Dyadic design interface between energy and agriculture: the case of Pinthali micro hydro system in Nepal

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Abstract Technology, like society, is heterogeneous. It mirrors the context in which it operates. Micro hydro development in Nepal is a rural energy strategy, which relies on technology and innovation and takes place in a specific social context. In designing this energy strategy, both technology and its social context, therefore, need to be considered seriously. In technical design processes, the interplay between the content (technology) and the context (society) needs to be considered, as the outcome will affect the people. For example, the content – micro hydro system – in the domain of the context – agriculture – provides an arena for an integrated water control system. Thus, it is possible to control water for two purposes: to produce power and to provide irrigation. The end product will be “energy” as a “consumptive” output and improved food security as a “productive” output of water. Therefore, within a sociotechnical framework, energy and irrigation become constitutive outputs of the sacrosanct “water”. Thus, the metaphor of power – the sociotechnical code of “content” and “context” – can be used with the term “agro-energy” in the design process of micro hydro systems. Evidence suggests that this interaction can lead to a transformed water use system for both productive and consumptive output for the benefit of rural communities.

Keywords Agriculture; agro-energy; consumptive; design; irrigation; micro hydro; Nepal; sociotechnical; technology; water control

Introduction
Water, as a natural resource, has the potential not only to generate electricity but also to transform local livelihoods through irrigated agriculture. For developing countries such as Nepal, where 80 per cent of the population depend on agriculture for their livelihood, an adaptive design process for harnessing water to generate energy and produce food is vital. Nepal has the theoretical potential to generate about 83,000 megawatts (MW) of hydropower. There are about 30,000 feasible locations where hydro electricity could be generated. However, harnessing water with small-scale hydro technology to generate power is a challenge in rural areas.

“Hydropower” in the form of a traditional vertical axis, ghatta (water wheel), has been in use in Nepal for centuries. The first modern hydropower installation in Nepal took place in 1911, with a 500 kW turbine. Since then, the design of hydro electricity supply has historically followed two distinct modes: the “central” state-controlled gridline that supplies electricity to urban areas and the “decentral” model with smaller capacity turbines that supplies electricity to rural areas. At present, only 253 MW of hydropower is generated, 1

1 Turbines for electricity generation in Nepal are classified as large (above 5,000 kW), small (1,000 kW-5,000 kW), mini (100 kW-1,000 kW) and micro (up to 100 kW). The micro systems are further categorized as very small (up to 8 kW), small (8-20 kW), medium (20-50 kW) and large (50-100 kW). Turbine designs vary from lift, Pelton, multi-purpose power units (MPPUs), cross flow, split flow, propeller and turbo. Micro systems are further classified as pico or nano. Picos generate 3 to 5 kW of electricity and nanos produce less than 0.5 to 3 kW. The nano systems include improved traditional wheels and MPPUs. A metallic runner, which increases its operational efficiency and capacity, replaces the wooden runner in a traditional wheel.
providing electricity to about 15 per cent of the population, of which only 4 per cent are rural based. Given the complex bio-physical terrain and the high costs involved in expanding the national transmission network, decentralized and community-oriented micro hydro systems have been promoted since the 1970s to meet rural energy needs. Since 1988, the micro hydro sector has seen a large number of experimental models, with over 1,200 different turbines. Only about 3 per cent of micro hydro plants use turbines bigger than a 20 kW capacity (Rijal, 2000). Despite continued interventions in the rural electrification sector, outcomes remain limited. This is mainly owing to inadequate understanding of the local sociotechnical environment and the failure of the designs to consider both societal and hydraulic aspects of water use. This paper focuses on micro hydro systems by examining the relationship between energy and irrigation as well as the possibility of interfacing the two sectors within a sociotechnical water resource use system.

Research objectives and methods
This paper summarizes the research findings of a case study of the Pinthali micro hydro plant, which is located in the central hills of Nepal. It examines both technical and social design features of micro hydro technology and how they interact with irrigated agriculture. In this regard, the design intervention explores the synergy between energy and irrigation, elaborates the adaptive design system and highlights the two dimensions of water resources. The first part of the paper examines the physical components of technology and the artefact as a composite hydraulic unit, and the second part reviews local practices in the allocation and distribution of water between energy generation and irrigation uses. Finally, the paper highlights the constitutive nature of technology, which interfaces agriculture and energy requirements, and emphasizes the technical and social principles and relationships that integrate them into one system.

The main research technique used is the case study method. A variety of other techniques have been applied in using this method, including collection of qualitative, quantitative and hydrological data. The findings of the study are presented from both theoretical and empirical perspectives. In this study, the technical and social design codes were taken as integrated, where the artefact and hydrological measurements are considered as the “technical code”, to describe these features of hegemonic value that prevail in the design process within a given “social code”. The “social code” illustrates local practices for allocation and distribution of water and energy within the hydraulic resource system and agrarian conditions.

Micro hydro technology as an agro-energy system
Micro hydro technology can be defined as a transformative assemblage of water, artefacts and agro-energy system, possessing both productive and consumptive capacities of water resource management. Technology is not only an artful, astute and measured formula but also an evolutionary process. Phrases such as “technological system” and “technology development”, therefore, often connote a continuum or an arrangement of artefacts, their impact on society and how societies respond to them. The conceptualization of technology ranges from a wide variation of nomenclature, reification of typology, and descriptive

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2 This paper is part of a research outcome from a field study conducted by the author in the Kabhre Palanchowk District of Nepal, based on case studies of Panauti small hydropower plant, Pinthali micro hydro system, Katune Bensi micro hydro system and Kusha Devi, pico power plant. Other observations have been included from a rapid appraisal of various other sites in other districts. This investigation is part of a comprehensive field study undertaken for a PhD research programme at the Irrigation and Water Engineering Group, Wageningen University, the Netherlands.

3 See Bijker, Hughes and Pinch (1987) for social shaping of technology.
references to activities and behaviour, to knowledge systems as well as to access technology as control mechanisms. All these constructs, combined together, give an artefact not just its unique technical rationality but also a combination of social and technical attributes. Technology can be used as a capacity, developed by human society, to transform and control it (Vincent, 1997). “Access” technology, which functions as transformative units at the rate water is lifted and conveyed, is also shaped by social and natural conditions where the capacity of transformation and control shapes the rate at which water can be lifted and conveyed (Knegt and Vincent, 2001). In micro hydros and irrigation systems, the design and assembly of technology not only concern conveying, controlling and channeling water but also sharing of resources. Technology structures, therefore, not only control water, but also become major elements of control or points of negotiation and struggle about rural transformation (Vincent, 1994).

A micro hydro system is a complex technology with multifaceted mechanical components. The running of a “turbine” depends upon other components such as a canal, forebay, penstock, desilting and desanding chambers, reserve ponds, dam, weir, power house, controller, intake, inductor, generator and outlets. A micro hydro system is also a very complex technology, especially when “water”, its principal agent, becomes the focus of a development intervention. In most hydropower projects in Nepal, micro hydro technology functions as an adjunct system, frequently superimposed within an existing irrigation technology. It is rare to find a stand-alone, run-off-the-river technology operating independently. Generally, energy production is firmly embedded in sharing of water resources with irrigation. As a result, the assemblage of hydropower technology is strongly influenced by the nature of linkages within the technology itself, where the existing technology becomes an important precondition for design intervention.

**Preview of the Pinthali micro hydro system**

The study area in the Kabhre Palanchowk District is located in the physiographic division of the Middle Mountain Region of Nepal. The maximum rainfall in the district occurs in the month of August and accounts for 80 per cent of the annual rainfall. Figure 1 illustrates the annual hydrograph of Daunne Khola (stream) at Pinthali. There are about 492 small and big rivers and streams in the district. These water resources are being used for energy generation and also for irrigation schemes. Currently, 353 systems irrigate 62 per cent of irrigable land. The total population of the district is about 391,000, of which 90 per cent depend on agriculture for their livelihood. There are 178 traditional water wheels, 246 diesel-operated mills and 279 electric mills in the district. There are 21 micro hydro plants in the district, of which 12 generate power for rural electrification.

Pinthali village nestles in the Himalayan plateau, 950 metres above sea level (masl), and is surrounded on three sides by the Mahabharat Range. In 1997, under the Rural Energy Development Programme of His Majesty’s Government of Nepal, financially supported by the United Nations Development Fund, a micro hydro intervention programme began on a local irrigation system. The project was completed in 1998 with an improved and widened
canal system that increased the volume of water from 30 litres per second (lps) to 60 lps. The increased volume of water not only enhanced the possibility of generating electricity for the village community, but also increased its irrigated command area, addressing both consumptive and productive aspects of water use. The 118 smallholder farmer households of Tamang ethnicity started harvesting four crops a year after the programme was introduced.

The Daunne Khola stream as illustrated in Figure 2, 2 km below the foothills of the range, provides water for electricity generation and irrigation. The design of the hydro power plant comprises a powerhouse with a crossflow turbine of 12 kilo watt (kW) capacity, ensembled with a rice huller for husking grain and an oil expeller for extracting oil from seeds. One hundred watts of power is assigned to each household. An 11-member executive committee of a micro hydro user group manages the plant. A meandering...
headrace canal, 1,890 metres (m) long, which bifurcates at the forebay into two separate canal systems, constitutes the main design characteristic of the canal. The split tailrace of 1,000 m leads to terraced agricultural fields through a primary canal and provides irrigation water through field channels. A secondary canal diverts water to the powerhouse to turn the turbine. A tertiary canal from the powerhouse draws water for irrigation at the point of transfer through the turbine. Human and hydraulic factors “control” the system. Allocation and distribution of water is dependent on seasonal variability, rainfall patterns and local practices. Water is used to irrigate fields and run agro-processing machines during the day and during low flows. At night it is used to generate power.

Hydraulics and technical code

Upon examination of the hydraulic properties that govern the design system, it was found that the stream source of Daunne Khola fluctuates according to the rainfall pattern, the discharge at the source averaging 3,284 lps during high flows and 131 lps during low flows. If we examine the design discharge, where \( Q = 60 \text{ lps} \), the canal capacity of \( Q = 200 \text{ lps} \) at the intake averages to a high flow of about 160 lps and 105 lps during low flows, as illustrated in Figure 3. With a given head of 38 m, 30 lps is required for generation of power of 11.4 kW; the net flow available for irrigation amounts to 75 lps during low flow and 130 lps during high flow periods. A cement and stone dam has replaced the temporary dam, increasing the width of the canal to 63 cm and its height to 1.35 m. In addition, the sedimentation tank close to the dam controls most of the obstructing particles such as sand, clay, boulders and silt before the water is discharged into the canal. The unlined canal system has been replaced by a partially lined canal, and in areas where landslides are expected, high-density polyethylene (HDPE) pipes have been used. The forebay structure is designed to flow water in two ways. One way is channeled to generate electricity and to run the agro-processing machines in the powerhouse and an adjacent sawmill and the second way is channeled to irrigate fields. Consolidated water measurements of two dry seasons and one wet season indicate that the design calculation of water availability in the canal near the forebay differs from actual flow. The time series data in Figure 4 indicate that an average of 72 lps is available during the peak flow and about 32 lps during the low flow period. The field data indicate that while 30 lps is being diverted for electricity generation, the remaining volume is available for irrigation. There seems to be a discrepancy between the design flow and the hydraulic flow, with conveyance losses amounting to as high as 44 per cent during the wet season and 31 per cent during the dry season. The dip in the graph indicates the low flow period, when water is diverted from irrigation to generate power and run agro-processing machines during the day. Thus, the design discharge has not taken into account the electricity use during the day. However, the cropping pattern during low flows is less water intensive, thus the diversion of water for energy use during the day is not significant. Even during the peak load period of electricity use, when water is required for...
irrigation use, water is diverted to fields and not to the powerhouse. Therefore, one can assume that the volume of water does form the principal “technical code” which determines the design, and irrigation takes precedence over electricity generation. The technical code is described as those features of technologies, which reflect hegemonic values and beliefs that prevail in the design process (Feenberg, 1995). However, technical principles are insufficient by themselves to determine the design. Technical codes also reflect particular social interests that define how water is to be allocated and distributed and for what purposes. As such, technical codes, which are usually invisible, like social practices, gradually become transparent. Therefore, the line of distinction between the “technical” and “social” codes becomes blurred, preempting examination of the social practices of irrigation water use within the notion of “sociotechnical” code.

Structure and sociotechnical code
Prior to the micro hydro intervention, there were three community constructed irrigation canals in the Daunne catchment area. The first was built in 1959 to irrigate cash crops such as cumin, garlic and grams in fields in the sloping unbunded terraces. In 1979, a secondary canal was constructed to irrigate the lower level bunded terraces for growing paddy, buckwheat and maize. Pinthali continued to witness water scarcity owing to high conveyance losses, difficulties in maintenance of canal alignment and the narrow width of the canal. In addition, the canal system became an issue of conflict over water rights, as there was no formal mechanism for water distribution and allocation among different claimants. Water division structure was based on an ad hoc adjustment, where the flow was either adjusted or changed by opening of an orifice or changing the operating head, which affected the upstream and downstream flow levels. The ad hoc human intervention in adjusting the flow increased disputes, and, in 1981, the community decided to resolve the issue by merging the two canal structures at the source. This was done by increasing the canal width to augment the volume of water and also by extending its length to irrigate the fertile plateau of Pinthali. However, the efficiency of water distribution remained contingent on the ability of the farmers to divert adequate water when required and on the establishment of distribution parity among the head-enders and tail-enders.
The micro hydro intervention began with an intensive community consultation process. A micro hydro users group was established with a manager and an operator to oversee the management and operation of the system. The primary responsibility of the group is to ensure that the finances of the plant are properly maintained by collecting monthly tariffs, keeping account books and approving purchases of major spare parts. The operator of the system is assigned as a “technical” watchdog to oversee the allocation and distribution of electricity, according to the wattage allocation plan and to check water stealing. This role also ensures minor cleaning of the canal, minor repairs of the plant, and regulation of flow for distribution between electricity generation and irrigation. The construction of the power plant introduced a formalized local irrigation plan, which regulates water distribution for irrigation on a time-share rotational basis. The 127 hectares of land under cultivation in the command area of the canal is classified under ward numbers 7 and 9\(^6\). The area under ward number 7 is one-third (less) of the area under ward number 9, and water allocation is on three and four consecutive days per week respectively. Water distribution starts either from the tail end or at the head-end, alternating the sequence on a daily rotational basis. This technology has introduced a new kind of hydraulic design and social legislation, reshaping the social and agrarian organization and minimizing conflicts. Thus, the “social code” as laws, rules and institutions has reshaped the interface between “social” code and “technical” codes, making opaque the line of distinction between the two. The social realities as social functions were incorporated in the initial design stages of the technology itself and integrated in the design process in a benign way. Thus, this technological system aligned the explicit and implicit nature of water control, the maintenance of system and the power of agro-energy for socio-economic transformation of rural households.

**Technology design and design codes**

The designing of technology begins with an abstract model of the artefact, which incorporates the design function measuring the feasibility of the site at its source in relation to the head and flow. In this sense, the primary feature of the artefact as an isolated “turbine” gives the novel property capable of generating mechanical energy through the enterprise of technology. In essence, this abstract principle gives the turbine its idealised essential function. The feasible design space thus becomes strictly limited (Vincenti, 1995) and indeed falls within the purview of micro hydro systems. The focus on the study of failures of technology examines the validity of technology design parameters and design landscape (Petroski, 1994). However, the study of success of technology can also be used to bring out the inadequacies of the failed systems. In this respect, the role of “social” in the design paradigm is perceived to act not as a part of the constraining envelope in the design of technology. If we examine the nature of hydraulic technology such as micro hydros, the constraining “envelope” could lead to elimination of inadequacies, signifying the merger of the “technical” with the “social”. Then, the possibilities of design are unlimited, where the consequences of failures decrease within the sociotechnical choices. In the case of Pinthali, the design at its inception moved beyond the abstract model through three known factors. There was water scarcity and conflict, community-need for electricity and irrigation, and no formal water allocation mechanisms. The unknown variable remained, given the technology choice between irrigation and electricity, which one would take precedence, and how viable would be the planned intervention in terms of institutionalizing the operation and management of technology. To incorporate the known and unknown factors, first, water flow in the initial

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\(^6\) There are 75 districts and 3,914 Village Development Committees (VDCs) in Nepal. Each district is further divided into about 52 VDCs. Each VDC is further divided into 9 numerical administrative boundaries known as wards.
design discharge included both the energy (night-time use) and irrigation (daytime) requirements. Second, the requirements congruently adhered with the principles of community consultation. In essence, the technology design was transformed to fulfil a function that did not exist by extending the artefact through a process of adaptation. Design was able to push the envelope of the “known” to bring out new aspects of the reality (Purkayastha, 2002). Signifying that given the technology choice, irrigation takes precedence and that a formal institutional structure functions as a negotiating platform. An unknown factor that has emerged is that when the powerhouse is installed with agro-processing machines, the volume of water that would be utilized for this application during the day also requires to be included in the initial design discharge. Significant conveyance losses in hilly agro-ecological terrain indicate implications for designing of hydraulic technology.

Conclusion

Over 60 per cent of the isolated micro hydro systems in rural and remote hills in Nepal have failed to meet the expected output on various social, technical and economic grounds. The relevance of adaptive technology is important in rural communities of Nepal, where over 90 per cent of the population depend on agriculture and natural resources for subsistence farming and livelihood security. Careful observations from the field illustrate the need to converge irrigation and electricity requirements. The Pinthali case study demonstrates that the success of micro hydro systems in Nepal depends primarily on the capacity of the technology to enhance rural livelihoods by interfacing with other local needs such as irrigation. Thus, design processes of technology, if composed to meet the local needs within a sociotechnical frame, can usher in a transformation that includes both productive and consumptive features of water management and utilization.

References


