In 2003, PEA was chosen by the government to implement a program entitled *palangan fai fa ua atorn*, or "electricity handout project". The program will use solar home systems (SHS) to provide basic electricity services to 290,000 of Thailand's remaining unelectrified households. The first stage of the project calls for 99.8% subsidized[52] solar home systems for 150,000 households by April 2005 with a government expenditure of 3.8 billion baht (about US$100 million) (Daily News 2004; Interview 2004.8). The government subsidy per household for solar electric systems ($650) is comparable with the average per-household capital cost of community micro-hydro. The considerable sums of government money involved have attracted the attention of a variety of international and domestic businesses. However, irregularities in the bidding process have led to a number of complaints about lack of transparency (Taan Setagit 2003; Interview 2003.9; Daily News 2004).

While villagers are happy with the prospect of having electric lights and television (Interview 2004.11), concerns have been raised about the quality and long-term sustainability of the systems (Interview 2004.6). There are few trained technicians in Thailand capable of installing solar home systems relative to the aggressive timetable set for the project, and it is not certain how the industry will ramp up and ensure installation quality. Thailand's existing remote solar installations have suffered from a variety of design and installation errors (Greacen and Green 2001).

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[52] Villagers must pay 50 baht for each 23,000 baht solar home system.

The PEA SHS program raises an interesting question: “what constitutes an electrified village?” Interestingly, the PEA definition of “electrified” appears to relate more to who is providing the service, rather than the level of service. Even households with solar home systems will be considered “electrified” if these come from PEA’s SHS program, but villages with DEDE community micro-hydro are not considered electrified, even though micro-hydro systems provide about 8 times more electricity per household.[53]

The impact of this program on community micro-hydro is unclear, but is likely that the purchase of subsidized SHS systems by those households in remote communities that can afford to do so will likely decrease community unity and commitment to work together to build community-scale micro-hydro solutions.

In contrast to PEA’s rapid deployment of solar home systems, the DEDE micro-hydro division lumbers along installing only one system per year. The DEDE micro-hydro division chief complained that their office lacks sufficient manpower. The office employs only three civil servants and six temporary hire engineer/technicians. Counting drivers and assistants there are a total of 20 people. Budget constraints and a cap on new civil servant hires limit expansion of the DEDE micro-hydro program (Interview 2001.03).

Another reoccurring problem is that existing DEDE employees are promoted to management positions in other divisions and expertise about micro-hydro is lost in the process. This causes particular frustrations at the village level. Though they may have

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[53] Because solar systems have batteries and thus provide more reliable power when the users need it, and because they are household-scale units without micro-hydro’s village-level common property challenges, arguments can be made that “quantity” of electricity not the right metric in comparing the two technologies.

limited theoretical understanding, village micro-hydro operators build up a familiarity with quirks and fixes for their generators through years of practical experience. When it comes to fixing broken equipment, however, they often must rely on DEDE engineers and the pay for the parts that they specify. Operators complain that rotation of DEDE staff sometimes means that inexperienced engineers specify unnecessary or inappropriate equipment, and that village cooperative must pay for this even though the village micro-hydro operator knows that there are perhaps cheaper ways to fix the problem. The social hierarchy makes it nearly impossible for the village operator to question the expert government engineer (Interview 2002.01).

The fact that only one or two systems are built every year means there is only enough work for a single equipment manufacturer, a metal shop located in Chiang Mai that specializes in micro-hydro. The company has close ties with the DEDE and has been virtually the only supplier since 1981. The company's current owner worked for seven years in the DEDE micro-hydro division (Interview 2002.05). Lack of competition means lower quality and higher-priced equipment. The DEDE director cited the failure-prone AVR circuit as an example. The design was originally obtained by DEDE from a British company. Later DEDE staff built their own with some assistance from foreign consultants, and eventually could build the AVRs themselves for 5,000 baht each. Now, however, they lack the manpower and generally purchase them for 20,000 baht (Interview 2001.03).

Marginalization of community-micro-hydro creates a vicious circle. Villagers everywhere know about PEA. Few know of the community cooperative micro-hydro alternative, or if they do, they are aware of its mixed reputation. The DEDE village micro-hydro program only builds systems if villagers come to ask for them at their little office in the small town of Mae Jo 15 km north of Chiang Mai. If they do not know about the projects, they do not know to ask for them.

Although individuals within the organization may be motivated by a sense of professional responsibility to keep projects operating, DEDE as a bureaucracy is rewarded on the basis of the number of community systems it builds – not the number that remain functioning. When PEA comes in DEDE often removes the generator and turbine and installs them in a new village – essentially double-counting the same equipment when compiling lists of how many projects they have built. Perhaps for this reason, the central DEDE offices are unable to say how many systems remain functioning. The information they omit in their reports makes it very difficult to find these systems in the field. For similar reasons, the imminent arrival of the grid also often serves as an excuse to avoid addressing problems. In the words of one DEDE official, it makes, "no sense fixing it if PEA is going to come and wipe it out anyway" (Interview 2002.04).

Even though micro-hydro is cheaper than the grid in many cases, it could be even less expensive. By way of illustration, in Nepal there is a micro-hydro industry consisting of well over a dozen manufacturers. Installations of comparable size and technology in remote hills of Nepal are about half the price of Thai installations, even though in Nepal all the equipment has to be carried in over mountain trails on the backs of Sherpa porters. One significant difference is that Nepali designs use much less cement. An experienced Nepali hydropower engineer, on seeing photos of the weir of a 20 kW Thai installation, said, "we use that much cement for a 1 megawatt system." (Interview 2004.3) Technical innovations such as over-current cut-outs that have been in use a decade in Nepal are unknown to micro-hydro professionals in Thailand.

Micro-hydro vs. the grid – a question of labor vs. capital

PEA decisions (under the strong influence of US advisors) to dismiss decentralized micro-hydro as an option and to fight against community cooperatives should not be understood simply as a mean-spirited, US Cold-War inspired effort to close the door on clean, democratic and decentralized energy. A key consideration is that while cooperative micro-hydro may be more cost-effective than grid-based rural electrification approaches, the former is not necessarily as easy or convenient as the latter given PEA's organizational structure. Fundamentally, grid-based rural electrification requires higher investment in electrical hardware and in long term fuel costs, while micro-hydro requires a greater investment in people and training.

The tensions between investments in capital vs. human resource development can be seen in an off-grid electrification program in Laos, funded by the World Bank. Even though conditions are apparently much more favorable to micro-hydro, similar decisions to choose more expensive but more expedient technologies are being made. The program is directed by an engineer with strong "Small is Beautiful" credentials: he is the author of one of the few comprehensive books on the topic of micro-hydro project development in non-industrialized countries. In an interview in 2004, the program director said:

> "We're now focusing on PV instead of micro-hydro because micro-hydro is just too difficult for our limited staff. It's not because there's no micro-hydro resources. In fact, I'd like to be doing a lot more micro-hydro. But we just do not have the time. Every micro-hydro site is unique, with different costs, engineering requirements, and output. With PV it's more of a cookie cutter

> approach, and we can reduce our workload and serve more households faster." (Interview 2004.2)

Ironically, in a developing country where labor is abundant and capital is scarce, it is lack of labor that constrains micro-hydro development and more expensive options are chosen because they require less labor and can be deployed faster. Because of the importance of showing results, spending money on the fastest or most replicable option is, in the contemporary Lao case, more important than spending money on the most cost-effective option. It is easy to imagine that PEA's access to abundant sources of concessionary financing fostered similar pressures in Thailand several decades ago, and reduced incentives to explore alternatives. It would be interesting to learn more about the experiences in other countries where capital resources for rural electrification have been historically more limited, and where community micro-hydro became more institutionalized. What methods were used to spread knowledge about the design, installation and management of these systems?

In addition to this factor, as is apparent in the historical narrative in this chapter, alternatives such as community-managed micro-hydro were especially incompatible with PEA's top-down administrative structure because they required (a) that power and decision-making be vested within communities, in contradiction to the decision-making arrangements that characterized the rest of the electrified communities under its domain; and (b) technologies that were not part of PEA's standard toolkit. Whereas grid electrification consists of repeated deployment of standardized poles, wires and transformers, village micro-hydroelectricity requires considerable customization with its variations in head, flow, and topography, as well as investment in community social capital to engage in building and operating a self-sufficient system.

Summary and conclusions

Early on, cooperatives and distributed generation held significant promise in Thailand. But starting in the 1950s, electricity took on a powerful political meaning. US Cold War planners decided that a centralized state-owned company would be the best way to provide the rapid rural electrification they believed was necessary to fight Communism. Thus, key decisions in the 1950s and 60s shaped options for rural electrification in ways that strongly favored centralization of both electrical generation and administrative arrangements. In the 1960s efforts to build electrical distribution cooperatives were squashed by PEA, and the prospect of substantial rural electrification through decentralized stand-alone micro-hydro was also dismissed.

By the time the Cold War impetus had receded, the bureaucratic structure it had spawned took on a life of its own. The essential nature of the electricity services PEA provided and its location under the strong Ministry of Interior facilitated growth in political power, while access to cheap concessionary international financing fueled the expansion of both wires and bureaucracy. Meanwhile, the NEA declined in importance and stature, in part due to the collapse of US-backed vision of Mekong-wide electricity-led development (and NEA's role in it), in part because Thai utilities were able to stymie NEA's weak efforts to exert regulatory authority, and in part because the NEA lacked clientele that benefited from its existence. In the midst of its decline, the NEA (with USAID support) initiated the progressive Renewable Nonconventional Energy Project, of which community-based micro-hydro was a component. Under the Reagan presidency USAID withdrew funding for the NREP, but it continued as an under-resourced Thai government program. Despite its cost-effectiveness, community micro-hydro remained completely overshadowed by PEA's vastly greater political power, and suffered from DEDE's inability to compete for cross-subsidies and international concessionary financing that fueled PEA's growth. As the country runs out of places to electrify, the state-owned utility has no qualms about bringing the grid (and more recently PV) to so-called "unelectrified" micro-hydro villages, with little regard for economic efficiency.

These historical events shape the current situation in which the DEDE and the PEA both seek rural villages to electrify. In many villages, DEDE micro-hydroelectric systems have been abandoned when PEA lines have come in. In other cases, PEA and DEDE compete over villages in which to implement renewable energy projects. In these cases, the PEA has advantages of greater bureaucratic political power and deep pockets to fund both labor and higher quality foreign equipment for installations, whereas DEDE requires voluntary contributions of village labor and uses locally manufactured equipment. Thus, locally manufactured, community-managed renewables, though less expensive, are losing ground to more expensive, centrally controlled, often foreign manufactured rural electrification technologies. Ultimately the burden for this inefficient investment falls to Thai consumers and taxpayers.

Chapter 6: Synthesis and conclusions

Why is micro-hydroelectricity losing to the grid as the technology of choice for rural electrification in Thailand? The preceding chapters suggest a variety of factors ranging from high apparent costs (reflecting low subsidies relative to grid extension), mechanical & electrical problems (substandard micro-hydro equipment), resource scarcity (inadequate water, inadequate generation capacity), local resource governance failures (rules governing tariffs and compliance with these rules), deficient state support and various obstructions imposed by the structure and politics of national rural electrification.

Which of these explain the situation? In what ways do these factors work together to produce the distinct outcomes observed? Chapter two posed seven hypothetical explanations based on several bodies of theory. This chapter considers these hypotheses in light of the evidence and counter evidence discussed in subsequent chapters. Two key questions are asked of each hypothesis. First, is the hypothesis sound in light of the evidence (and counter evidence)? Second, to what extent, and in what contexts, is each hypothesis relevant as an explanatory factor? To further structure this second query, it is useful to consider the dissertation question in two parts: first, *Why were so few micro-hydro projects built?*; and second, *Why have many of the existing projects been abandoned?*

Recognizing that some hypotheses are more useful than others, this chapter ends with a discussion on the applicability of the theoretical perspectives discussed in Chapter 2 and the implications of the empirical findings for further developments of theory.

I begin by considering the extent to which each of the hypotheses appears to be validated or refuted by empirical and historical data presented in the preceding chapters.

Hypothesis veracity

Hypothesis 1: For the Thai public, there are few cases in which micro-hydroelectricity is an optimal investment

There appears little evidence to support hypothesis 1, and much evidence against it. However, an incomplete understanding of benefits leaves some room for doubt. Working against the hypothesis are the following: the mathematical relationship between households economically served by microhydro and distance from the grid (Eq 4-2) suggests that micro-hydro is economically preferable (assuming sufficient water resources) in many areas. Even in the current era in which the distribution grid extends deep into the rural countryside, the formula suggests that many areas remain most inexpensively served by hydro. Economic analysis of projects in the field suggests that in practice as well as in theory, micro-hydro has proven to be a cheaper way to bring electricity to unelectrified rural villages.

On the other hand, the spatial and temporal dynamics of rural electrification planning, the long-term uncertainties of rural development and the difficulties of economically valuing power quality introduce sufficient uncertainty into economic comparison of micro-hydro and the grid to suggest that despite considerably higher costs, grid extension may still be more economic depending on what benefits that are assessed and how they are valued.

With this said, opportunities now available to interconnect micro-hydro profitably with the grid afford considerable benefits for the Thai public as well as villagers (if they have rights to revenues). Thus it appears that risks of "building and then regretting" are low. To the extent that these risks were ever a significant concern, it is a reflection not so much on micro-hydro *per se*, but rather the realities of poorly coordinated rural electrification planning vis-à-vis micro-hydro (addressed in hypothesis 7).

Hypothesis 2: For villagers, there are few cases in which micro-hydroelectricity is an optimal investment

Economic analysis in Chapter 4 upholds this hypothesis. Tariffs paid by villagers for micro-hydro (typically 2 baht or $0.05 per kWh) exceed tariffs paid for PEA electricity by small residential customers (1.576 baht or $.0394 per kWh).

In addition, constructing the micro-hydro requires a collective village labor contribution of 15 laborers working for one solid year, whereas PEA electricity requires no such contributions. Assuming an average village size of 221 households, the labor requirement per household is approximately 25 person-days.

In the case in which the grid arrives to a village that already has a micro-hydroelectric system, the analysis in Chapter 4 also indicates that unless costs of repairing and retrofitting the micro-hydro are exceptionally expensive, it is favorable from both from the public perspective and from the villagers perspective to continue operating the facility and to interconnect it to sell electricity back to the grid.

Hypothesis 3: Physical circumstances do not favor micro-hydro in Thailand.

Overall, physical circumstances in a significant minority of cases do appear to be unfavorable to micro-hydro. The physical circumstance of paramount concern in this context is the availability of sufficient water dropping sufficient height. As discussed in Chapter 3, respondents from villages claimed that water supplies were inadequate year-round in three cases (two with abandoned installations, and one in an installation that remains functioning), and inadequate during the dry season in 20 cases (12 villages with abandoned projects, 8 villages with operational projects).

This appears a significant number, considering that there were 59 projects overall. Water availability may be insufficient because original surveys and plant designs overestimated the resource. This is quite plausible given that lack of long-term hydrological data forces DEDE micro-hydro project designers to make assumptions about year-round stream flow based on calculations of catchment area, annual rainfall, and assumptions of runoff coefficients. In cases where water flows were originally sufficient, they may now be insufficient due to land-use changes in the watershed. This is expected to be true especially during the dry season, as reduction of vegetation reduces the rainfall retention capability of the watershed (Chow, Maidment et al. 1988).

A significant compounding factor is that village respondents appear to intuitively blame lack of sufficient electricity on water supplies when, in fact, the true causes of power shortages may arise from other factors such as collective over-consumption of electricity. In 14 out of 14 projects, villagers verified signs of consumption exceeding generation capacity: sufficient electricity for the first several years, a general pattern of increasing appliance ownership, followed by persistent low evening time voltages.

However, the fact that villages identified low *dry-season* flows suggests that water availability is in fact the correct diagnosis of the problem in a significant minority of systems. The reason for confidence in villager’s assessment in this case is that electricity demand is not likely to increase during the hot dry season (air conditioning is not a load found on any systems). Thus, even if villagers do conflate electricity shortage with water shortage, dry season electricity shortage is still best explained by seasonal variation in water supply.

Another physical circumstance of possible concern is that the terrain, soil conditions, or other factors are not suitable for the construction or long-term operation of micro-hydroelectric projects. The fact that only a very small minority (3 systems) suffered problems from landslides or other terrain related problems suggests that these are not a significant concern.

Hypothesis 4: There is a mismatch between village electricity consumption patterns and the production capabilities of village micro-hydro – and this is linked to a mismatch between rules governing user behavior and the technical characteristics of the system

That there is a mismatch between generation and demand is clear from the depressed evening voltages and concomitant high evening time current readings datalogged in the course of this research (e.g. Figure 12 and Figure 14), and the widespread complaints of frequent brownouts (48 out of 58 systems) and blackouts (41 out of 58 systems). If the results of the in-depth investigation of two villages are representative of the situation in most villages then the causes of this mismatch are also clear: a pernicious combination of generating equipment that performs considerably below rated capacity, lack of power factor correction, and unchecked growth of collective electrical consumption.

These circumstances lead not only to low power quality, but also to frequent equipment failures. As an electro-mechanical device, micro-hydro units have clear limits. Even when functioning properly and with adequate water the systems can only produce a limited amount of electricity. In practice in the field, these limits are stretched when collective consumption of electricity rises above the generating capacity of the system. Shafts break, controllers fail, bearings seize up, and AVRs (which appear to be designed with inadequate self-protection) burn up.

Rules governing behavior, especially the tariff structures used in villages, are not well matched with the technical characteristics of the micro-hydroelectric generator. Villages either charge a flat rate per household (7 systems), use kWh meters (37 systems) or charge per appliance owned (6 systems). The flat rate system is clearly inappropriate as it provides no incentive whatsoever to conserve electricity. The kWh meter system charges users on the basis of total monthly electricity consumption, but fails to provide a signal that reflects the peak-power limited nature of stand-alone micro-hydro. Of the three tariff arrangements employed, the “per appliance” system is perhaps most appropriate, but penalizes people for how many appliances they own rather than how many they use at any one time.

Experience in Nepal and Uganda indicate that electricity sold on a subscription basis using current-limiting cutouts provides can be useful in avoiding the endemic peak period over-consumption problems documented in Chapter 3.

Hypothesis 5: Village management is deficient

Village management may be deficient in some cases, but in general does not seem to be a core problem. Contrary to the expectations of PEA naysayers in the 1960s (Chapter 5), organizing rural Thai communities to engage in cooperative management of electrical infrastructure is not a “waste of time”. As discussed in Chapter 3, out of 50 villages, respondents from 35 claimed that their cooperatives were profitable. Surprisingly even the cooperatives of projects that were abandoned were profitable while they were operating. Out of 27 abandoned projects, 20 were described as profitable. Micro-hydro cooperative funds have played an important role in micro-credit lending and in financing community development projects. Another indicator of the efficacy of village management is the perceptions of residents: respondents from a majority (35 out of 59) of villages positively perceived the projects.

Clearly village management has not succeeded in addressing demand growth (see hypothesis 4 above). But it appears that this is more the result of lack of training and support from the outside (see hypothesis 6 below). It is difficult to expect that the village by itself would be aware that (a) load growth was a significant problem; or (b) that there are a number of tools available to address the problem.

Hypothesis 6: The state program charged with supporting community micro-hydro has failed to address key areas for sustainable operation (misallocation at program level).

With limited resources, the DEDE village micro-hydro office has managed to work with villages to build one or two new projects a year for the past decade. In addition, the office has provided repair services for existing installations – though often at a pace frustratingly slow for communities left without power. The office and its subcontracted technology providers have performed particularly poorly, however, in addressing the root technical causes of persistent or common equipment failures: weak AVRs, over-rated equipment, and non-existent power factor correction. Much of this can be attributed to the office’s failure to stay abreast with changes in world-wide standard micro-hydro practice. Equipment remains expensive and at the same time, not as reliable as it could be if innovations already commonplace in other countries were adopted in Thailand.

The office has also failed by defining their role too narrowly, focusing only on supply and offering virtually no guidance or support on demand-side issues. Virtually no attention is given to working with communities to develop rules and ultimately patterns of electrical consumption that maximize benefits and work within the limitations of these systems -- with consequences discussed above in hypothesis 4.

Hypothesis 7: The hegemony of the parastatal rural electrification utility and its focus on grid electrification have reduced opportunities for cost-effective deployment and operation of micro-hydroelectricity.

Chapter 5 documents the emergence of the PEA as a large parastatal monopoly that came to control, for practical purposes, rural electrification decisions in the country. The PEA was essentially allowed to self-regulate and to pass costs directly to both urban and rural consumers. Profits were fixed as a percentage of expenditures, so PEA could only earn more by spending more. Economic efficiency took a back seat to expansion.

The site-specific nature of the technology of micro-hydroelectricity was incompatible with PEA’s standardized rural electrification model of “wires, poles and transformers”, and with the hurried timetables of aid-funded, Cold-War inspired rapid service expansion. The prospect of electrical cooperatives threatened PEA’s administrative structure in which expertise and control are centralized. Thus PEA in the late 1960s fought successfully against public ownership and control of electricity infrastructure, and developed a nearly exclusive reliance on conventional centralized technologies rather than distributed renewable energy generation. The rival bureaucracy, NEA, which embraced cooperatives and micro-hydroelectricity was radically reduced in stature through a combination of bureaucratic infighting, poor strategic positioning, lack of a clear constituency, lack of analytical capacity, and inability to extract information from the parastatal utilities it was authorized to regulate.

Administratively centralized grid electrification became institutionalized. Thousands of careers were built on the practice of grid-based electrification. Supply chains were established, lines of credit were opened with international finance intuitions, and the public universally associated rural electrification with a centralized grid model. Decentralized micro-hydroelectricity were (and still are) never systematically considered as an alternative in electrification plans. The original stated organizational objective of universal rural electrification took on a defacto meaning of “universal grid-extension rural electrification”.

To the extent that PEA did initiate renewable energy projects, it was always using turn-key technology from foreign suppliers, tapping into foreign aid opportunities, Thailand’s domestic ENCON fund for renewable energy, or direct government funds. The experience of locally-made, locally controlled village-cooperative micro-hydro has been willfully ignored.

To summarize, of the eight hypotheses discussed above, all except 1 “micro-hydroelectricity appears more costly to the state” and 6, “village management is deficient” appear to be validated by empirical and/or historical data. Empirical data indicates that community-micro-hydro is *less* expensive from the state perspective; and that village management is, for the most part, not deficient.

Hypothesis relevance

To what extent are the hypotheses relevant? That is, to what extent do they provide convincing explanations for the key questions of this dissertation: *Why were so few micro-hydro projects built?* and *Why have many of the existing projects been abandoned?*

Part 1: Why were so few micro-hydro projects built?

In answering the question, “Why were so few micro-hydro projects built?”, hypothesis 7 plays a primary role, with hypothesis 2 playing a secondary role, and others playing minor roles.

Hypothesis 7 suggests that the dominant position of the parastatal rural electrification utility and its focus on grid electrification have reduced opportunities for cost-effective deployment and operation of micro-hydroelectricity. One of the key ways that this happened was through the structuring of rural electrification decision-making in ways that did not include cost-based analysis of micro-hydro (or other options) as alternatives to grid extension.

Since its inception, PEA’s performance has been perceived as generally satisfactory, and PEA has remained in firm control of the national rural electrification agenda. Community micro-hydro began on the sidelines and remained there. Decisions establishing programs, setting rural electrification targets, allocating budgets, and decisions concerning *where* electrification happens, *when* and with *what* technology were therefore made for the most part, in the Bangkok offices of the PEA. Villages do not ask for PEA electrification. Rather, PEA expands its service area in accordance with internally generated plans and priorities – that do not include consideration of community micro-hydroelectricity as an option.

As long as community micro-hydroelectricity was not an electrification option under consideration, the lower cost of micro-hydro to the state (explored in hypotheses 1) did not matter as the types of analyses that might provide this kind of answer were not included in rural electrification decision-making.

The community micro-hydro program was from the beginning granted authority to install systems only in the declining margins of areas not served by PEA's expanding network. Furthermore, DEDE can only initiate village micro-hydro projects when leaders from villages (that are sufficiently far from the grid, and meet other criteria) come to ask for an installation. Because there are so few installations, few communities[54] are aware that micro-hydroelectricity is an option, and therefore few approach the DEDE to collaboratively build the projects.

The fact that micro-hydro is more costly from the villager's perspective (addressed in hypothesis 2) further prevents substantial numbers of communities from opting for community micro-hydro if the arrival of the grid was expected. Thus, micro-hydroelectricity was from the beginning a "second choice" pursued by a handful of communities aware of the option and who felt that they had little prospect of being connected to the grid in the near future.

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[54] Limited awareness of the micro-hydro option is suggested by the geographic clustering of systems in Chiang Mai province, compared with the expanse of remote territory with suitable terrain throughout the country and especially in the northwest: Mae Hong Song, Fang, Chiang Rai, Tak, and Nan provinces.

The physical conditions (hypothesis 3), common-pool resource issues (hypothesis 4), and challenges with village and state management (5 & 6) are relevant only to the limited extent that word of these issues spread among villages considering the micro-hydro option.

Before the first DEDE community micro-hydro project was built in 1983, PEA had electrified over 23,000 communities, and was electrifying villages at a rate of over 3000 villages per year. It had over 15,000 employees, had spent over $1 billion, and was growing rapidly. By 2000, PEA has 30,000 employees, and electrified an average of 2,400 villages per year between 1981 and 2000. DEDE’s community micro-hydro program, on the other hand, employs 20 people and has electrified on average about 3 villages per year over the same timeframe. In a budget allocated for years 2001-5, the government authorized PEA to spend (US$100,000,000) for grid extension to 150,000 rural households in the country – not including funds generated from its own revenues and from cross subsidies from urban electricity users. During the same period, the DEDE’s village micro-hydro office will receive less than 1/100th this amount.

To summarize – for answering the question *Why were so few projects built?*, villagers’ experience with micro-hydro hardly mattered. Through foreign aid, state support, cross-subsidy, and generally satisfied constituents, PEA became the dominant force in rural electrification. Against the backdrop of PEA’s strength, DEDE’s community micro-hydroelectric alternative, housed in the provincial offices of a declining bureaucracy, was a virtually invisible competitor. PEA grid expansion occurred with no consideration of the possibility that community micro-hydro might be more cost effective. To the extent that community micro-hydro was chosen, it was only by villages

(a) aware of the option; and (b) willing to pursue it despite higher apparent village costs because grid-extension did not appear to likely to reach their village in the foreseeable future.

Part 2: Why do so few projects remain operating?

The "part 2" question, in many ways, is the more interesting one: *why do so few micro-hydro projects remain operating*? Here village experience matters much more, because village micro-hydro cooperatives ultimately make the decision of whether or not to continue operating the micro-hydro plant and households also decide whether to connect or disconnect. Again, however, the dominant position of PEA and its grid expansion activities (hypothesis 7) plays a key catalytic role: in the vast majority of cases, according to village respondents the micro-hydro generator is abandoned *when* and *because* the grid arrives (see Chapter 3, Figure 4). By prioritizing grid extension to clustered communities with existing electrical loads, PEA grid expansion plans favor villages with existing micro-hydro generators over those with no electricity.

Hypothesis 1 (for the Thai public, there are few cases in which micro-hydroelectricity is an optimal investment) appears to have limited relevance for system abandonment as the "public investment" in question is already a sunk cost, and not a cost borne by the villagers who ultimately decide whether or not to abandon the system.

Hypothesis 2, that there are few cases in which micro-hydro appears to be a good investment, appears to be relevant for the most part. Tariffs paid by villagers for micro-hydro (typically 2 baht or \$0.05 per unit) generally exceed tariffs paid for PEA electricity by small residential customers (1.576 baht or \$.0394 per unit). Considering that household wages in most of the villages are under \$2 per day, even small differences in monthly electricity bills between micro-hydro and grid electrification may be sufficient to entice households to disconnect from the micro-hydro and choose PEA if they have the option. Furthermore, benefits in terms of power quality from PEA appears to be higher than with micro-hydro systems, especially in the long run as village loads grow. Thus, given a choice, rational economic actors would choose PEA.

Hypothesis 3, relating to lack of sufficient water supplies to run the micro-hydro are clearly an important factor in decision of a significant minority of projects (12 that were abandoned) that have these problems. In these cases, lack of water is yet another cause of blackouts and brownouts that plague most systems.

Hypothesis 4, concerning the mismatch between electricity supply, demand and the tariff structures, appears to be very significant in virtually all projects. The majority of projects (abandoned or not) suffer(ed) from some combination of blackouts and brownouts which, as analyzed in Chapter 3, are due to pernicious combinations of poor equipment and collective over-consumption. Collective over consumption, in turn, is linked to tariff arrangements that fail to provide incentives to reduce peak evening load. Low quality equipment combined with collective over-consumption leads to various manifestations of low power quality and equipment failures that raise frustrations that respondents report as reasons for abandoning systems.

Hypothesis 5, that village management is deficient, is not relevant because empirical findings of this research suggest that it is generally not true.

Hypothesis 6, that support from the state program charged with supporting community micro-hydro is deficient, appears to be an important explanatory factor as well. In the short-term, delays in fixing broken equipment add to costs and frustrations experienced by villagers. In the larger scope of the program as a whole, the DEDE micro-hydro office appears to place strong emphasis on supply side (project construction) while placing very little emphasis on demand side issues or on researching and adopting innovations from international micro-hydro experience. As a result, as discussed in Chapter 5, Thai micro-hydro installations are expensive yet perform poorly compared with installations in other countries, and generators are overwhelmed after several years from unchecked growth in electrical demand (hypothesis 4).

Together the issues covered in hypotheses 2, 3, 4, and 6 constitute significant burdens for communities with micro-hydro systems. It is clear that many villages “muddle through” with frustrating blackouts and brownouts, broken appliances from voltage extremes, and long waits to fix village micro-hydro generators – though they also remain proud of “their power plant” and a majority still have a positive view of community micro-hydro (even intermittent electricity is better than none).

PEA’s arrival, decided in distant Bangkok offices that do not consider villages with micro-hydro as “electrified” yet prioritizes them due to their clustered nature and presence of electrical loads, has spelled the death knell for 31 out of 34 abandoned systems. Thus, though issues addressed in hypotheses 2, 3, 4 and 6 contribute strongly, ultimately PEA’s dominant position and increasing grid network (hypothesis 7) is catalytic.

Implications for theory

What are the implications of this research for the further development of theory? Below, I consider the theoretical bodies of literature employed in this research and discuss the theoretical implications of the empirical findings and the hypothesis they support.

Political economy of technology choice

The strong explanatory power of "hypothesis 7" in addressing the core question posed by this research suggests that, at least in the choice of electrification technologies in Thailand, bureaucratic history and politics matters a lot. In this context, following Ferguson, it is an illustrative exercise to reflect on micro-hydro and its interactions with the political economic structure in place as a way to understand that structure.

With this in mind, the importance of political power and the dominance of the parastatal PEA is underscored by the simple fact that the vast majority of rural electrification proceeds on terms and timetables prescribed by PEA, in areas determined by PEA, with no consideration of alternatives. Vast rural electrification budgets are defacto grid-extension budgets. PEA faces no contest to its service territory claims of the entire country outside the Bangkok metropolitan area. To the extent that micro-hydro happens, it is with tiny budgets in vulnerable service territory in the declining margins of PEA's frontier.

In an effort to understand the structure that constrains community micro-hydro, and the origins of that structure, it is clear that Winer's concept of "technological inertia" applies to PEA's single-minded adherence to grid extension. Similarly, the empirical evidence developed in this research validates Thomas' observation that the ways in which technologies are chosen are often consistent with organizational objectives. PEA's hierarchical centralized administration fits well with the traditional grid model of a one-way flow of electricity, a one way flow of money, and centralization of dispatch and control of generators.

But labeling interests of actors and noting that they are similar to the nature of outcomes is not sufficient. Digging deeper into why the structure has evolved the way it has, this research makes the (hardly unique) appeal to agency: key people and key events shaped history in specific ways. The actions were not necessarily driven by a desire to consolidate power for PEA. Rather, they were motivated by a variety of context-specific concerns including increasing economic efficiency, improving in power quality, enhancing rural/urban equality, or even geopolitical concerns. Together, however, these had the effect of strengthening the dominance of the PEA and the hegemony of grid electrification. Some of the key events, groups, and reasons are listed below:

- Driven in part by Cold War concerns, the World Bank (with support of Thai government) encouraged and helped fund Thailand to conduct rural electrification using a centralized parastatal administrative structure. US advisors encouraged centralized grid over non-centralized alternatives.
- Specific PEA policies, conceived as part of a plan to build system stability and lower costs in the long-term, promoted grid expansion specifically to eliminate auto-generation, and absorbed or eliminated independent utilities.
- Efforts to establish cooperative rural electrification by NRECA and NEA were seen as a threat to PEA's early rural electrification efforts and crushed by high level PEA officials and their US advisors.

- Cost of electricity provision was de-emphasized with the establishment of a national uniform tariff and accompanying cross subsidy from MEA to PEA. This provided PEA with a long-term source of funding for non-economic investments. The World Bank and other bilateral and multilateral agencies supplied PEA with concessionary financing while Thai governments (both democratic and military) consistently provided loan guarantees, seeing universal electrification as a key national-building activity.
- PEA gained power relative to the NEA because it had a readily-identifiable constituency and it delivered results, whereas NEA lacked the analytical tools, access to data, and ability to perform its authorized role as energy regulator.
- The NEA's micro-hydro program faltered from the beginning because it was part of a relatively insignificant, low-budget alternative rural development program, because its constituency was small, rural and powerless, and because it was denied guarantees of service territory.

The challenges encountered in efforts to pursue the economically and technically obvious interconnection of village micro-hydro generators to the grid suggest that even though PEA is a powerful actor in the perpetuation of centralized grid model, it is not the only one. Other arms of the state including tax authorities, and those in charge of granting power generation concessions have built up bureaucratic aparati that support a particular technological and administrative approach to rural electricity provision. This constellation of control follows Foucault's decentralized conception of power (Foucault, 1979) in suggesting that in connecting outcomes with power, it is not sufficient to give the utility a central place.

This research shows that political economy theories -- when extended to the include specific concerns of technological inertia, technology choice, and decentralized power (both in Foucault’s sense, and in the sense of decentralized electrical generation) -- provide key insights into understanding the specific ways in which politics and constellations of other factors eclipse rational economic behavior regarding provision of electricity.

Diffusion theory and barriers to clean energy dissemination

In trying to apply diffusion theories and social barriers literature to the situation of village-scale micro-hydroelectricity in Thailand, one shortcoming that emerges is that the theories generally addresses technology uptake *in the marketplace* by supposedly *autonomous individuals*. This perspective offers insufficient guidance in the case of technology choice in community or larger-scale rural electrification infrastructure which is dominated by intervention by the state, as is the case with rural electrification and micro-hydroelectricity (and indeed most renewable energy) in Thailand. In addition, because barriers literature focuses on technology diffusion and uptake, rather than long-term use, it offers insufficient explanations for cases in which technology has been adopted only to be later abandoned in a number of cases. There are exceptions to this generalization, however. Roy’s (1994) focus on where and how diffusion agencies operate is certainly relevant in understanding how DEDE’s single small yet centralized office, and its emphasis on technology installation rather than long-term sustainability have provided insufficient support to stem marginalization of micro-hydro (hypothesis 6). This failure, however, has origins outside of the small DEDE office itself.

The example above highlights that perhaps the most important shortcoming of both diffusion and barriers literature is that while the literatures are useful in recognizing symptoms they provide little insight into the structural or historical bases these problems. Regarding the barriers to renewable energy dissemination in Thailand, barriers literature tends to view these problems as problems of inadequate information or capacity. For example, the challenges described above that emanate from bureaucratic power are categorized as an "insufficient policy environment" (G8 Renewable Energy Task Force 2001) or "poor coordination among government agencies" (Sajjakulnukit 2000).

While these diagnoses are true to a certain extent, they barely scratch the surface and present a misleading impression that with increased meetings to coordinate activities or an improved policy document the issues would be resolved. The diagnosis misses the extreme differences in political power between actors, and the prospect that what may on the surface appear to be "coordination problems" may actually reflect deep long-standing rivalries, or reflect the fact that a weak government agency or program may have very little to bring to the table when bargaining with a large agency (or parastatal utility) reluctant to change customary practices.

Thus, this research suggests that diffusion and social barriers literature, as applied to renewable energy in developing country contexts, would be more effective if it paid closer attention to agency, history, and power relations among actors.

Economics

Economics holds a mixed position in this research. At the national level in which allocations of rural electrification budgets are made, while economic calculations almost certainly play a role in system expansion plans it appears that economic analysis of alternatives such as community-managed micro-hydro is completely absent. The potential economic advantages of these systems are masked by a predetermined technology choice for grid extension. On the other hand, at the village level where people make choices involving their own money or their own labor, economics is very relevant.

Economic benefit cost analyses, as those developed in Chapter 4, show micro-hydropower to be very competitive with conventional grid options in many cases, especially if steps can be taken to manage village load growth in the long term, or if opportunities exist to connect and sell electricity back to the grid if or when the grid comes. Community development benefits and environmental externalities further increase the competitiveness of the technology. However, economic competitiveness does not matter if economic analysis comparing options are not part of the planning process. Here the economics of micro-hydro is circumscribed by bureaucratic politics and technological inertia.

To state a similar point in different terms, much of the existing literature that addresses the dissemination and sustainability of renewable energy is fond of noting that subsidies distort markets. In the case of Thai micro-hydro (and what is going on in much of China, and many other countries where the state plays a strong role in rural electrification and technology choice) the subsidy and the politics of subsidy are so overwhelming that it makes little sense to speak of markets – at least in the micro-economic sense that "markets allocate resources."

At the village level, however, economics is very relevant. Though villagers cannot choose when or whether grid power will arrive, they can choose to collectively invest in a village micro-hydro system, and they can also decide collectively whether or not to continue using an already built micro-hydro in the event that the grid does arrive. As individual households, villagers make economic choices about whether or not to hook up or disconnect from either micro-hydro or the grid if they are available. These choices entail costs and benefits, as well as implicit assumptions about discount rates.

Ironically, at the village level where choices are made in part on the basis of costs, the relative costs of micro-hydro and the grid are severely distorted. Micro-hydro is subsidized far less than grid electrification, with the consequence that villagers who behave economically rationally choose the grid if it is available.

This research suggests that cashflow analysis from the perspective of various actors (chapter 4) plays a useful role in illuminating and quantifying the favorable overall costs of microhydro, revealing the extent of subsidies for the grid, and explaining the economically rational behavior of villagers in deciding to be wary of choosing to implement micro-hydro projects. However, while micro-economics illuminates perverse incentives that operate at variety of levels to encourage grid and discourage community micro-hydro, like barriers literature it offers little explanation of how these arise. Though many micro-economists could find ways to extend the economics further than the relatively limited analysis in this research, it appears that in cases such as these micro-economics is blinded by its fundamental assumption that economic actors make economically rational decisions. In arenas like this in which outcomes are based on many non-economic factors, micro-economics is useful as a tool of critique but has limited explanatory power unless combined with other analytical approaches that are sensitive to history and politics.

Common Pool Resource theory

The findings and analysis in Chapter 3 suggest that CPR theories are a useful new addition to the theoretical toolkit of those involved in village-scale renewable energy systems. This research pioneers a methodology combining data logging, assessments of equipment damage, surveys of appliance, and surveys of user experiences to produce quantitative assessments of the nature, severity, and consequences of collective over consumption in village power systems. Application of the methodology reveals causal linkages between appliance use patterns, equipment limitations, power quality, and equipment failures.

Explaining and analyzing the origin of collective over consumption problems as arising in part from a linkage between and the design and enforcement of the tariff (the “rules governing behavior” to use Oakersons’ language) and the technical characteristics of the generator is a key theoretical insight afforded by CPR theory. Besides capturing the essence of the problem, the insight offers new theoretical basis for understanding a key solution so far unheard of in Thailand: current limiters to align tariff structure with the peak power limited nature of community micro-hydro.

Given the strong explanatory power of CPR theory in diagnosing village power systems, it is surprising that this dissertation is apparently the first time that CPR theory has extended into the domain of electrification: a search of over 22,000 entries in the *Comprehensive Bibliography of Common Pool Resources* revealed no relevant articles with keywords “electrification”, “micro-hydro”, “hydroelectricity”, “village power” (Hess 1999).

On the basis of these findings, I suggest a variety of interventions and areas of further research on community micro-hydro systems spanning technical issues, community governance, details of state support, and opportunities for reforming the relationship between micro-hydroelectricity and the national grid. These are discussed below in Chapter 7

Chapter 7: Policy implications and areas for further research

This research has identified a constellation of factors that shape and limit opportunities for community-managed micro-hydro in Thailand. This chapter explores options that are available to facilitate continued cost-effective deployment of this and other village-scale technologies in Thailand and the region. The chapter discusses VSPP laws that allow small renewable energy generators in Thailand to interconnect to the grid. This is followed by a discussion of options available to facilitate long-term use of existing micro-hydro systems in villages that remain distant from the grid. Finally, a number of suggestions are proposed for further research.

Grid-connected village micro-hydro

This research has shown that as the grid expands, the option to interconnect village micro-hydro generators to connect to the national grid under favorable terms presents win-win possibilities for villagers and the public. I was fortunate to have the opportunity to help draft such legislation for Thailand during the course of this research. The laws, known as “Regulations to purchase electricity from Very Small Power Producers (VSPPs)” were adopted by the Thai Cabinet in May 2002. The laws require MEA and PEA to allow micro-hydroelectricity, solar, wind, biomass or biogas generators up to 1 MW per installation streamlined access to connect to the grid. The regulations provide for *net metering*, which means renewable energy producers can literally “spin the meter backwards”. Under this arrangement, generators that produce less than they consume in a monthly period receive the retail tariff rate for electricity fed onto the grid. For net excess production, producers are compensated at the “bulk supply tariff” – which is the average cost of generation and transmission in Thailand and is about 80% of the retail rate.

The new laws creates income opportunities for rural communities based on locally produced, clean, renewable energy supplies. The average village micro-hydro project is rated 35 kW. Assuming the actual power production is 25 kW, and the installation operates at 80% capacity factor, this represents potential annual revenues for micro-hydro cooperatives of over 350,000 baht, or about US$9000.

Profiles of potential and existing grid-interconnected systems

As of January, 2004, two micro-hydro systems have installed equipment to interconnect under the VSPP regulations and each expects to generate electricity worth at least US$10,000 per year, while another two villages are presently exploring interconnection. Moreover, five additional villages with both operating micro-hydro and the grid have shown considerable interest. Thirty-one additional villages now served by the grid no longer use their micro-hydropower systems, but the weirs and pipes of many of these installations remain intact. Refurbishing these systems and tying them to the grid can provide funds to support community development, micro-credit, health and education.

Micro-hydro is just the tip of the ice-berg. According to studies commissioned by the Thai government and the European Commission, biomass and biogas fuels in Thailand present over 3,700 MW of commercially viable potential grid connected renewable energy (Redlinger 1998; Black & Veatch 2000; COGEN3 2002). This is considerable, considering that Thailand's peak electrical demand in 2003 was approximately 18,100 MW. Much of this potential is most suitably developed at small scales (1 MW or less) due to the distributed nature of Thailand’s considerable rice, cassava, sugarcane, palm, coconut, and livestock residues. Since the VSPP regulations were adopted, over fifty potential renewable energy producers have submitted applications for interconnection of 6,880 kW of generation under the VSPP laws. In terms of power output, biomass accounts for 5000 kW and biogas accounts for 1,800 kW.

Essential features of the regulations

The legislation, entitled “Regulations for the Purchase of Power from Very Small Renewable Energy Power Producers", consists of two sections: commercial and technical. The commercial regulations discuss permitted renewable energy fuels, application and connection procedures, costs incurred by each party, tariffs, and billing arrangements. The technical regulations specify the requirements for a small renewable energy generator to connect to the grid. These include the discussion of responsibilities for each party (utility or customer generator); criteria for synchronization (acceptable voltage levels, frequency, power factor, harmonics); required protection relays, and provisions for emergency disconnect.

With respect to community micro-hydro, one feature of the regulations worthy of note is that they provide for *aggregate* net metering. Aggregate net metering allows an entire renewable energy generating community (such as a cooperatively-operated micro-hydro project) to connect as a single customer and continue to manage its own distribution system.

The process of drafting and defending the policy

The process that led to the adoption of Thai net metering policies demonstrates that it does not always require an army of engineers and lawyers to enact these regulations in a developing country. In 2001 officials at the Thai Energy Plan and Policy Office (EPPO) directed MEA and PEA to develop regulations allowing small-scale renewable energy generators to connect to the grid. The utilities shelved the request, effectively stalling progress until EPPO officials asked me to produce an initial draft the regulations.

I began by reviewing technical and commercial net metering regulations from several utilities in the United States, generously supplied by Dr. Thomas Starrs (ERG Ph.D. ’96). Using existing Thai technical interconnection requirements for larger generators as a model, I worked with Thai civil servants to adapt the US regulations to the Thai context. Subsequently, I joined a working group formed by EPPO consisting of utility and government representatives. The working group debated the proposed regulations line by line. After three months, a final document was submitted to the Thai Parliament. The regulations were passed on the second of May, 2002. Shortly afterwards, the utilities adopted the regulations and announced that they would begin accepting applications from net metered generators. The entire process – from research to enactment – took less than nine months.

Persuading the utilities to agree to net metering provisions was not easy. In Thailand, as elsewhere, some decision-makers in electric utilities perceived net metering legislation as a threat to their monopoly control over power generation and distribution. Because utilities do have legitimate safety and reliability concerns, it was often difficult to sort the genuine objections from the specious. It helped that we moved quickly, and the working group assembled before utilities had the chance to mount significant resistance. It also helped that “VSPP” was considered too small to merit the attention of strong critics within the utilities. Fortunately, some key utility decision-makers recognized the benefits of these policies to Thai society, and to the country's energy independence, and supported the proposed regulations.

Remaining challenges and questions

Despite Thailand's successes in adopting net metering regulations, much work lies ahead in educating potential customer-generators, facilitating access to needed equipment and financing, and assisting Thai utilities to meet regulatory requirements in a timely manner.

Lack of awareness about net metering is one of the most significant barriers. Those involved with micro-hydroelectricity in villages are not aware of the opportunity to interconnect. Similarly, rice mill owners, farmer cooperatives, and others with substantial renewable energy resources are unaccustomed to thinking about using agricultural "waste" to produce electricity, and generally lack the background needed to evaluate an investment in renewable energy equipment.

Another substantial barrier is the shortage of high-quality, affordable equipment suitable for deploying grid-connected renewable energy systems. Indeed, work remains even in identifying the key technology gaps. For community micro-hydro known problem areas include choice and availability of cost-effective protection relays for interconnection of rotating generation, and questions of whether protection relays need to be installed at the high voltage or low voltage side of a transformer when connected to medium voltage (11-33 kV) lines. In general, expertise in interconnection of small generators is in short supply.

The Thai utilities are uncertain about appropriate testing procedures for net metered systems, and lack experience developing the type of administrative arrangements required to efficiently process applications. Both of these issues are being addressed by introducing Thai utility officials to their counterparts in the United States. Shortly after the regulations were passed, Thai utility officials participated in a net metering study tour of the US. Three months later, net metering experts from California's Pacific Gas & Electric Company and Sacramento Municipal Utility District led a workshop for utility engineers and administrators in Thailand.

Many questions remain. What opportunities exist to maintain and build on the gains made possible by VSPP regulations? Will the regulations have the hoped for effect of increasing opportunities for decentralized renewable energy? On the one hand, the interest shown by applications under the VSPP program seems promising. On the other hand, a key concern is the lack of an independent regulatory body to ensure that these and other regulations are implemented in an even-handed manner. Indeed, in the two years since the regulations were adopted, only a small fraction of systems have actually been approved, and even fewer have been actually built. One challenge is that while VSPP laws make interconnection possible, other challenges still stymie projects. In the case of grid-connected village micro-hydro, one significant and as-yet unresolved issue concerns ownership of assets. Will government, which originally invested the capital cost for micro-hydro plants, get revenues from electricity sales? Or will these revenues flow to electrical cooperatives to operate and manage the systems? How should Thailand’s value added tax (VAT) be calculated? Should VAT be assessed on net electricity generation, or separately on both production and consumption? Is it necessary to obtain a government concession for electricity generation? Though these issues warrant simple “yes/no” answers, the issues have become entangled in drawn-out inter-ministerial skirmishes.

Stand-alone village micro-hydro

Micro-hydro in Thailand was originally intended as a rural electrification solution for communities too remote from the grid to be likely candidates for grid electricity. For hundreds of remote villages in Thailand, new community micro-hydro installations may remain the most cost effective option. More immediately, 25 of the original 59 stand-alone Thai micro-hydro systems are in operation. What can be done to improve the benefits that villages derive from these systems?

Power (kW) tariff for stand-alone village micro-hydro

One finding of this study is that it is important to look at patterns that emerge over the course of several years. In particular, it is essential to monitor and anticipate increases in consumption as the community grows and households accumulate (and use) more electrical appliances. If increasing consumption is left unattended, within several years electrical demand often outstrips the generating capacity of the original system. What opportunities exist to reduce load growth, particularly during peak usage times? What options exist when demand begins to exceed supply?

This challenge can be seen from a supply side “the power plant isn’t big enough” or a demand side, “too much power is consumed at certain times” – or both.

Pure supply side thinking offers several opportunities for resolving the problem. Building additional micro-hydro plants in the village is sometimes possible, if there is a suitable site upstream or downstream from first installation within a reasonable distance of the village. This alternative is limited to villages in steep mountainous terrain, and is often precluded by existing water use patterns in which flows are already dedicated for agriculture. One village, Mae Kam Pong, has successfully pursued this option on two occasions, expanding an original 20 kW installation first by 20kW and later by an additional 40 kW. Another option is increasing the height of the dam to increase reservoir volume, and then increasing the size of the generator and turbine to allow for greater peak generation. This option, however, generally requires increasing the size of the headrace and penstock pipes and associated valves and fittings to accommodate increased flows. Increasing dam height is often impossible for structural reasons. Other supply-side options, such as adding supplementary generation (diesel or solar electricity) and/or a battery and inverter to supplement evening peak generation are possible. Additional studies would be useful to explore the feasibility of these approaches, and to possibly implement and monitor the most promising approaches.

Focusing on demand side offers an even richer set of options, including household education campaigns, over-current cutouts, and priority load shedding.

In many cases studied in this research, over the course of a 24 hour period a stand-alone micro-hydro produces more than enough energy for the village in which it is located. The problem is that most users want electricity in the evening, and some use more than their share. Measures are needed that encourage people to conserve electricity and to shift consumption from peak evening periods. Chiang Mai University has started a pilot user-education program in two micro-hydro villages that teaches people how much power common appliances use, and how this relates to the total power production capability of the micro-hydro. The campaign draws links between high consumption and low voltage, and both encourages purchase of energy efficient appliances, turning off appliances when not in use, and voluntary restrictions during evening peak hours.

Monitoring compliance with the voluntary program, however, has proven to be difficult (Interview 2004.4). One approach (discussed in Chapter 3) used in micro-hydro systems in Nepal, Sri Lanka, and other countries is to use a tariff based on peak power (kW) consumption rather than cumulative energy (kWh). Users have no meters, instead they pay a monthly fee for a connection that allows a certain amount of current (limited by a mini-circuit breaker or a positive temperature coefficient (PTC) resistor) and can use as much as they want whenever they want as long as it does not exceed the limit. If the limit is exceeded, the overcurrent device opens, stopping current flow. Users can reset the device, but in practice quickly learn they must turn off certain non-essential appliances in the evening in order to stay within their limit. A load management program for a micro-hydro in Uganda combined over-current cutouts with distributed load controllers installed on low priority loads. The program decreased black-outs from an average of 5 per month down to 1.6 per month, combined with a 15% increase in total electricity utilization (Smith, Taylor et al. 2003). (Smith, Taylor et al. 2003). Anecdotal evidence from the use of over-current cutouts in Nepal also shows reductions in peak loads, and increases in productive off-peak use (Interview 2000.01).

Additional studies in collaboration with the DEDE, villagers and operators in one or more villages would be useful to design and implement a peak power based tariff system and monitor the results. Ideal villages would be those in which demand has not already exceeded supply. The study should include data logging of “before” and “after” conditions in order to gauge effectiveness of demand-side measures.

Technical issues for Thai village micro-hydro

The DEDE appears to use technology that has hardly changed since the 1980s when the first projects were initiated with assistance from USAID. The DEDE has emphasized replication of existing practices, and appears to lack the resources to research and incorporate changes in village micro-hydro technology and practices that have become commonplace internationally. Because of this, additional studies would be useful on several technical topics that appear inadequately addressed with current Thai micro-hydroelectric technology.

It may be possible to reduce the occurrence of AVR and generator failures through use of power factor correction capacitors. Additional studies could explore the power factor of stand-alone village loads at different times of day and determine whether capacitors would help, and if so what amount of capacitance should be added. Because low voltages are also linked to consumption, and because power factor will change as the load pattern changes, it would make sense to engage in power factor correction studies in a coordinated effort that also addressed consumption patterns.

New designs and techniques for weir and intake construction should be investigated. Intake design in Nepal, for example, uses a fraction of the cement used in comparable Thai systems, with attendant cost reductions (Interview 2004.3). Because streams flood, and some strong floods will destroy nearly any weir structure, it may make sense to build inexpensive, easily replaceable structures using local materials rather than large “permanent” structures that may withstand greater floods, but if damaged are much more expensive to repair or replace. Environmental impact from this “soft approach” may be considerably lower as well.

Similarly, it would be worthwhile to investigate electrical and mechanical improvements to Thai micro-hydro systems. Field results from this research have shown that AVRs used in Thailand fail frequently, and there have been significant numbers of shaft, turbine, bearing, and controller failures as well. It would be helpful to investigate international practices in micro-hydro equipment design and identify candidates to address weaknesses in Thai micro-hydro technology.

Studies that address candidate improvements in technology should have strong involvement of DEDE staff as well as village micro-hydro operators. Study tours to nearby developing countries with well-established yet innovative micro-hydro programs would be a useful first step to provide direct experience with long-running experiences, practices and technologies used abroad. Appropriate countries include Sri Lanka, Nepal, and China. Participants should include government staff, private sector engineers and village operators directly involved in micro-hydro systems. Attention would need to be given to overcoming language barriers, as virtually none of these groups are comfortable with English or Chinese – the languages in which most of the experiences of micro-hydro is communicated.

Extending the common pool resource analysis to other village power technologies

This study has taken initial steps in applying common pool resource frameworks to understand particular common pool resource challenges faced by stand-alone village-scale micro-hydroelectricity. These stem directly from the system’s common pool characteristics: limited yields and difficulty in excluding users from appropriating more than their share.

Considerable investment in many countries around the world is also being made in village-scale renewable energy systems employing solar electricity, wind power, and biomass or biogas power. It would be worthwhile to apply common pool resource insights to these systems as well. Stand-alone village power projects (such as wind or solar electricity) that use storage batteries, for example, have special common pool resource concerns. Because batteries are irreversibly damaged by deep discharge (Lasnier and Ang 1990), high collective cumulative consumption in systems with batteries can subtract from the ability of the system to provide electricity in the future. In this sense, a village power system with a battery is similar to a common pool resource system such as a shared grazing area that can be damaged by over-grazing – with consequences for future yields.

This study used appliance surveys and datalogging of voltage and current to identify patterns of collective instantaneous overconsumption relevant for micro-hydroelectric systems. It would similarly be possible and useful to recognize patterns of cumulative overconsumption for village power systems with batteries. Such a tool kit would include appliance surveys and datalogging as well as an understanding of battery electro-chemistry, and would focus on long-term trends in battery voltage and in the ability of the system to recover from periods of high extended use.

Household, ethnicity, rural-urban dynamics

The analysis in this dissertation stops at the level of the household, implicitly assuming a static, unitary model of the household. As such, it does not include factors affecting electricity use and decisions that result from power divisions within the household. In order to better target campaigns for peak demand reduction it might be useful to know whether electrical appliances are purchased from pooled household income, or from income that household members hold separately, and to understand who determines what appliances are used at what times.

Likewise, this study pays little attention to race and ethnicity of villages with micro-hydro plants. A number of studies have traced how Thai ethnic minorities are negatively impacted by infrastructure development projects (Hirsch and Warren 1998; Phongpaichit 1998; Wangwinyoo 2001). A significant minority of villages in the 59 micro-hydro villages self-identified as ethnic minorities. Are there significant differences in the experiences of village micro-hydroelectricity of ethnic Thai and Thai minority communities? How does cooperative management fit (or not fit) with local governance practices? Does the micro-hydroelectricity project change the relationship between these communities and the state vis-à-vis other resource management issues?

Similarly, it would be useful to more broadly consider rural electrification in light of evolving relationships between the rural periphery and the Bangkok center. Thai national development policies have long relied on rural areas for resources. Rural farmers subsidized urban development through export taxes on rice, through the use of the rural sector as a flexible pool to provide cheap labor during times of rapid growth and absorb the unemployed during times of economic recession, and through direct resource extraction (e.g. large hydroelectric dams) that exploit rural resources for direct urban consumption (Hirsch and Warren 1998; Phongpaichit 1998). How has rural electrification fit into the evolving social contract between rural Thais and the governing center? How has this contract been understood and used by different parties? How have these relationships shaped electrification priorities and choices, and what have been the implications for community managed options like village micro-hydro? This study has scratched the surface by discussing how Thai leaders and US Cold-War era planners shared mutual interests in rural electrification, and how their collaboration shaped rural electrification priorities, administrative structures, and facilitated the flow of international aid, but the field appears fertile ground for further historical research.

Privatization, rural electricity, and micro-hydro

Privatization of state owned enterprises has been a priority of several recent Thai administrations. How will the privatization of PEA shift the rural electrification social contract and the organizational objectives of PEA? In a key government-commissioned study leading up to privatization, the long-honored principle of national uniform tariff has been challenged as an impediment to economic efficiency (Arthur Andersen, National Economic Research Associates et al. 1999). In a privatized scenario, shareholder interests are expected to gain ground over government priorities and electricity will become defined more as a commodity and less as a universal service (Greacen and Greacen 2004). But at the same time, nationalism, decentralization, and labor opposition to privatization are shaping the electricity sector in unpredictable ways. What are the implications for rural electrification of remote communities? For the micro-hydro option? Will grid-interconnection of micro-hydro and other small-scale generation remain a possibilty? What new opportunities and threats can be expected for community ownership and control?

Countries with a rural electrification “blank slate”

Key rural electrification decisions Thailand were made in the 1960s. In contrast, in dozens of developing countries around the world, rural electrification has reached only a small portion of the population. What lessons from the history of Thai community micro-hydroelectricity are relevant for rural electrification in these countries?

Cambodia provides an interesting example. Events taking place there now are similar in many respects to those that took place in Thailand four decades ago. Only 7 to 10% of rural population has electricity, almost all from an estimated 600-800 village diesel-powered mini-grids typically 5 kW to 100 kW in size (Enterprise Development Cambodia 2001). These Rural Electricity Enterprises (REEs) are generally entrepreneur-owned and operated, although in some cases owned and operated by cooperatives or municipalities. A battle is currently on between these REEs and the (bankrupt) state-owned monopoly utility Electricité du Cambodge (EdC). Though the REEs claim they can provide electricity services at competitive prices, they remain at a strong disadvantage because what little financing they can arrange is extremely expensive, whereas EdC is eligible for hundreds of millions of dollars in concessionary financing from the Asian Development Bank to build transmission and distribution networks (Kimsong 2003). EdC has proclaimed virtually the entire country as its service territory and has moved to shut down REEs in larger towns. The regulatory authority in Cambodia, which is comprised mainly of ex-EdC officials, generally grants only short term licenses to REEs. This, combined with the threatening posture of EdC reduces incentives for REEs to invest in improving the safety and reliability of their mini-grids. But some REEs are moving forward to invest in upgrading the quality of their distribution systems. A number are also investing in biomass power, taking steps to purchase biogassification equipment that will use nitrogen-fixing trees grown on degraded land to provide up to 85% substitution for diesel fuel. At the same time, these

REEs are banding together to form associations to increase collective bargaining power (Interview 2004.5).

If events unfold in Cambodia as they did decades ago in Thailand there will be no alternative to the EdC in rural areas, there will be little diversity in forms of ownership, and few opportunities for distributed renewable energy generation. However, Cambodia in 2004 is not the same as Thailand in 1964. The Cold War is over, Cambodia has a weak government compared to Thailand in the 1960s, and there are far fewer multilateral and bilateral funds available for parastatals and grid expansion. As part of their increased support for private sector involvement in electricity, multilateral agencies are also (at least in principle) more supportive both of small and medium enterprise development and distributed renewable energy options (World Bank 2003). In addition, technologies have changed. Small-scale renewable energy sources are more reliable and less expensive than they once were. They are also technically much easier to integrate with the grid (Greacen, Greacen et al. 2003).

This dissertation has argued that in Thailand, lack of integration of decentralized renewable energy in rural electrification planning has led to sub-optimal over-investment in relatively less cost-effective grid extension technologies. Are there ways to better coordinate rural electrification planning to avoid this scenario in countries like Cambodia? Are there ways in which parastatal utilities, cooperatives and small private rural electrification companies can work together or at least find ways to coexist that are not mutually threatening? How can access to financial resources be distributed more equitably? What is the appropriate role of regulatory bodies vis-à-vis technology and administrative choices for rural electrification?

Final thoughts

A reasonable definition of “rural electrification public interest” might be the following: customers benefit from cost-effective electricity service; the state does not waste scarce resources to disseminate technologies and administrative models that are poorly matched to communities’ preferences, resources and needs; electricity provision is accomplished in ways that preserve the environment; local people have sufficient say in developments that impact their livelihoods. This research has shown that that while Thailand’s extensive rural electrification results are a significant accomplishment, the current set of arrangements has actually run counter to public interest as defined above in important ways.

This is not to say that the centralized grid is always inappropriate. On the contrary, the centralized grid model is clearly an excellent choice in many circumstances. But there are also many circumstances where it is not. This research has shown specific ways in which Thailand’s preoccupation with centralization of decision-making and centralization of electricity generation have created circumstances in which existing, more cost-effective, more environmentally friendly, more participatory technologies are endangered to the brink of extinction. This dissertation has also argued that to the extent that micro-hydroelectricity has been deployed in Thailand, it has been technically deficient in important aspects and has been deployed in ways that fail to address crucial demand-side issues and the common-pool nature inherent in village-scale systems.

There is the opportunity in the future to imagine, design, and implement arrangements in which appropriate technologies are chosen on the basis of their merits in meeting specific needs in specific contexts. There is the opportunity to implement administrative arrangements in which different technologies build on each others' strengths and complement weaknesses. There is the opportunity to establish arrangements for ownership and control that are distributed in ways that are in the best interest of civil society. And there is the opportunity to implement rural electrification solutions that are technically competent and that take into consideration the match between characteristics (limitations) of chosen technologies and local peoples' needs and capabilities.

Hopefully lessons learned from Thailand's mixed experience with community micro-hydropower will help an informed public to move towards a future that realizes these ideals.

Appendix : Terms and Abbreviations

ARD	Accelerated Rural Development
AVR	Automatic Voltage Regulator
CIDA	Canadian International Development Association
DCCM	Department of Credit and Cooperatives Marketing
DEDE	Department of Alternative Energy Development and Efficiency (formerly DEDP)
DEDP	Department of Energy Development and Promotion (formerly NEA)
DOLA	Department of Local Administration
DTEC	Department of Technical and Economic Cooperation
EdC	Electricité du Cambodge
EdL	Electricité du Lao
EGAT	Electricity Generating Authority of Thailand
EPPO	Energy Plan and Policy Office (formerly NEPO)
EPS	Energy Planning Section (of the NESDB)
IBRD	International Bank for Reconstruction and Development
IPP	Independent Power Producer
kV	Kilovolt (1000 volts)
kW	Kilowatt
kWh	Kilowatt-hour
LOLP	Loss of Load Probability
LV	Low voltage (240/400 volts for PEA)
MEA	Metropolitan Electricity Authority / Administration
Mekong Committee	Committee for the Coordination of Investigations of the Lower Mekong Basin
MP	Minister of Parliament
MV	Medium Voltage (11 kV or 33 kV for PEA)
MWh	Megawatt hour (1000 kWh)
NEA	National Energy Authority / Administration
NEPC	National Energy Policy Council
NEPO	National Energy Policy Office
NESDB	National Economic and Social Development Board
NESDP	National Economic and Social Development Plan
NPV	Net Present Value
NRECA	National Rural Electric Cooperatives Association
NREP	Renewable Nonconventional Energy Project
OPEC	Organization of Petroleum Exporting Countries
PEA	Provincial Electricity Authority
PPA	Power Purchase Agreement
RTG	Royal Thai Government
USAID	U.S. Agency for International Development
USOM	United States Operations Mission
VOLL	Value of Lost Load

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