

## MASTER

### The diffusion of micro-hydro power for rural electrification in Bolivia a learning approach

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# The diffusion of micro-hydro power for rural electrification in Bolivia

- a learning approach -

Wouter Drinkwaard





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- A learning approach -

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**Wouter Drinkwaard**

**May 2009**

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## Preface and Acknowledgement

This thesis is written for the fulfillment of the Master of Science Technology & Policy of the Department Industrial Engineering & Innovation Sciences at the Eindhoven University of Technology. It is the result of one of the most exciting periods in my life. The five months Linde and I lived in Bolivia brought me more than I ever expected. In the centre of Latin America, Pachamama has created a country of extremes. In Bolivia the difference between  $-10\text{ }^{\circ}\text{C}$  and  $+35\text{ }^{\circ}\text{C}$  is just a five hours' (very slow) bus drive. Those five hours include the joint effort of all passengers to pull the bus (literally) over the muddy roads after a night of rainfall. This characterizes the country and the micro-hydro power projects I have visited, which were scattered through the country. These visits have been the most beautiful part of my stay. The contacts with the local communities have been wonderful. Despite my broken Spanish (thanks Andreita for all the efforts to learn el ñoño some of the basics, and of course for the wonderful cooking) they always had time for a chat about the micro-hydro power plant or local affairs. I am still surprised about their honesty about problems they (have) had. I am still astonished at their openness and the way we could take part in their everyday life, even in periods of grief. Through their kindness and willingness to cooperate they have contributed enormously to the realization of this thesis.

This thesis would not have been possible without the help of many people. First of all, I would like to thank the people of Energética, especially Miguel Fernández Fuente, who accommodated us, introduced us to the country and its people and gave us a unique opportunity to see the actual implementation of developmental programs. Second, I would like to thank los señores Emiliano Montaña Gonzáles and José Luis Monroy Cuellar of IHH for their enormous helpful support and all the time they have made free for me. I would like to congratulate them with their micro-hydro program. I believe it is amazing what they have achieved. They may be very proud of everything they do to bring electricity to remote communities. I really hope that they well be able to expand their program in the near future.

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Last, but absolutely not least, I want to thank Linde for living with me in Cochabamba, for joining me on all the trips (and keeping me from danger several times, sorry, I will try to stay out of trouble our next trip), for all her support and for having a wonderful time.

I hope you will enjoy reading this thesis,

Wouter Drinkwaard

Eindhoven, 2009



## Summary

This thesis is a study about the diffusion of micro-hydro power for rural electrification in Bolivia. Bolivia is the poorest country in Latin America. The lack of infrastructure is one of the biggest problems the country faces. In total, 3.3 million people (a third of the population), almost all living in rural areas, still do not have access to electricity. One of the ways to electrify rural areas is the implementation of micro-hydro power (MHP) schemes, roughly defined as schemes having a capacity between 5 and 100 kW. The technology uses the potential energy of small rivers. MHP technology is reasonably simple. A head difference is created through a slowly descending canal alongside a mountain slope. The water falls through a penstock and the mechanical energy is converted by a hydro-turbine and a generator into electricity, which is distributed via a mini-grid. But although MHP has a huge potential in Bolivia, the technology is not yet widely diffused. Energética, a Bolivian NGO that implemented several micro-hydro plants in the past, commissioned this study in order to obtain insight into the reasons why the MHP potential is not being utilized. To investigate this, the following research question has been formulated:

*'How do barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia, and how can learning help to overcome these barriers?'*

## Research framework and methodology

Previous diffusion studies on rural electrification in developing countries – and on MHP in particular – have yielded extensive lists of barriers to the successful implementation and spread of the technology, such as financial constraints, organizational and managerial weaknesses, lack of technological capabilities, adverse political and economic contextual factors, and so forth. However, such studies are of limited practical use because they do not tell us why sometimes barriers act as true "killer constraints" that cause projects to stagnate and fail, whereas at other times barriers spur local communities and MHP-implementing organizations into action to resolve them, serving as inducements for local learning and strengthening capabilities over time. Hence, the aim of this study has been to probe beyond the static approaches taken in these earlier studies. In addition to identifying diffusion barriers, the study aims to uncover the deeper-rooted causal factors that underlie the processes by which these barriers get entrenched and resolved.

In order to achieve this, a dynamic learning-based approach has been used to tackle the research question. An analytical framework has been built by combining three complementary theoretical approaches: Strategic Niche Management (SNM); Boru Douthwaite's "learning selection" approach to innovation; and David Korten's "process approach" to success and failure in development projects. SNM is a framework that is used for studying factors that influence the development and diffusion of a so-called "niche-technology". Niches are breeding places where new technologies can develop. They are protected areas where inevitable uncertainties surrounding new technologies can be dealt with. Niches act like incubation rooms for innovations. According to SNM-scholars, three internal niche processes drive the incubation process: 1) The articulation of expectations and visions; 2) The building of social networks; and 3) Learning processes. These processes take place at two interlinked levels, the global niche level and the local project level. The global niche level can be seen as the emerging technological trajectory. It consists of accumulated, global, abstract and generic knowledge. The local project level consists of concrete real-life projects and experiments, carrying and feeding the global niche. The projects are carried out by local actors, using local networks and knowledge and a specific configuration of the technology.

The main focus of this study is on learning processes within the niche. However, it is not clearly articulated within SNM how exactly learning should take place, and what makes it happen. Douthwaite's learning selection approach and Korten's process approach furnish more detailed insights into these issues. According to Douthwaite, technological learning is a result of systematic sense making and action by local user-communities to resolve existing barriers to the proper functioning of a certain technology. This tends to happen when users identify with the technology and feel responsible for it. Korten focuses more on institutional learning within project-implementing organizations. He argues that learning should take place within three stages: learning to be effective (i.e., getting the technology to function); learning to be efficient (i.e., use it with less resources); and learning to expand.



This learning framework is incorporated into a multi-level perspective (MLP), which consists of a socio-technical landscape, a socio-technical regime, and the niche. MLP is used for a broader contextualized view of the development of the niche, in order to understand the context shaping the development and the diffusion of the niche-technology. The socio-technical landscape refers to three factors: slow trends and developments (usually in the order of decades), factors that do not change, or that change only very slowly (geographical conditions, climate), and unexpected events, like terrorist attacks or mega-tsunamis. It is an exogenous environment which can (in general) not be influenced by actors in the niche or at the regime level. The landscape puts pressure on the socio-technical regime, which is defined by a dominant technology and a set of rules and institutions (actors) related to this technology. Through this pressure, windows of opportunity for the emergence of novelties are created.

## Data collection

Eight MHP case studies were carried out, by means of site visits and in-depth interviews with several actors. Within the case-studies, past and ongoing learning processes were reconstructed, and the spread of lessons learned within the projects, directly between projects and between the local projects and actors in the global niche were investigated. The interviews served to examine learning by MHP implementing organizations.

## Analysis and conclusions

The case studies proved to be a valuable source for investigating diffusion barriers. Technological and institutional barriers were found most, before financial/economic barriers. Some evidence of resolution of barriers through learning was found in the projects investigated, but the extent of learning varied across projects and organizations. One local plant (Epizana) and one organization operating in the global niche (Instituto de Hidraulica e Hidrologia - IHH) showed evidence of several sequences of learning cycles. These examples show that it is possible to remove barriers through learning and to improve the design of the socio-technical system through incremental innovation. However, many plants and organizations do not achieve this. Within local organizations managing a micro-hydro plant, the lack of staff continuity was found to be a crucial impediment to learning. The majority of the local plants make use of an organizational structure in which a new management is elected every one or two years. The tacit form of the knowledge that is needed to manage a plant prevents an efficient transfer of knowledge. Each new management has to re-invent the wheel, so that sequences of learning cycles cannot be formed.

Continuity also plays a key role in implementing organizations. In Bolivia, IHH is the only organization that has acquired a lot of experience with the implementation of micro-hydro plants, to the point that it has managed to evolve an efficient implementation routine (centered on intensive user-involvement in construction) based upon its accumulated knowledge about best practices. Moreover, this institute is the only actor that is legally allowed to execute the whole MHP project cycle – from identification to design to implementation and maintenance. Both these factors greatly foster learning.

Furthermore, it was found that weak social networks hinder the diffusion of micro-hydro power considerably. As in many collectivist cultures, Bolivian communities have very strong inward ties. However, mistrust exists between communities, so that information and knowledge is not shared. Local organizations also do not pass on the lessons learned and experiences acquired to other plants in the vicinity. Communication channels between global organizations were found to be weak as well. Knowledge is not shared and collaboration is avoided. Lastly, vertical ties between local projects and the global niche are often lacking or weak. Many implementing organizations lose sight of the plants after some time. Evaluations are not carried out systematically, so that there is no awareness of barriers hindering a proper functioning of the plants. Implementing organizations should learn more from implemented projects in order to improve future plants.

## Policy recommendations

The question remains how to strengthen the Bolivian MHP sector and how to foster learning processes in order to overcome barriers to the diffusion of MHP? On a local level, organizations should be stimulated to make tacit knowledge more explicit, in order to ease the switch to new local managements. A period in which the old and new boards overlap will stimulate the transfer of knowledge. Furthermore, local organizations should get the possibility to receive a technical, organizational or financial training if the operator or board changes. To foster the exchange of

lessons learned between projects, a regional solution has to be sought. The establishment of a regional platform for knowledge and experience sharing in areas with a number of plants, managed by an intermediary, can be a solution. To foster generalization and aggregation activities, evaluations of projects should be conducted frequently.

Globally, the sharing of knowledge and experiences should be fostered as well. A first step should be to bring together the main actors (implementing organizations, financing institutions, government) in order to create some trust and later on to carefully sketch the outlines of a widely supported plan or program. In order to do this, a more or less neutral actor that has not been involved deeply in programs in the past, should take the initiative. Otherwise, an international organization can possibly act as an intermediary. In the end, this should result in an all embracing program, that put emphasis on the incorporation of all actors (including organizations specialized in agriculture and the establishment and implementation of productive end-use facilities) and on the dissemination of knowledge.



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## Abbreviations

### Framework and methodology:

CBA	-	Cost-Benefit Analysis
IRR	-	Internal Rate of Return
MLP	-	Multi Level Perspective
NPV	-	Net Present Value
SNA	-	Social Network Analysis
SNM	-	Strategic Niche Management
STS	-	Socio-Technical Systems

### Main actors:

ENDE	-	Empresa Nacional de Electricidad
FCIL	-	Fonds Canadien d'Initiatives Locales
FNDR	-	Fondo Nacional de Desarrollo Regional
Fonodal	-	Fondo Nacional de Desarrollo Alternativo
FPS	-	Fondo Nacional de Inversión Productiva y Social
GEF	-	Global Environment Facility
GTZ	-	Gesellschaft für Technische Zusammenarbeit
IHH	-	Instituto de Hidraulica e Hidrologia
JICA	-	Japan International Cooperation Agency
KfW	-	Kreditanstalt für Wiederaufbau
NGO	-	Non-governmental organizations
PNCC	-	Programa Nacional de Cambios Climaticos
SGP	-	Small Grant Program
TDE	-	Transportadora de Electricidad
UNDP	-	United Nations Development Program
VMEEA	-	Viceministerio de Electricidad y Energías Alternativas

### Programs:

PLABER	-	Plan Bolivia de Electrificación Rural
PMCH	-	Programa Nacional de Micro Centrales Hidráulicas
PRONER	-	Programa Nacional de Electrificación Rural

### Other:

GHG	-	Greenhouse Gas
MHP	-	Micro-hydro power
MHPS	-	Micro-hydro power scheme
RE	-	Rural Electrification
RET	-	Renewable Energy Technology
SIN	-	Sistema Interconectado Nacional

### Metric system symbols:

Hz	-	Hertz
kW	-	kilowatt
kWh	-	kilowatthour
l/s	-	liter/second
MVA	-	Mega Volt Ampere
MW	-	MegaWatt
Rpm	-	Rates per Minute

### Currencies:

Bs	-	Bolivianos
€	-	Euro
US\$	-	United States dollar



# 1 Introduction

This study deals with one of the most important services in the world. Something that is taken for granted in the western world, but that is absolutely not the standard in a developing country like Bolivia. It is about electricity. More specifically, it is about how to use micro-hydro power for the electrification in rural areas. As this study will show, it is not quite so easy to use this technology, but it is not absolutely impossible to use if the right strategy is chosen. More about this will be said in a little while; first a short introduction to Bolivia will be given. Thereafter, the problem definition and the research objective and questions will be discussed, together with the justification of this research, its boundaries and the way the data was gathered.

## 1.1 Introduction to Bolivia

The República de Bolivia (Republic of Bolivia) has a long history of ancient empires, occupation and struggle for independence. The first great Andean empire, the Tiahuanaco, had its centre around Lago Titicaca. The Inca-empires left their traces during the 15<sup>th</sup> and 16<sup>th</sup> century and Bolivia was one of the most important colonies of Spain, bringing the Spanish conqueror its wealth from the Bolivian silver mines. After its independence in 1825, many wars were fought with the neighbouring countries and peace was rare. Many governments passed, but none was able to bring long lasting stability or to eradicate poverty. (Encyclopædia Britannica, 2009a)

Poverty is still one of the main issues in Bolivia. The average income of the 9.2 million Bolivians is 4,400<sup>1</sup> US\$ per capita (CIA World Factbook, Bolivia, 2009). Especially the indigenous Quechua's (30% of the population) and Aymara's (25%) live in poverty. For them, there is hope though. Evo Morales was elected as the first Indian president of the country in 2005. His policy is characterized by the nationalization of the oil and gas industry and attempts to nationalize other sectors as well. Furthermore, Morales wants to redistribute wealth, which is leading to protests by the four wealthiest departments. Morales nevertheless still has the support of two-third of the population thanks to his programs to build schools, hospitals, market places and roads to make the remote areas accessible, and his efforts to improve education and healthcare in the rural areas. Besides this, inflation has been brought under control, the economy is growing faster than the regional average, and the Boliviano, the national currency, has been stabilized. (Encyclopædia Britannica, 2009a)

## 1.2 Problem Definition

Bolivia is the poorest country in Latin America. The lack of infrastructure is one of the biggest problems the country faces. Many people in the rural areas do not have access to drinking water, modern communication methods, health care or education. Electricity is a very important component to foster these services. In total, 3.3 million people (approximately 580,000 families), almost all living in rural areas, do still not have access to electricity. (UNDP, 2007; Intelligent Energy Europe, 2006)

The Bolivian government has many programs to electrify rural areas. Renewables play an important role in these efforts. The VMEEA (ViceMinisterio de Electricidad y Energías Alternativas, translated: Vice Ministry of Electricity and Alternative Energy) calculated that approximately 200,000 families in remote areas can best be served with renewable alternatives for the generation of electricity, because of the potential of these alternatives, the costs of extending the grid, or to bring fossil fuels to these areas (VMEEA, 2006). Another study showed that 300,000 families could get electricity generated with renewable sources (Intelligent Energy Europe, 2006).

Bolivia follows two paths to extend the electricity coverage. Some programs aim at the extension and densification of the central grid, others at the increase of access through the installation of local stand-alone systems, using renewable energy technologies, mainly solar panels and micro-hydro power schemes (MHPS) (VMEEA, 2005). Micro-hydro power (MHP) has a lot of potential in Bolivia. The government, some NGOs and the University of La Paz have tried, and are still trying to boost the diffusion of MHPS. Unfortunately, many programs and projects fail. The major attempt of the last decades was the set up of the Programa Nacional de Micro Centrales Hidráulicas (National Program for Micro-Hydro Power) in 1996. The program encompassed the building of 100 MHPS to supply 20,000

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<sup>1</sup> 2008, measured in Purchasing Power Parities (PPP)

families with electricity (7 MW in total) in 15 years (Secretaria Nacional de Energía, 1996). The program was an initiative of the government. However, after the 1997 elections the newly elected government did not support the program and sent it to the trash bin.

The rejection of the program was a big blow for the MHP sector. Instead of 100 new systems, on average only three new systems a year were built since 1997 (Fernandez F., Bolivia masterplan for rural electrification - Ch. 3.3 Hidroelectricidad, 2005). Some other programs were started. A project of the United Nations Development Programme (UNDP) aimed at installing five MHP plants and the VMEEA in cooperation with the KfW, a German development bank, planned to construct seventeen installations. However, both programs face delays of years.

Many obstacles have been encountered in the diffusion process of MHP in Bolivia, whereas the technology has spread widely in other (developing) countries like China, Nepal, Sri Lanka, Pakistan, Vietnam and Peru (Khennas & Barnett, 2000). The question arises what barriers hinder the spread of MHP in Bolivia and how can these barriers be removed?

### 1.3 Research Objective

Not much is known about factors influencing the diffusion process of MHP in Bolivia. Some projects have been evaluated, but results were never disseminated nor compared. Studies have been done in other countries. Khennas and Barnett (2000) e.g. wrote a best practice for MHP based on projects in Nepal, Sri Lanka, Mozambique, Zimbabwe and Peru. Smith (1994) and the ESHA (2005) wrote articles about key success factors. More generally, studies have been done on barriers hindering the diffusion of renewables, especially solar and biomass. See e.g. Painuly and Fenhann (2002), Khattak et al. (2006) or the IPCC (2001).

These studies however resulted in lists of (general) barriers, but not in an improved understanding of the dynamics of the processes that are required to remove those barriers. In this study overcoming barriers is seen as a result of learning. Barriers are impediments for the functioning and diffusion of a technology. One should learn how to overcome or deal with these impediments in order to make way for the further development of the technology and the system in which it (is going to) function(s). If the lessons learned are used for improvements the barriers will gradually disappear. However, if learning does not take place, the impediments – the barriers – will not be removed. In this case, the functioning of the technology will not improve, and barriers for the diffusion of the technology will continue to exist. (Hoogma, 2000; van der Laak, Raven, & Verbong, 2007) So investigating how barriers hinder the diffusion-process actually encompasses investigating where and how learning takes place or should take place.

The goal of this study is twofold. The first goal is to get insight into the barriers that are hindering the diffusion of MHP in rural areas in Bolivia. What barriers exist, how do they relate to one another and what are the reasons behind the existence of those barriers? Therefore, the first research objective is:

*‘The identification and analysis of barriers to the diffusion of micro-hydro power for rural electrification in Bolivia.’*

When the barriers are known, the question remains how to eliminate those barriers. Above is explained that learning is the driving force behind the removal of barriers. Therefore, the second research objective is:

*‘The investigation of how learning processes contribute to the removal of barriers to the diffusion of micro-hydro power for rural electrification in Bolivia.’*

### 1.4 Research Question

These research objectives lead to the following research question:

*‘How do barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia and how can learning help to overcome these barriers?’*

If this question is answered, it is possible to make recommendations to improve the functioning of micro-hydro power projects and to promote the further diffusion of micro-hydro power in Bolivia.

### 1.4.1 Sub-questions

To answer this research question, four sub-questions are formulated. The aim of the first question is to identify the barriers that hinder the diffusion of MHP. This should be done first in order to be able to investigate how barriers hinder its diffusion. The first sub-question therefore is:

*‘What barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia?’*

The second sub-question is about the way learning contributed to overcoming the barriers identified. It is about *whether* learning has contributed and if so, how this process has taken place and what the results of those lessons learned were. These lessons can be valuable for future projects, and thus are necessary for the diffusion of the technology:

*‘How has learning contributed to overcoming these barriers?’*

If this is known, it should be possible to investigate the driving forces behind and the impediments for those learning processes. It is important to examine these forces and impediments. Once one knows how learning processes can be fostered, it is also possible to stimulate and start new learning processes. On the other hand, if impediments are known, it is possible to remove them. In both cases, learning will be promoted through which knowledge is created that can be used to remove existing barriers. So the third sub-question is:

*‘What factors foster and impede learning processes?’*

Fourth, many MHP projects have been completed in Bolivia in the past. In each project carried out there are lessons that could have been learned, but that were not. The last sub question will lead to a reflection of the author of existing barriers in projects. Learning has not yet taken place by the Bolivian actors to remove these barriers, but the lessons that the authors has learned can be a first step in this process.

*‘What additional lessons for the diffusion of micro-hydro power can be learned from implemented projects?’*

These questions will guide me to find an answer to the main research question of this study.

## 1.5 Research Justification

In this section, the societal and scientific relevance of this study will be discussed, in order to make clear what this investigation contributes to the Bolivian society, and to the scientific state-of-the-art.

### 1.5.1 Societal Relevance

Societal relevance is a broad concept. It encompasses socio-economic issues like the increase of income, education, healthcare. But it also includes environmental topics, like improved living conditions. It answers to the question ‘how will the people in Bolivia benefit from the diffusion of MHP?’; so what are the potential advantages of rural electrification? Both socio-economic and environmental benefits will be discussed.

Socio-economic benefits of electrification

In the ‘70’s and ‘80’s many rural electrification (RE) programs in developing countries were carried out. It was thought that these programs would cause rural development (Foley, 1992). RE was often seen as a solution for a wide range of problems, including poverty, income generation, deforestation and problems related to migration to urban areas. Unfortunately, many programs were not able to fulfill these hopes. Scholars investigated the effects of RE programs in the late 1980’s and early 1990’s. Almost all had to conclude that electricity is not a simple remedy for poverty. Like Schramm (1991) (in Zomers, 2001, p.51) said that there is “sufficient evidence to argue that electrification by itself has never been a catalyst for economic development.” However, many scholars, including Schramm, concluded that electrification can have (direct) benefits when an integrated rural development approach is used (Zomers, 2001, p. 293). For example Foley (1990) concluded that electrification *on its own* does not necessarily cause development. Munasinghe (1990, p. 202) said that a comprehensive package of infrastructural services (including electrification) “would be much more likely to result in greater benefits and welfare improvements through synergistic effects”. While it became clear that direct economic benefits of RE are small, one also began to understand that electrification has many indirect benefits. Among others, Foley (1997) (in Zomers, 2001, p.54) and

the WB (Cecelski, 2000) concluded that electricity is extremely important for education, healthcare and the availability of information (especially through radio, radiocommunication and television). Vogels (1993) (in Zomers, 2001, p.53) argued that electrification should be seen as an infrastructural prerequisite and that it should be evaluated on the contribution to achieve positive developmental impacts and the satisfaction of basic social needs. In this view, electrification is seen as social infrastructure, like education and health care. This is more in line with the recent focus of development programs, which shifted from the hardware of development (e.g. infrastructure) to software, including e.g. institutional and human development and empowerment. Electricity does influence these software aspects. (Kanagawa & Nakata, 2007)

Recently, there are some studies that claim a positive (direct) relation between electrification and productive end-use. Barkat et al. (2002) investigated the long term (20 years) effect of electrification by comparing electrified and un-electrified houses in (un-)electrified villages. They discovered that for electrified households 16.4% of the annual income can be attributed to electrification. Furthermore, 13.6% of the electrified households said that they had new sources of income, while this was only 1.6% for un-electrified households. (Barkat, et al., 2002) Another study showed evidence of economic benefits of RE in China, but also showed that more developed provinces benefit more than less developed provinces (Yang, 2003).

The above can be summarized by citing Zomers (2001, p. 15): "Bringing electricity to the people is, in itself, not a contribution to reducing poverty nor does it automatically lead to rural development". However, bringing electricity can provide the necessary prerequisites for development or lead to significant cost reductions.<sup>2</sup>

#### Bolivia

As said before, more than 3 million people in Bolivia, almost all living in rural, remote areas do not have access to electricity. Extension of the grid is often not economically feasible, because of the isolated location of these villages and the low population density. So other solutions are required to supply these villages with electricity.

There are a lot of places in Bolivia with favorable conditions for MHP. In many of those places, the villages can best be served by the installation of such systems. I hope my research will provide insight in learning processes in MHP projects and the MHP sector, and thus contribute to a better understanding of barriers to the diffusion of MHP in Bolivia and how they can be overcome. I hope this understanding will contribute to a better functioning of the technology and a further diffusion of MHP, so that the living conditions of many people will improve. Moseley and Fulford (1999) claimed that MHP is very suitable for achieving this, by saying that MHP "is a relatively efficient method of poverty reduction, in terms of costs per person moved across the poverty line. [And] [...] micro-hydro is also able to reach a number of the extremely poor [...] through the channel of wage employment [...] and linkage activities." (in Cecelski, 2000, p.8) Furthermore, a study of Practical Action to the perceived economic benefits of MHP in Peru, a neighbouring country with a lot of similarities to Bolivia, showed that 60% of the people living in villages with MHP believes that his/her income has improved thanks to MHP.

#### Environmental benefits

Besides socio-economic benefits, environmental benefits exist. When households do not have access to modern energy sources (electricity and gas), kerosene, batteries, diesel and candles are used for lighting and communication activities (11% of the energy use of households in rural areas in Bolivia) and biomass (deadwood, grasses and manure) for cooking (89%<sup>3</sup>) (Espinoza, 2005). Electricity does usually not replace biomass for cooking purposes, so only 11% of the energy use can be substituted by a more environmentally friendly alternative. Micro-hydro is such an alternative. Compared to other (renewable) energy sources, green house gases (GHGs) per kWh are low. A life cycle analysis will show that the CO<sub>2</sub>-emissions are among the lowest of all kind of electricity generating alternatives. SO<sub>2</sub>- and NO<sub>x</sub>-emissions are the lowest. For more details, see chapter 4.3.

Moreover, the quality of the air in houses will improve through the replacement of kerosene and candles by electricity. Especially the burning of kerosene oil for light has a number of adverse effects. One of the short-term

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<sup>2</sup> Households in rural areas in Bolivia spend on average 37 US\$ per year on fuels (gas not included). Electricity costs on average 30 US\$, which means a reduction of 17% (Espinoza, 2005).

<sup>3</sup> Energy used for productive end-uses is negligible.

effects is problems with the eyes. A study in India showed that 21 per cent of the households using kerosene for lighting reports that one or more family members suffered from eye problems (Chakrabarti & Chakrabarti, 2002). Furthermore, respiration sickness, caused by the emission of small particles, will be reduced if the air quality is improved. (IEG, 2008)

Some local environmental costs will be created as well, although these are limited. A micro-hydro plant claims some land and will lead to some visual intrusion (Anderson, 1997). These are minor effects though.

### 1.5.2 Scientific Relevance

#### Barriers

In the past, some work has been done to identify barriers hindering the diffusion of renewable energy technologies. These studies have resulted in wide-ranging lists or categories of barriers of those technologies in general.<sup>4</sup> More specific studies have been done on biomass and solar panels, but never on barriers to MHP, although some authors have investigated key success factors for the implementation of MHP.<sup>5</sup> This will be the first study that investigates barriers to the specific technology of MHP.

#### Strategic Niche Management

This study will use a new approach to investigate barriers. Until now, studies to barriers resulted in static lists, without referring to the dynamics and causes of these barriers and their mutual relations. It is often clear which barriers exist, but not how they have developed and how they can be removed. In this study, I will use a learning approach to identify and analyze barriers and to get a better understanding of the dynamics behind them. If learning processes within projects and within the micro-hydro power sector are identified and examined, an understanding of the roots of the barriers will be brought to the surface. Without knowing these roots, it is impossible to structurally remove them. Moreover, investigating learning processes does not only incorporate barriers, but also incorporates the diffusion of the technology. Because learning is not only viewed at a local project level but also at a sector level, learning processes within policy makers, implementing organizations, the financial sector, and so on, are also incorporated. All these different aspects are interlinked, and the lack of learning in one segment of the sector will influence the other. When learning does not take place at all levels, the diffusion of the technology will continue to face barriers. Strategic Niche Management (SNM) provides a framework for the investigation of learning processes and provides insight in the processes of the development and diffusion of an emerging, developing technology. This is the first new aspect of my research. Secondly, I will adapt the SNM framework. Originally, it has been developed to get insight in the development of new sustainable technologies in high-income countries. Van Eijck (2006; van Eijck & Romijn, 2008) was the first who used SNM in developing countries. Later on, some other students of the Technology and Development Studies group of the Eindhoven University of Technology used SNM in developing countries. Van Eijck (2006, p. 81) suggested that SNM should be brought together with other literature on the development of innovations in developing countries, to get a more detailed insight of actual management of learning processes in experiments and projects. The adaptations to the model will be discussed in chapter 4.<sup>6</sup>

#### Micro-hydro power in Bolivia

Besides the lack of knowledge of barriers to the diffusion of MHP, there is also a lack of knowledge about MHP in Bolivia. No umbrella organization exists in Bolivia and there is no coordination of projects or data. It is e.g. not known how many systems have been built, and if these systems are still functioning. Even the implementing organizations often do not have sufficient data about their own projects. I hope this study will contribute to the creation of knowledge about the micro-hydro sector in Bolivia.

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<sup>4</sup> See for example Painuly (2001), the IPCC (2001), Painuly and Fenhann (2002), Beck and Martinot (2004), Reddy and Painuly (2004) and Khattak et al. (2006).

<sup>5</sup> See for example Smith (1994), Khennas and Barnett (2000), Paish (2002) and ESHA (2005)

<sup>6</sup> A more or less similar study is being conducted in Indonesia, by Jacqueline Kooij. Results will be compared to discover similarities in the diffusion process in both countries. This however will not be part of the MSc. thesis.



## 1.6 Research Boundaries

Geographically, this study is bound to Bolivia and only to areas with suitable conditions for MHP. Conclusions and recommendations that are drawn in this study can be relevant for (neighboring) countries with similar conditions as well, but should be handled with care.

The study is also limited to *micro*-hydro power, which means that pico- and mini-hydro are not taken into account. A detailed overview of the differences and definitions is shown in chapter 4.2.1. Furthermore, only stand-alone systems are studied; grid-connected systems are not analyzed.

Detailed technical studies have not been done for this analysis. This was not necessary because of the nature of the study, which takes into account a wide range of factors.

Causes of barriers can be categorized into proximate-, intermediate-, and ultimate causes, depending on the time-scale (see chapter 3 for a more detailed explanation) (Szirmai, 2005). This study only investigates proximate and some intermediate causes. It is impossible for a foreigner who spends just six months in Bolivia to thoroughly study intermediate- and ultimate causes which are embedded heavily in the social structures of a country.

## 1.7 Method of Data Collection and Assembling

Data was gathered through MHP project case-studies and interviews. The purpose of the case-studies was to investigate whether learning occurs and if so, which learning processes take place at the local project level, and whether projects use social networks to communicate the lessons learned with other projects or organizations. Nine case-studies have been analyzed, of which eight turned out to be useful. The case-studies have been selected by their size, age and location and elevation, in order to be able to generalize findings for the whole Bolivian micro-hydro sector. Of those nine projects five are located in the section of La Asunta.<sup>7</sup> These have been investigated to see if differences exist when systems are situated closely together in comparison to relatively isolated systems.

Data for the case-studies was being collected through interviews with the local management of the plants and with the implementing organizations, through conversations with and administering questionnaires among the local population, and from existing sources like feasibility studies, plant-designs, final reports and evaluations. Structured interviews were conducted using open questions. The same questions were asked in all the case-studies, in order to compare the results. In some case-studies topics are more emphasized than in other cases, e.g. in case of competition with the national grid. Conversations with the local population were unstructured and open. For one case-study a questionnaire was used among the local population to investigate what the main reasons are for people to choose between electricity of the MHP plant and the national grid. Twenty villagers were questioned, chosen randomly and according to availability. The case-studies are described in Appendix II and analyzed in chapters 7 to 11. Furthermore, important organizations and persons in the MHP sector were interviewed. This was done to get a better understanding of the learning processes that take place at the global niche level (later more about this). These were structured interviews with open questions. The interviews are used for the analyses in chapters 7 to 11. A list of the persons and institutes interviewed can be found in Appendix III

## 1.8 Structure of the Report

The report has been divided into two parts (see figure 1.1). Part A can be perceived as the preparation of the actual research and it is based on existing literature. Besides this chapter, it consists of an explanation of the research framework (chapter 2, Research framework) and a description of how this framework is translated to a tool to collect and analyze the data collected (chapter 3, Data collection and analysis methodology). The technology is explained in chapter 4 (Micro-hydro power).

Part B will be containing the actual analysis of the diffusion of MHP in Bolivia. Landscape factors influencing the Bolivian electricity sector and the MHP niche are examined in chapter 5 (The socio-technical landscape). The

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<sup>7</sup> The section of La Asunta is a special case, because the electricity grid will not be expanded to the region, although it is located relatively close to urban areas. This is because the area produces high quality coca. The government does not want to stimulate the cultivation of coca and therefore does not allow to expand the grid.

electricity regime itself is described in chapter 6 (The electricity regime). The analysis of the MHP niche is divided into five separate chapters. The first one contains all the background information necessary for an understanding of the sector (chapter 7, The micro-hydro power niche). Thereafter, learning processes in local projects (chapter 8) and by implementing organizations (chapter 9) are analyzed before additional findings will be discussed in chapter 10. The last part of the niche analysis consists of an investigation of barriers to dynamic niche processes (chapter 11, Networking and barriers to dynamic niche processes). This thesis will come to an end with the conclusions, recommendations and a methodological reflection in chapter 12.

The case-studies used for the analysis are described in Appendix II. Each case-study can be read separately.

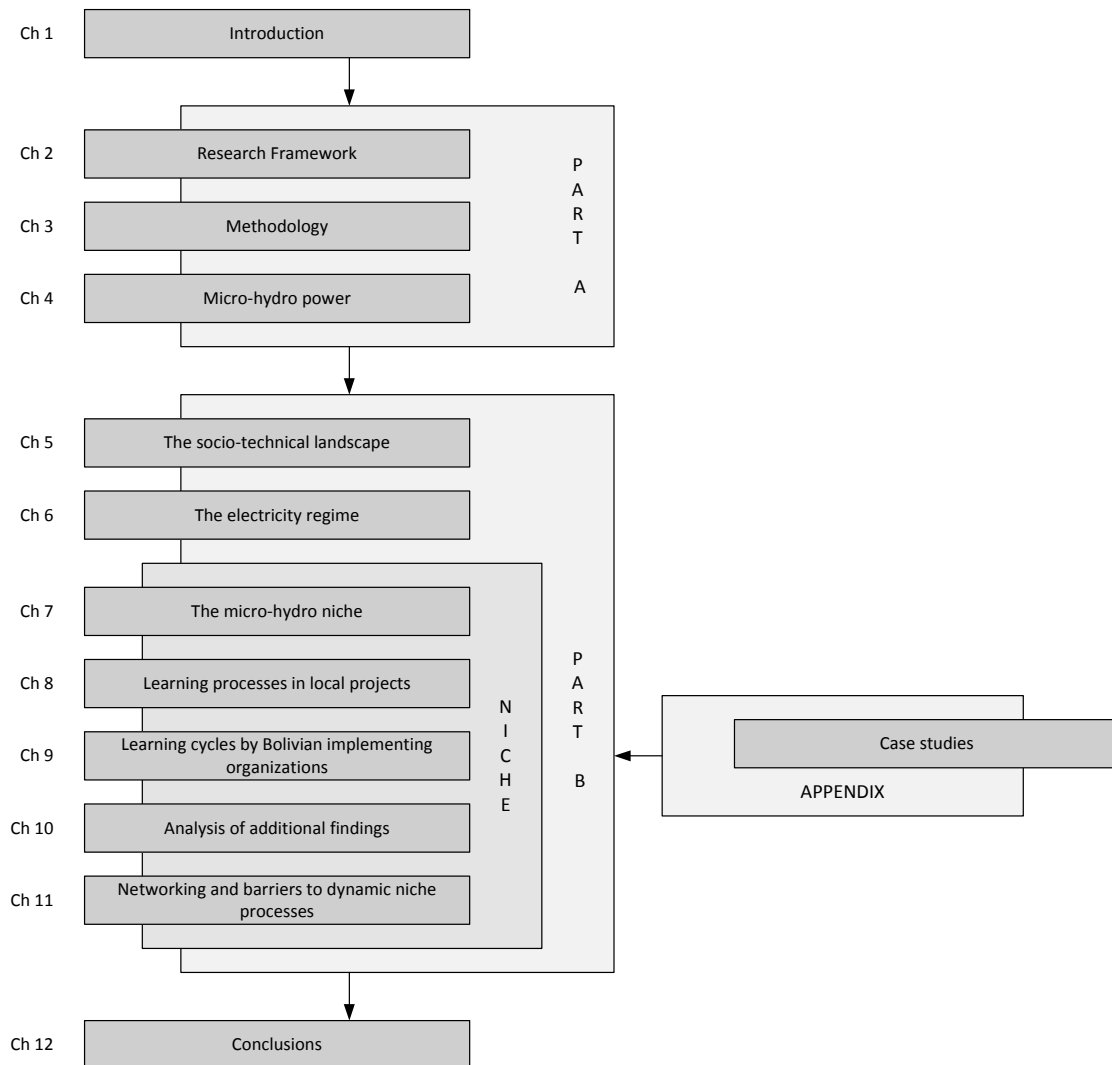


Figure 1.1: Structure of the report



# RESEARCH PART A

## 2 Research framework

'How do innovations develop and diffuse?' This short question seems quite simple but has employed researchers for decades. Many diffusion models have come by. One of the first and most well-known is Rogers' Innovation-Decision Process model that assumes that people's attitude towards an innovation is the key element in its diffusion (Rogers, 1995). This linear diffusion model dominated diffusion literature for many years. Later, other (linear) models like Technology Transfer<sup>8</sup> (TT) appeared. This model assumes that an innovation transfers (diffuses) from one organization/country to another, enabled by and dependent on the amount of techno-ware, human-ware, info-ware and orga-ware of the receiving party (van Egmond - de Wilde, 2006).

Evolutionary, dynamic approaches emerged in the 1980s, starting with the work of Nelson and Winter (1977; 1982), Dosi (1982) and Kline and Rosenberg (1986). The emerging evolutionary view of innovation understood that innovation is an iterative process of trial and error and that technology is an endogenous factor in this process, not exogenous. Some new innovation models were brought forth from this approach. One of the first was Systems of Innovation<sup>9</sup> (SI). It emerged in innovation studies in the 1990's. One of the main contributions of SI is a broadening of the scope of analysis, from artifacts to systems, from individual organizations to networks of actors. All elements of the diffusion process became interlinked, influencing each other. (Geels, 2004)

Social-technical systems (STS) were developed during the last decade. This approach contrasts with SI through the inclusion of both supply and demand side, and through the focus on the diffusion and use of a technology, while the latter concentrates on the supply side and the development of knowledge. Moreover, users were seen as active partners in the innovation process and play a key role. STS also address the transition process from one system to the other. These processes are explained using a multi-level perspective (MLP), consisting of a macro-, meso-, and micro-level. The latter can be described under the heading of Strategic Niche Management (SNM), which emerged under the notion that many sustainable novelties never leave the laboratory or showroom (Raven, Heiskanen, Lovio, Hodson, & Brohmann, 2008). SNM studies determinants for the development of a niche technology, in order to understand and explain why these innovations do not develop and/or diffuse. (Geels, 2004)

The framework lastly discussed will be used in this study. The MLP will be used as a broader contextualized view of the role played by niches, which are protected places where an innovation can develop while it is not able yet to compete with the established technologies, in order to understand the context of the development and diffusion of a new technology (Schot & Geels, 2008). However, SNM especially is developed to model processes in high-income countries. Because it is not clear about how niche processes exactly take place, it will be accompanied by some literature stemming from development studies.

How does this framework relate to the investigation and analysis of barriers? As will be discussed in this chapter, learning takes place in experiments. The lessons learned are aggregated, through which knowledge accumulates and the technology can be developed. Therefore, experiments are the building blocks of the niche. Hoogma (2000) defines experiments as "unique socio-technical laboratories for learning about the problems, shortcomings and barriers a new technology faces." So learning encompasses the search for solutions for the removal of barriers and thus, barriers can be identified by investigating which learning processes have taken place and are taking place.

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<sup>8</sup> Also known as Transfer of Technology

<sup>9</sup> System of Innovations include sectoral systems of innovation, technological systems and large technical systems. Influential authors in System of Innovation literature are e.g. Charles Edquist (see e.g. his book 'Systems of Innovation: technologies, institutes and organizations' (1997)), Richard Nelson (National Systems of Innovation (1988)) and Christopher Freeman (Japan: a new national system of innovation (1988)).

## 2.1 Multi Level Perspective

The multi-level perspective (MLP) is developed to model transitions in socio-technical systems. A socio-technical system is a concept describing interlinked social and technical phenomena that all influence the functioning of an established technology and the development and diffusion of an innovation (Ropohl, 1999). It consists of "a cluster of elements, including technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and supply networks" (Geels, 2005, p. 446). Transition in socio-technical systems are complex, due to the interaction of these elements. The MLP defines three levels in which a technology is embedded, namely the landscape developments (macro-level), the socio-technical regime (meso) and technological niches (micro). The phenomena at the three levels interact in a dynamic way, through which transitions can take place, see figure 2.1.

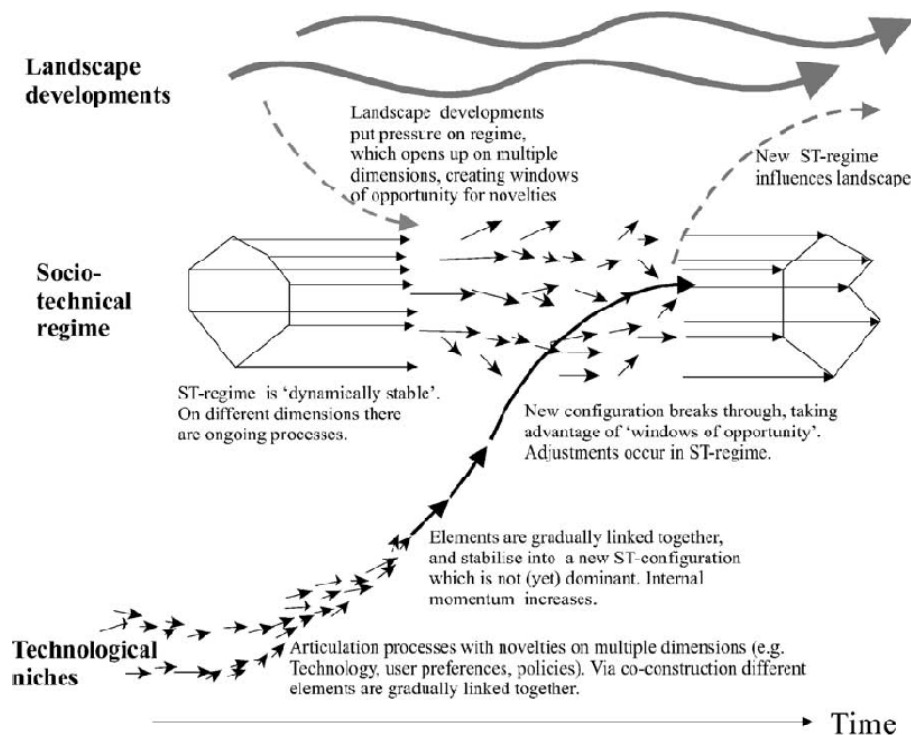


Figure 2.1: A dynamic multi-level perspective (Geels, 2002b)

### 2.1.1 The socio-technical landscape

The socio-technical landscape refers to three factors: slow trends and developments (usually in the order of decades), factors that do not change, or that change only slowly (geographical conditions, climate), and unexpected events, like terrorist attacks or mega-tsunamis (Van Driel & Schot, 2005). It is an exogenous environment which can (in general) not be influenced by actors in the niche or regime level (Schot & Geels, 2008). The socio-technical landscape has a wide range of impacts on many people, societies and for instance the economic and political context. This impact is not constrained to single sectors or countries.

Important elements of the landscape are the physical infrastructure, political culture and coalitions, social values and lifestyles, societal and managerial commonsense, macro-economic developments, pervasive technologies, demographic developments and the natural environment (Geels & Kemp, 2000, pp. 16-17). The landscape puts pressure on existing regimes, which opens up on multiple dimensions, creating windows of opportunities for novelties. An example is the increasing global environmental awareness. This awareness is slowly opening up the existing regime based on fossil fuels, creating space for renewable alternatives.

### 2.1.2 The socio-technical regime

A socio-technical regime is shaped by a dominant technology and a set of rules and institutions (actors) related to this technology. One of the main characteristics of the regime is its stability (Geels, 2005, p. 450). This stability is caused by three concepts. First, rules and regimes provide guidance for perceptions and actions. Unfortunately, it makes actors 'blind' for alternatives of the dominant trajectory. Besides cognitive and normative rules regulative and formal rules can hinder innovations. Second, "actors and organisations are embedded in interdependent networks and mutual dependencies" (Geels, 2004, p. 910). These structures form organisational capital, which is hard to break. Lastly, the regime has a certain hardness, caused by existing material structures. These structures represent a value in terms of money and sunk costs (Geels, 2004). This stability does not mean that the regime does not develop. It is a dynamic stability. Innovations do still occur, but they are of an incremental nature (Geels, 2002b).

### 2.1.3 The niche

Niches are breeding places for new (radical) technologies to develop. A niche is a protected area where uncertainties can be dealt with and where new technologies can develop in order to compete with the dominant technology in a later stage of development. It acts like an incubation room for radical innovations (Geels, 2002a). Niches facilitate social- and learning-processes, through which the technology can increase its stability and technical performance. Moreover, niches function as stepping stones for further diffusion of the technology (Geels & Kemp, 2000). Several transition pathways exist to accomplish the diffusion and adoption of the novelty. If the regime-technology is completely replaced by the niche-technology *technological substitution* has taken place. This can occur when the niche-technology has sufficiently developed and much landscape pressure has led to windows of opportunities. A sufficiently developed novelty can also be embedded in the regime as add-ons or component replacement of the dominant technology, usually as a result of economic considerations. One speaks of a *reconfigurations pathway* if this leads to changes in user practices, search heuristics and perceptions of regime-actors. If the basic architecture of the regime is not disrupted, usually because the niche-technology is not fully developed yet, one speaks of a *transformation pathway*. This leads to a reorientation of development trajectories, but can be seen as a change from within the regime. The last way in which a niche-technology can enter the regime is by the *de-alignment and re-alignment path*. The regime faces internal problems causing actors to lose faith leading to a hollowing out of the regime. Niche-technologies are not fully developed yet, but have to enter the vacuum created. Several niche-technologies compete for a place in the regime, of which one will become dominant. (Geels & Schot, 2007, pp. 406-413)

## 2.2 Strategic Niche Management / Niche developments

Before I will discuss the process of niche development, which eventually should lead to the diffusion of the niche-technology, I will first explain which processes are important to develop a sound niche-construction.

### 2.2.1 Internal niche processes

According to SNM-scholars, three internal niche processes exist (Schot & Geels, 2008): 1) The articulation of expectations and visions; 2) The building of social networks; and 3) Learning processes. These processes are interlinked, and positively influence each other. Through more robust expectations, broader and deeper networks and the creation of knowledge through learning, stability is created through the crystallization of rules and networks. (Kemp, Schot, & Hoogma, 1998; Geels & Kemp, 2000; Mourik & Raven, 2006)

According to Mourik and Raven (2006, p. 19), expectations are a "means to facilitate the construction of a shared research agenda, to guide search processes, to increase the quality of design processes through enhancing the specificity and finally to attract resources such as financial and managerial resources, actors, knowledge and expertise." The voicing and articulation of expectations and visions is important to make them more robust. Robustness is defined as becoming more specific, detailed and consistent and broadly supported within the relevant network. Robust expectations are important because they prevent differences of opinions destabilizing the niche from within (Mourik & Raven, 2006) and the future development of a technology will be more streamlined (Kemp, Schot, & Hoogma, 1998).

Network formation is important because it reduces risks, complexity, scale, and uncertainty. Furthermore, it creates coordination of the actors involved and materializes expectations and the accompanying division of roles and tasks (Mourik & Raven, 2006, p. 22), and it enables the spreading of knowledge. Networks contribute more if they consist of insiders and outsiders with respect to the dominant regime.

According to Mourik and Raven (2006, p. 26) “learning in local projects and niches is focused on the changes necessary to couple with opportunities and overcome oppositions/barriers in the environment outside of the local project and niche with the aim to make a new innovation function properly”. Rosenberg (1982) articulated it even more vigorously. He sees technological innovation as a learning process, in fact, as several distinct kinds of learning processes. Learning in niches should entail all aspects; like learning about the necessary technological development, the development of the user context, the societal and environmental impact, industrial development and government policy and regulatory framework. SNM particularly focuses on learning-by-interacting and learning-by-using. The first one relates to network formation, aiming at learning from involved actors and sharing the lessons learned. The latter aims at learning from previous designs in local projects (the form in which the experiment is carried out) and using the lessons learned in future local projects. It leads to disembodied knowledge, leading to alterations in the use of the technology, not to modifications in the hardware. According to Rosenberg (1982, p. 23) learning-by-using is important because “technical knowledge in high-technology society tends to be extremely specialized or specific [...] and cannot [...] be accurately predicted from experience with related or analogous technologies.” If this is true in high-income countries, why shouldn't it be true in developing countries? If outcomes cannot be predicted accurately somewhere it should be in developing countries were, as Korten (1980, p. 497) described 'objectives are often multiple, ill-defined and subject to negotiated change, task requirements unclear, outcomes unbounded by time, environments unstable, and costs unpredictable'.

The three internal niche processes are linked. If experiments are successful, expectations will rise. This will in turn enlarge the network. Promising expectations and a larger network will mean an increase in funding. More funds mean more possibilities for learning. More learning gives better temporary outcomes, which gives higher expectations and a larger network, and so on. This cycle of internal niche processes creates more stable rules and networks, through which a new socio-technical regime can be created (Geels & Kemp, 2000).

### 2.2.2 Niche development

The development of the niche takes place at two interlinked levels, the global niche level and the project level, each reinforcing and building upon each other by the sharing of accumulated knowledge (see figure 2.2). The internal niche processes take place at both levels. In this section, both levels will be explained together with an analysis of the mutual interaction.

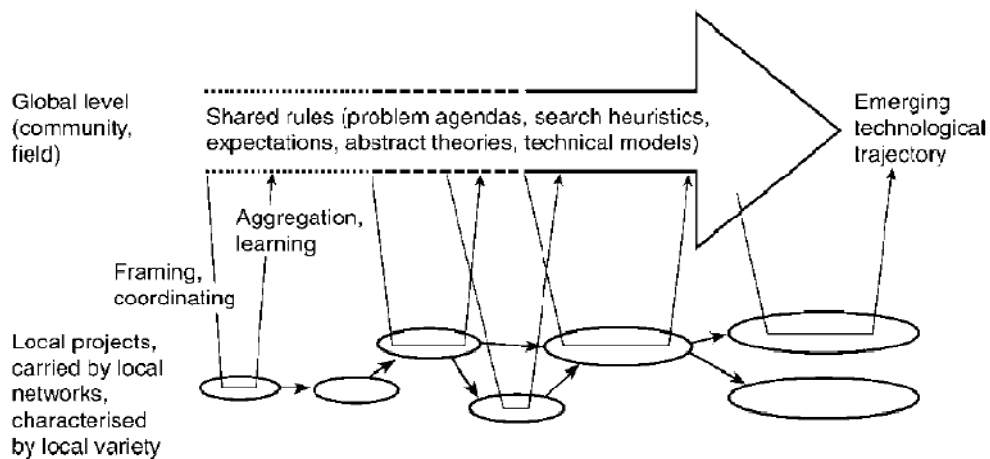


Figure 2.2: Technological trajectory carried by local projects (Geels & Raven, 2006)

### Global niche level

The global niche level can be seen as the emerging technological trajectory. It consists of accumulated, global, abstract and generic knowledge, such as abstract theories, technical models and formulas and forms and frames (problem agendas, search heuristics, guiding principles, rules of thumb, exemplars) that are shared within the emerging community (Geels & Raven, 2006). Rip (1997, p.616 in Geels and Deuten 265-75) refers to 'cosmopolitan knowledge', knowledge that has abstract features and is no longer tied to its original, specific context. It is generalized, delocalized and can therefore be used at various locations (Geels & Deuten, 2006).

### Local projects

The local project level consists of concrete real-life projects and experiments, carrying and feeding the global niche. The projects are carried out simultaneously and/or successively, using local actors, networks, knowledge and a specific configuration of the technology (Mourik & Raven, 2006). The principle idea of this level is that projects should build on each other and must seek and utilize existing strengths. This level should be constructed carefully. In the early niche formation, projects should start simple. Complexity should/can be added in future projects, when basic features of technological and organizational aspects have been mastered through learning in preceding projects. Doing so, new knowledge can be created and accumulated. (Caniels & Romijn, 2008)

How should this 'building upon each other' actually work? Local projects should make use of the accumulated knowledge existing in the global niche, through so called 'framing and coordination activities'. Experiences and knowledge from previous projects are used as input for the formulation of new projects. Doing so, the project does not have to re-invent the wheel again, and can add to the existing pool of knowledge in the global niche. However, it is not as easy as copying and adding. The knowledge in the global niche has been made generic. It has been stripped from the specific local context and does not fit directly to the specific characteristics of the local situation. Therefore, actors should be able to respond to the uniqueness of the situation, and be able to make interpretations and adjustments. (Geels & Raven, 2006; Geels & Deuten, 2006)

The global niche develops when lessons learned in local projects are communicated and shared with other projects and the emerging field. This should be done via so called 'aggregation activities'. Aggregation is "the process of transforming local knowledge into robust knowledge, which is sufficiently general, abstracted and packaged, so that it is no longer tied to specific context" (Geels & Deuten, 2006, p. 267). It is a bottom-up process. Knowledge, lessons learned and experiences have to be evaluated, made context free, cumulated and aggregated to the global dimension.

The transformation of local outcomes into generic lessons and cognitive rules does not occur automatically. Typical aggregation activities include standardization, codification, model building, formulation of best practices, etc. Also circulation of knowledge and actors is important, to enable comparison between local practices and formulation of generic lessons: conferences, workshops, technical journals, proceedings, newsletters play a role here. (Geels & Raven, 2006, p. 378) Intermediary actors play an important role in aggregation activities. Firms traveling between local practices may aggregate local knowledge as well. Lastly, the creation of an infrastructure is important. Think again of forums, conferences, etc. (Geels & Deuten, 2006)

According to Geels and Deuten (2006) the process of aggregation will strengthen when the niche is more stable and structures and networks exist. They identify four phases in knowledge accumulation. In the local phase, the technology emerges in local relatively independent projects, creating knowledge for their own purposes. Some interactions take place, but the projects are relatively isolated. In the inter-local phase, the knowledge is circulated more and more within networks. Learning and accumulation (aggregation) take place on a (inter-)local scale. In the trans-local phase, knowledge is created that is not intended to serve a single projects but the field as a whole. Intermediary actors play an important role in this. Lastly, dominant cognitive rules are established through institutionalization and standardization in the global phase. (Geels & Deuten, 2006, p. 266) When these phases are passed through the niche-technology should be sufficiently developed to enter the regime.



### 2.2.3 Learning selection (Learning in projects/experiments)

One can conclude from the framework discussed above that learning in local projects and the sharing of the created knowledge is of vital importance for the development of the niche. However, it is not clearly articulated by SNM how exactly this learning should take place. What are the processes behind learning, and especially behind learning in developing countries?

Boru Douthwaite (Douthwaite, 2002; Douthwaite, Keatinge, & Park, 2002) provides an answer to this question. He designed an approach called 'learning selection'. He used a learning cycle developed by Kolb to understand the process of technical learning in projects and extended it for learning between projects. Kolb (1984) presents a four stage cyclical model of learning, consisting of 1) concrete experiences, 2) observations and reflection, 3) forming abstract concepts, and 4) testing in a new situation. Douthwaite extended the cycle to the process of learning selection. The figure below is a representation of the process of learning selection.

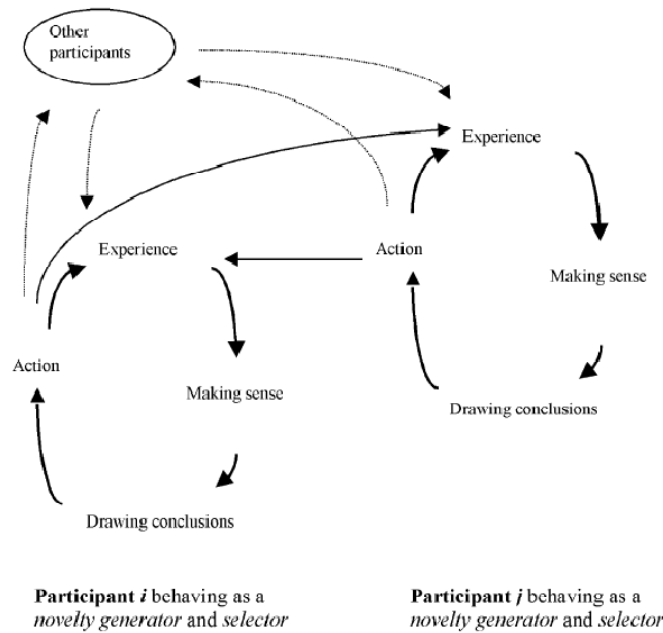


Figure 2.3: The process of learning selection (Douthwaite, 2002, p. 47)

Participant *i* has experienced or has learned from an experience (not necessarily his/her experience) that a technology does not function well. He/she makes sense of the implication of the malfunctioning, and discovers the real problem. Then, (s)he draws conclusions about the causes of the problem, leading to action to overcome it. This action leads to a new experience, leading to new problems, and so on. This action does not stay unnoticed by other adopters. If other participants believe the action of participant *i* improves the functioning of the technology, they will adopt the innovation as well, experience other problems and adapt again. This process can be seen as problem-based learning.

### 2.2.4 Process approach

While Douthwaite focuses on technical learning, David Korten (1980) focuses on institutional learning and differences in the implementation of projects between high-income and developing countries. First, Korten says that projects in developing countries should focus on "organizations with a capacity for embracing error, learning with the people, and building new knowledge and institutional capacity" (Korten, 1980, p. 480) in order to be successful. This goes far beyond the adaptation of technology, but includes institutional learning.

Second, Korten warns against the use of blueprints. The framing and coordination from the global level to the local projects does not mean, according to Korten, that a new project can use generalized experiences (the shared rules on the global niche level) from previous projects as blueprint. This is already stressed by SNM, but Korten emphasizes

that it is even more true for developing countries. A blueprint approach might work in developed countries or for large scale projects, where objectives are clear, knowledge existing and capacity present. However, in developing countries these factors are ill defined. New projects can use shared rules created from previous experiences, but should emphasize the learning process within the project itself. Korten (1980, p. 497) noticed that successful projects are not designed and implemented, but rather emerge out of learning processes in which (inter-)local knowledge and resources are shared to "create a program which achieved a fit between needs and capacities of the beneficiaries and those of outsiders who were providing the assistance". Learning has a twofold meaning. The local population should learn in order to develop, e.g. by building local capacities. On the other hand, the implementing organization has to learn, e.g. about the optimal design, and the organization. The implication is that projects in developing countries might be able to use less knowledge derived from the global niche, and have to go through more learning cycles within the project. Therefore, the development of the niche might possibly take place at a slower pace than it would be in high-income countries.

According to Korten, this learning process within the project has three stages. First, learning to be effective should take place. The major concern is to get the program running, by investing in knowledge and capacity building. The second stage is learning to be efficient. This is about using fewer resources while achieving the same. Lastly, learning to expand should occur. The last form of learning does often apply to the implementing organization and entails the expansion of a program, not a single project. (Korten, 1980)

### 2.3 Conclusion / Integrated framework

The figures below provide an overview of the theories discussed above, integrated in one picture. A technological trajectory emerges at the global niche level. Shared rules and aggregate experiences are used for framing and coordination of the new projects, mindful of Korten's warnings for blueprint approaches (number 1 in the figure). The project has started up, problems are experienced by users, whether this is in the learning to be effective, efficient or expand stage (Korten), and action is ideally undertaken to solve these problems (Douthwaite) (number 2). Reflection of the experiences takes place (3) and the lessons learned are generalized (4) and aggregated (5) to the global niche level. In the next project, these lessons are used again for framing and coordination activities (6). Experiences and lessons learned do not only diffuse via the global niche, but also directly between projects (7).

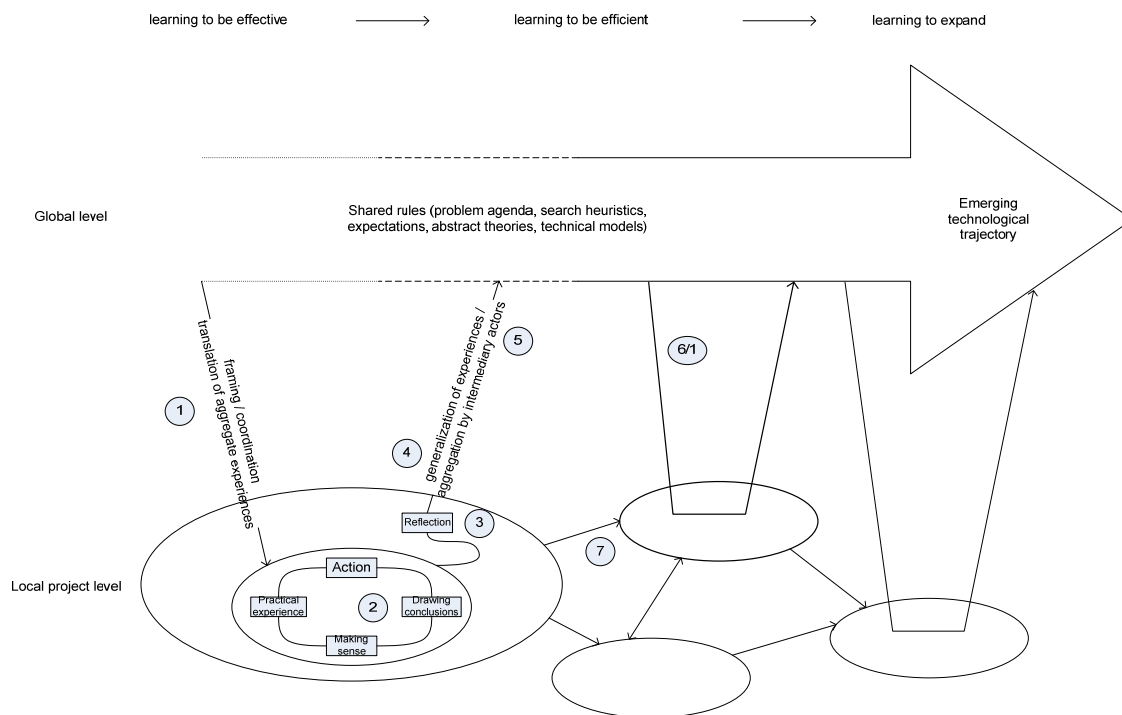


Figure 2.4: Trajectory carried by local projects adapted from Geels en Raven (2006), combined with Douthwaite's learning selection and Korten's process approach.

A list of key success factors for the development of the niche are distilled from the theories discussed (see the textbox below). These factors are the starting point of this investigation. It is assumed that if they are present, one can expect that the diffusion of MHP develops well. The numbers in figure 2.4 correspond with the numbered items in the textbox.

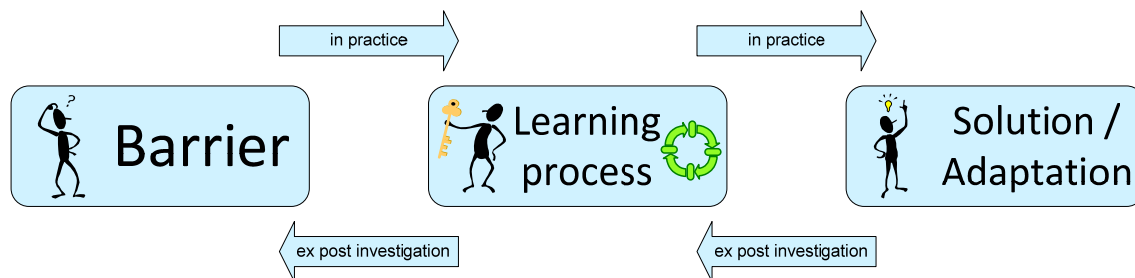
**Table 2.1: Key success factors for the development of the niche**

1. Experiences and learning from previous projects are known and used for framing and coordination.
2. Experiences and learning within the project takes place according to Douthwaite's learning selection model, extended by Korten's observations.
3. Experiences and learning are evaluated.
4. Experiences and learning are generalized by (an) intermediary actor(s).
5. Findings are communicated and aggregated to the global niche level.
6. New projects use these findings for coordination and framing purposes.
7. Experiences and learning is directly shared with other projects.

### 3 Data collection and analysis methodology

In this study the learning framework discussed in the previous chapter is used to identify and analyze (the removal of) barriers. In order to do this, learning has to be related to barriers. It has been explained in chapter 2 that according to Douthwaite, learning stems from negative experiences caused by problems that individual people and organizations, the users, have had with a technology. It did not function as they wished it did. These problems are barriers for a proper functioning of the technology. Through these barriers, the technology or the system in which the technology functions had to be adapted. One learned how to improve the technology or the functioning of the technology, through which it became more successful and had a better chance to diffuse. Other users will see the adaptation and will adapt the technology as well. However, users are not always able to adapt a technology or its system. Sometimes there is not enough knowledge or resources available for adjustments, so that the technology keeps functioning poorly. In this case, the learning process has not been completed yet.

So there are two situations that should be considered when searching for barriers. In the first one, the technology has already been adapted to remove a barrier. But although the barrier has been removed already, it is still useful to investigate these adaptations. It is possible that the lessons learned in the process of removal do not reach other projects, so that the barrier keeps hindering the diffusion of the technology. Therefore, it should be examined whether the adaptation is channeled through networks to other projects or not. In the second situation, the problem is still hindering the functioning of the technology, so the barrier still exists.



**Figure 3.1: Schematic representation: A learning process is provoked by a barrier, leading to adaptations. In this report, learning processes or adaptations are investigated to retrieve the barriers**

Chapter 2 has shown that learning should take place at two levels, the global niche and the local project level. So adaptations and problems have to be examined at both levels as well. Case-studies are used to identify lessons learned in local projects. How data exactly is gathered is discussed in chapter 1.7.

Learning processes within projects are identified through so called Innovation Histories. This is a method for recording and reflecting on an innovation process. It was originally developed by the MIT's Center for Organizational Learning as an answer to the question how lessons from the past can be processed by an organization so that they are translated into more effective action (Kleiner & Roth, 1997)? Douthwaite and Ashby (2005) used the tool and transformed it to analyze learning processes in projects in developing countries. Their Innovation History has two purposes. First, it allows people concerned to reflect on their actions, and second, it allows external parties to learn. The adapted Innovation History consists of two concepts; An Innovation Timeline and an Actor Network Matrix. The first one sequentially lists the key events. These events consist of adaptations of the technology or the system in which it functions, and of the still existing barriers, the unfinished learning processes. The Innovation Histories are incorporated in the case studies in Appendix II. The second shows the links between stakeholders and other actors in the network. The matrix shows how lessons learned are spread to other projects and how the knowledge created is diffused. Actor networks of each case study are incorporated in section 7.4.

Case studies are very useful to determine learning within projects and learning directly between projects. However, local actors are often not aware of or cannot interfere with the global niche level. Therefore, in order to identify framing, coordination and aggregation activities, and to identify barriers at the global niche level, actors involved in

this level are interviewed and existing sources are examined as well. For the exact method of data collection, see chapter 1.7. The information obtained is used as input in the case-studies, but also to investigate, analyze and describe the context in which the projects function. The case-studies and context lead to a niche-analysis, in which learning processes and related barriers come forward.

The barriers identified are classified in five categories, deduced from different sources.<sup>10</sup> These categories are:

- Market barriers
- Economic / Financial barriers
- Institutional barriers
- Technical barriers
- Social, Cultural, and Behavioral barriers

In order to identify the barriers, learning processes are investigated (see figure 3.1). These are divided into the five categories as well. This however does not mean that learning processes in one category necessarily lead to barriers in the same category.

As said before, the learning processes are described in three different chapters. Chapter 8 investigates in detail the learning processes in local projects. This is visualized in the left picture in figure 3.2. Chapter 9 investigates learning processes by implementing organizations (middle figure) and how these processes are translated in subsequent projects. Lastly, chapter 10 (right-side figure) is an analysis of additional findings of the author.



**Figure 3.2: Visualization of the three learning processes within the niche**

Analyzing barriers also means trying to find out what causes the existence of the barriers. Causes can be analyzed on different levels, based on a time scale. Proximate causes are directly related causes and have strictly to do with the specific barrier. They are embedded in intermediate causes that form a wider context. The basic societal factors underlying these proximate and intermediate causes are the ultimate causes of barriers.<sup>11</sup> Ultimate causes are hard to identify and to remove or change. (Szirmai, 2005) This is beyond the scope of this study. The intermediate causes to barriers are seen as the factors fostering and impeding learning cycles (fourth sub question). These are discussed in chapter 11.

<sup>10</sup> See Painuly (2001), Painuly and Fenhann (2002), Khattak et al. (2006) and the IPCC (2001).

<sup>11</sup> E.g. long-run trends in knowledge, demographic trends, historical development, basic social attitudes and capabilities, etc.

## 4 Micro-hydro power

### 4.1 History

The origin of micro-hydro power can be traced back to two distinct places. The first horizontal waterwheel was presumably invented in Mesopotamia, in the third century before Christ (Wölfel, 1987). The vertical shaft Norse Mill on the other hand was developed in Scandinavia, around 2,000 years ago. The latter one is still being used in Afghanistan and the Himalayan region, and played an important role in the development of the vertical shaft turbine, in the late 19<sup>th</sup> century. The first one however, was the reason for the wide spread diffusion of the waterwheel, and later on the turbine. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991, pp. 2-4)

After its invention the horizontal waterwheel was being used in countries like Egypt, Persia and China, before it was introduced in Europe, during the era of the Roman Empire (Wölfel, 1987). The Greeks and Romans used waterwheels for irrigation and water supply systems, but usually not for the generation of mechanical power, which was being done in the Eastern countries. This can be assigned to the lack of technical knowledge, but also to their attitude towards nature, that was seen as divine and in which interfering like the repositioning of a river was seen as provoking the gods. Lastly, no investment climate for technological innovations existed. (Basalla, 1993)

Europe had to wait for the wide-spread diffusion of the waterwheel until the 12<sup>th</sup> century AD. The technology gained momentum during the next centuries and was widely used in the 16<sup>th</sup>, 17<sup>th</sup>, and 18<sup>th</sup> century, especially in Great-Brittain and Western Europe. The wheels were used for grain milling, textile mills, the mining industry, irrigation purposes and the water supply. Waterwheels were fueling the Industrial Revolution, and because of their importance, much research was done, especially in England and France (Encyclopædia Britannica, 2009b). (Basalla, 1993)

French research focused on the design of the blades. This led to the development of the Breast-wheel by Poncelet, and later to the more compact variant designed by Benoît Fourneyron in the 1820s, which is seen as the first turbine. Between the 1820s and the 1880s, many innovations in order to construct more compact turbines operating at high speeds were carried out. This led to the generation of electricity with water power in the 1880s. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991) Later on, many new turbine designs were invented, e.g. turbines with vertical shafts, derived from the old models used in Scandinavia.

During the end of the 19<sup>th</sup> century, the turbine took over the waterwheel almost completely. Many small-scale systems were built in Europe and North America until the 1930s of the following century. From the 1930s to the oil crises in the 1970s a trend away from small-scale towards large-scale hydro power schemes took place. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991) Europe and North America built 50% of its technical potential and large-scale hydro played a dominant role in the energy supply sector (Paish, 2002). The big disadvantage of small-hydro was the large costs of the power control systems, which were often as expensive as the rest of the scheme. However, innovations in electronic control systems in combination with the trend towards independent energy systems between and after the oil crises led to a short comeback of small-scale hydro. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991)

Many attempts to modularize micro-hydro schemes have been made from the 1980s onwards. This proved to be difficult, because of the very specific conditions at each site. This is still the area where a lot of research is being done. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991; Alexander & Giddens, 2008)

Nowadays, small-scale hydro is often not seen as a solution for electricity generation in high-income countries. In developing countries though, it is becoming more often regarded as a remedy for the lack of electricity in remote areas. Especially China, Nepal and Peru serve as pioneers in an emerging field.

## 4.2 Technology

### 4.2.1 Classification

What exactly is *micro*-hydro power? This seems to be a quite easy question, but still no international agreed definition exists. In literature, one can find many classifications, but even the categories are ill defined. Usually, hydro-power is subdivided in large, small, mini, micro, pico. However, sometimes the category 'medium' is added. The following table shows several classifications used by important organizations and authors.

**Table 4.1: Classification of Hydro-power**

	Pico	Micro	Mini	Small
ESHA <sup>12</sup> (2005)	< 5 kW	< 100 kW	< 1 MW	< 10 MW
Practical Action <sup>13</sup> (2007)	< 5 kW	< 100 kW	< 1 MW	< 15 MW
Ren21 (2008)	0.1 - 1 kW	< 100 kW	< 1 MW	< 10 MW
Paish (2002)	< 10 kW	< 500 kW	< 2 MW	< 10 MW
Nouni <i>et al.</i> <sup>14</sup> (2006)		< 100 kW	< 1 MW	< 25 MW
Khennas & Barnett (2000)		10 - 200kW		
Alexander & Giddens (2008)		< ± 20 kW	> 25 kW	

According to Fraenkel et al. (1991, p. 1) schemes of approximately 300 kW can be seen as micro-hydro, because this is the maximum size for stand-alone systems (not interlinked with the grid), that are still suitable for run-of-the-river installations (more about this in paragraph 4.2.3). I will use a combination of this reasoning and the classifications mentioned above, that shows that in general, MHP is seen as systems smaller than 100 kW. For this thesis, MHP is bound to stand-alone systems, using run-of-the-river schemes smaller than approximately 100 kW. No absolute maximum and minimum are defined, because this can lead to the exclusion of systems just above or below this line which are similar to systems above it. Therefore, the criteria that will be used for very small systems (<10 kW) to be classified as micro-hydro is that there is an automatic power control system to regulate frequency and voltage. This requires an amount of knowledge that is often not available to local people and entails the involvement of an expert, and does therefore make a big difference.

### 4.2.2 General Principles

The general principle behind hydro power is that potential energy ( $E_{pot}$ ) of a body of water is transformed into kinetic energy ( $E_{kin}$ ). This is done by creating a difference in height ( $H$ , the actual height that the water falls) and transport the water from a high level to a lower level.  $E_{kin}$  is transformed into mechanical energy ( $E_{mech}$ ) by the hydro-turbine. The mechanical shaft power drives a generator, generating electrical energy ( $E_{el}$ ).

The amount of mechanical power generated can be predicted by the following formula:

$$P_{mech} = \eta_{tur} \rho g Q H$$

In which  $P_{mech}$  is the mechanical power produced at the turbine shaft,  $\eta_{tur}$  the hydraulic efficiency of the turbine,  $\rho$  the density of water,  $g$  the gravitation acceleration and  $Q$  the volume flow rate.  $\eta_{tur}$  is approximately 80-90% for large systems. For MHP, the efficiency is between 60 and 80% and for very small systems of a few kW (Paish, 2002),  $\eta_{tur}$  will be around 50% (Practical Action, 2007). The electrical power ( $P_{el}$ ) can be calculated by multiplying  $P_{mech}$  with the efficiency of the generator.

### 4.2.3 Micro-hydro schemes

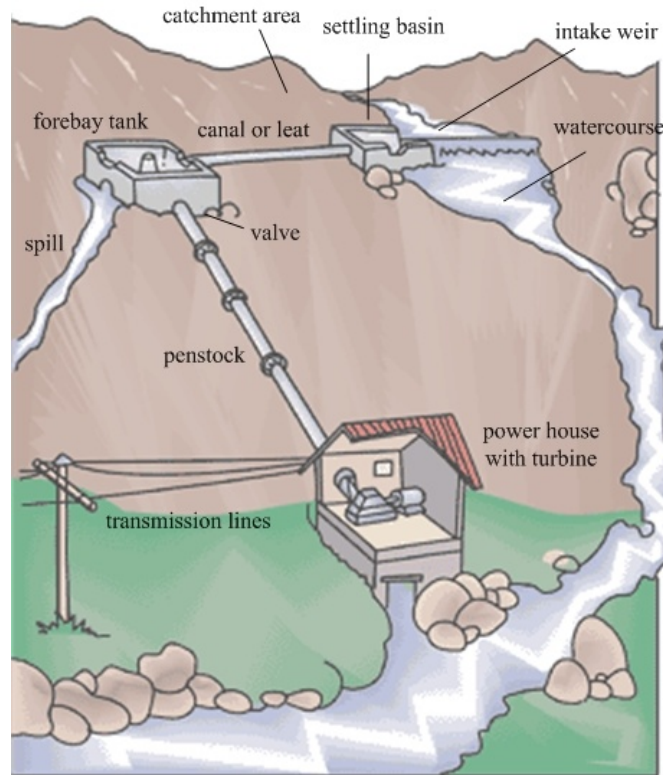
Several designs of micro-hydro schemes exist. Penche (1998) identifies four different schemes; a run-of-the-river scheme, a powerhouse located at the base of a dam, schemes integrated in an irrigation system, and schemes integrated in a water supply system. However, in practice only two of these schemes are different, because the last

<sup>12</sup> Supported by European Commission as well

<sup>13</sup> Formerly known as ITDG

<sup>14</sup> Classification used by Central Electricity Authority (CEA) India

two can be regarded as extensions/variants of the first scheme. They use the same technology and construction works, except, usually, the canal, which is adapted for their specific purpose (irrigation or water supply). Otherwise, the spill of the forebay tank can be used for these purposes. Irrigation-practices are especially applied when there is an excess of water and the canal is long and passes agrarian areas. Powerhouses located at the base of a dam do exist, but are generally used in mini-hydro schemes, not in micro schemes, and in high-income countries (Meier, 2001, p. 50).



**Figure 4.1: Typical run-of-the-river scheme (Source: Energetica, adapted)**

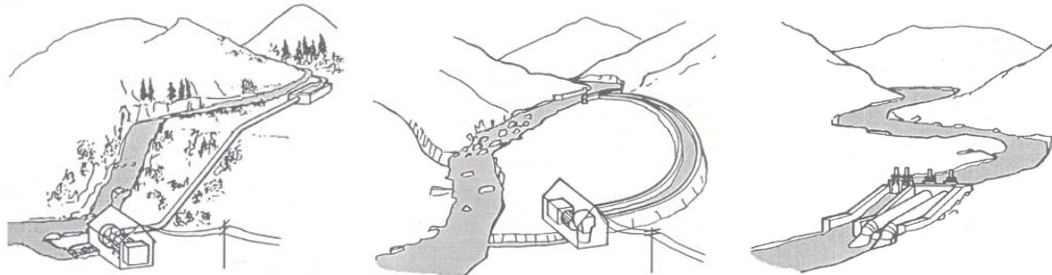
Thus, run-of-the-river schemes are used most. Figure 4.1 shows a typical scheme. The catchment area provides the watercourse, the body of water, usually a small river, which stems from springs or rainwater (Curtis & Langley, 2004). Sometimes a dam or barrage (the weir) is used to lead the water into a settling basin, where it is slowed down so that sediments settle out. If there is any weir, it is quite small, and often it is not necessary to dam (parts of) the river. Therefore, little or no water is being stored. Sediments may block the entrance, so one should take this into account in the design-phase. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991) The water is channeled via a canal along the hillside to the forebay tank. In areas with few vegetation and non-gravelly terrains a concrete channel with a rectangular u-shape form can be used. The canal can be covered with concrete plates in case where there is a chance that sediments can enter the canal. In cases with a lot of vegetation, e.g. forested areas, a plastic tube can be used. Tubes are more expensive, but require less construction efforts and less maintenance and will last longer.

The forebay tank is protected by a rack of metal bars in case the water still contains large particles. Within the tank, a concrete wall is placed that separates the part in which the water from the canal enters, and the part where the water leaves the tank via the penstock. This wall reaches till just below the surface of the water, through which all remaining sinking parts (stones, etc.) cannot enter the penstock and cannot damage the turbine. Remaining floating particles are prevented from entering the penstock by a fine wire mesh. The water is carried through a valve into the penstock, leading the water through the turbine into the power house. The valve can be closed, e.g. for maintenance of the turbine. In case of closure, the spill leads the water from the forebay tank back to the river. (Paish, 2002)



The turbine at the end of the penstock is connected to the generator, transforming mechanical power into electricity. The electricity is transformed to high voltage in case of long transmission distances (more than one or two kilometers). This is not done when the powerhouse is located near the users.

Schemes will not always be exactly as in figure 4.1. Different variations exist, depending on local circumstances. Some components may not be necessary, e.g. the canal in case of the powerhouse is situated below a waterfall. Figure 4.2 shows three different variations.

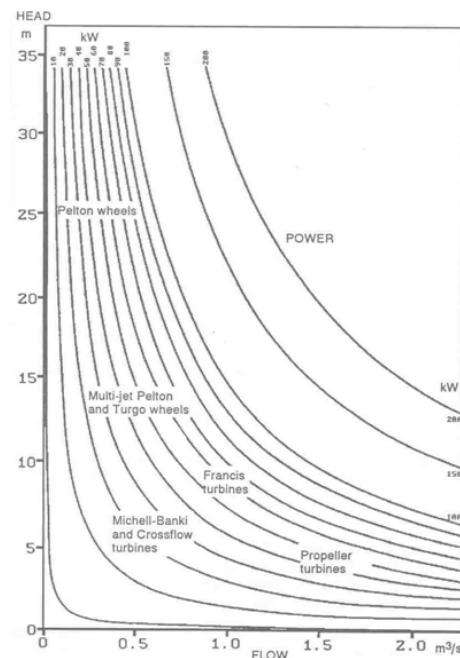


**Figure 4.2: Three different variations of run-of-the-river schemes. Left-side: A high head scheme with no channel; Middle: A low head scheme with channel; Right-side: Low-head river barrage. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991)**

#### 4.2.4 Turbines

The choice of turbine is very important for the functioning of the system. Head and flow available are the most important characteristics on which the choice depends. All turbines have a power-speed and an efficiency-speed characteristic, which determines the efficiency for particular speeds, heads and flows. Given head and flow, a turbine should be chosen so that the shaft-speed is close to 1500 rpm for 50 Hz or 1800 rpm for 60 Hz (Holland, 1983), which is the speed a generator requires. (Paish, 2002)

Turbines can be classified by the optimum head of operation (high-, medium-, low-head), or their principle of operation (impulse and reaction turbines). The latter will be used here.



**Figure 4.3: The choice of a turbine depends on the flow rate and head (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991)**

**Table 4.2: Classification of turbines (ESHA, 2005)**

	High (>50m)	Medium (10-50m)	Low (<10m)
Impulse	Pelton	Crossflow	Crossflow
	Turgo	Turgo	
	Multi-jet Pelton	Multi-jet Pelton	
Reaction		Francis (spiral case)	Francis (open-flume)
			Propeller
			Kaplan

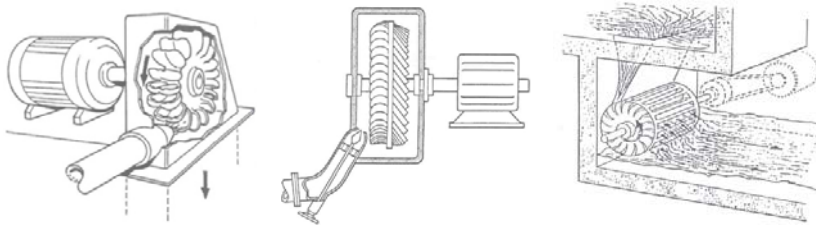
### Impulse turbines

Impulse turbines use a nozzle to convert the water into a high-speed jet that strikes the blades (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991). They operate in air and do not create a pressure difference before and after the water hits the blades (Paish, 2002). The three most well-known and used representatives of this family are the Pelton-, Turgo-, and Crossflow-turbine. The first two have a similar design, the latter, also called Michell Banki turbine, has a somewhat different appearance.

Pelton and Turgo turbines consist of a set of specially designed buckets, mounted around a shaft. The shaft is driven by one or more jets that are being discharged from one or more nozzles and strikes the buckets. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991) In Pelton turbines, the jet(s) is/are directed at right angles to the blades and strike them in the centre on a ridge that divides the flow into two parts, each leaving the turbine at one side. (Encyclopedia Britannica, 2009c) Turgo turbines use the same principle, but the jet(s) strike(s) the blades at an angle, hitting them on one side and discharging at the other (Encyclopedia Britannica, 2009c).

Crossflow turbines have a different design. They are formed by two parallel discs, connected together by a series of curved blades. The nozzle directs the jet onto the full length of the blades. The water is being discharged at the opposite side, hitting the blades once more. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991)

Impulse turbines are especially used for high- and medium-head sites, in combination with low-flow rates (Encyclopedia Britannica, 2009c). However, the efficiency also depends on the size of the turbines. A small Pelton can operate with lower heads than a big one.



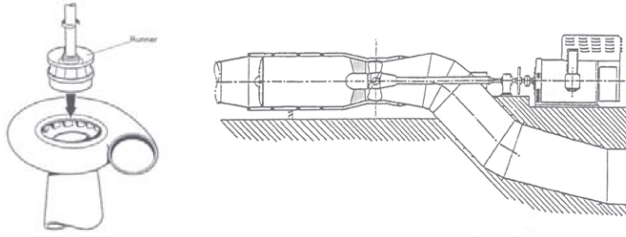
**Figure 4.4: Three impulse turbines. Left: A Pelton turbine with one jet; Middle: A one jet Turgo turbine; Right: A Crossflow turbine. (Fraenkel, Paish, Bokalders, Harvey, Brown, & Edwards, 1991)**

### Reaction turbines

Reaction turbines operate by creating a pressure difference across the blades, which is created by the design of the blades. The principle is the same of that of an aircraft wing. The turbine is fully immersed within water and enclosed. (Paish, 2002) Three reaction turbines most often used are the Francis turbine, propeller turbine and the Kaplan, which is a variant of the propeller turbine. A Francis turbine makes use of a snail-shaped casing enclosing the runner (shaft) that distributes the water uniformly at the correct angle. The water is entering the runner radially inward, leaving it axially from the centre.

The propeller turbine consists of a propeller situated in a tube. The principle is the same (but opposite) of the propeller of a ship. Propeller turbines are used for sites with low head and high volumes of water. (Encyclopedia Britannica, 2009c) The Kaplan is a variant of the propeller turbine, using adjustable blades instead of fixed ones. The advantage is that the direction of the blades can be adjusted by different flow rates, through which efficiency can be optimized.

These turbines are especially used for low-heads and moderate to high flow rates (Encyclopedia Britannica, 2009c).



**Figure 4.5: Two reaction turbines. Left: Snail-shaped Francis turbine; Right: Propeller turbine**

#### Impulse and reaction turbines for developing countries – a comparison

Impulse turbines (especially Pelton and crossflow turbines) are usually used in developing countries. They have several advantages over reaction turbines. First of all, impulse turbines are more tolerant of sediments in the water in comparison with reaction turbines. Therefore, the design of the civil works requires a bit less perfection and the constructions can be cleaned a bit less frequently and thoroughly. This can extend the lifetime of the scheme considerably. Moreover, reaction turbines require some sophisticated fabrication, because of the carefully profiled blades and casing (Meier, 2001). Impulse turbines on the other hand are much easier to fabricate and can be manufactured relatively easily by local manufacturers. Furthermore, maintenance is easier for impulse turbines, due to better access to the working parts and the absence of pressure seals. Unfortunately, impulse turbines are not suited for low head sites. (ESHA, 2005)

#### 4.2.5 Electrical components

Figure 4.6 shows the components of the power house. A flywheel and/or break, the generator and the electrical controller are installed after the turbine. The break is not necessary when an induction generator is used. A flywheel is only necessary when large start up currents are required, which is often not the case in developing countries. The generator converts the mechanical power into electrical power. Larger schemes will use a three phase generator, while smaller installations (< 10 or 20 kW) more often will use a one phase generator. Three phase generators are cheaper per kW. Furthermore, one phase generators cannot feed machines of about seven horse power or more, so it is not possible to use e.g. agricultural machinery. On the other hand, three phase distribution networks are more complicated and expensive. One should ensure that the three phases are equally loaded, or else large voltage drops will occur. Therefore, one phase generators are often preferred in small rural villages with small schemes. (Holland, 1983)

The electrical controller regulates frequency and voltage. This is a very important and quite complex part of the system. If the demand suddenly in- or decreases, the output power must be adjusted to prevent voltage drops or peaks, which can damage electrical devices. Two methods exist to govern power control. One way is to run the system continuously at full power and constant speed. The excess power should be dumped into a resistor bank. The other method is to regulate and adapt speed to demand. (Alexander & Giddens, 2008) This can be done by a carefully shaped spear or needle that slides forward or backward in the nozzle, regulating the flow rate that can proceed through the nozzle (Encyclopedia Britannica, 2009c). Another method is to use mechanically moving valves. In general, it is agreed that the first method is economically more interesting for micro-hydro. Furthermore, it allows the use of more simple and reliable turbines. (Holland, 1983, p. 19)

The voltage of the transmission lines depends on the length of the distribution network. If one uses a three phase generator, transformers should be used if the network is longer than two kilometers. If possible this should be avoided, because generators are expensive.

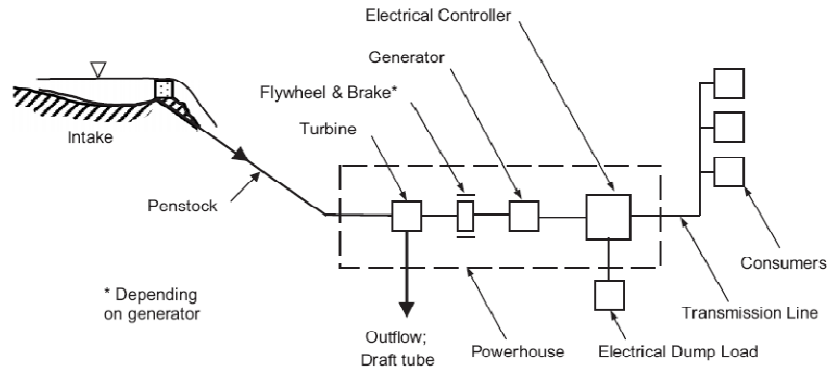


Figure 4.6: Components of the power house of a typical medium head installation (Source: Alexander and Giddens, 2008, p.1380)

### 4.3 Why micro-hydro?

Why should one use micro-hydro power? The advantages of rural electrification have already been discussed in chapter 1.5.1. Rural electrification can be accomplished however by various sources, renewable or non-renewable. Micro-hydro has some advantages over other renewables. To start with, rivers are a more concentrated energy source than the ‘fuel’ of other renewables, e.g. wind or solar energy. It is not only more concentrated, but can also be used as mechanical and electrical power, which is not an option with other sources. The energy supplied by MHP is continuously available and the amount reasonably predictable if the seasonal fluctuation in their water flow are known. Furthermore, the technology used requires little maintenance and is long-lasting, up to 50 years (Paish, 2002).

The cost of MHP varies per project. Khennas and Barnett (2000) found in an extensive study that the cost of shaft power varies from 714 US\$<sup>15</sup> to 1,233 US\$ per kW, with an average of 965 US\$. The costs of electricity generation are higher due to the generator and transmission and distribution, varying from 1,136 US\$ to 5,630 US\$ per kW, with an average of 3,085 US\$. Costs per kWh vary for micro hydro from 7 to 20 US\$ cents, comparable with a small biomass gasifier (8-12 cents), but considerably cheaper than small wind turbines (15-35 cents) and solar home systems (40-60 cents) (Ren21, 2008). MHP is thus one of the cheapest off-grid renewable energy sources. Competition mainly comes from diesel generators, especially if the area is not that far from bigger communities. If however the area is very remote, the transportation costs will be such that diesel cannot compete either.

Besides the low costs, the emission of the polluting gasses CO<sub>2</sub> (greenhouse gas) and SO<sub>2</sub> and NO<sub>x</sub> (cause of acid rain) calculated over the lifetime of a system are very low. Table 4.3 shows the emissions of various renewable and non-renewable, small and large-scale systems. These figures show that MHP is, considering these emissions, the preferred technology.

<sup>15</sup> US\$1998

**Table 4.3: Life cycle air emissions for the generation of electricity with various fuels in g/kWh (IEA, 2002).**

	Life cycle air emissions (g/kWh)		
	CO <sub>2</sub>	SO <sub>2</sub>	NO <sub>x</sub>
Coal	955.0	11.8	4.3
Oil	818.0	14.2	4.0
Gas (Combined Cycle)	430.0	-	0.5
Diesel	772.0	1.6	12.3
Crops	17-27	0.07-0.16	1.1-2.5
Hydro (large-scale)	9	0.03	0.07
Hydro (small-scale)	3.6-11.6	0.009-0.024	0.003-0.006
Solar (Photovoltaic)	98-167	0.20-0.34	0.18-0.30
Solar (Thermal Electric)	26-38	0.13-0.27	0.06-0.13
Wind	7-9	0.02-0.09	0.02-0.06
Geothermal	79	0.02	0.28

Besides low costs and emissions, the technology of MHP is relatively elementary, although this does not imply that everyone can build a system. The scheme can be maintained by an electrician, a mechanical engineer and someone who is in charge of the administration. It is often possible to appoint these three people because sufficient income is been generated by the users of the system. This is not possible for e.g. solar cells.

Some disadvantages exist as well though. Maybe the biggest one is the site specific character of the technology. Villages have to be located close to a relatively steep river with water flowing all year round (Practical Action, 2007). High head sites are the most cost effective places for MHP, but these sites have often low population densities. Villages and houses are often scattered, so that long transmission lines are needed and power losses occur (Nouni, Mullich, & Kandpal, 2006). Variation in river flows has to be taken into account as well. In many areas (especially monsoon areas) the flow will vary over the year. Furthermore, the maximum output is fixed, and up scaling requires large capital investments. Besides this, the maximum output is almost never demanded, and if so, only during short periods. The excess of electricity cannot be stored, and systems are therefore designed larger than they theoretically should, resulting in higher costs. Another disadvantage is the lack of familiarity with the technology in many countries. MHP is still unpopular, or at least less popular than e.g. solar, biomass or wind. (Holland, 1983) Lastly, high head schemes can conflict with irrigation, while low head schemes can conflict with fishery (Paish, 2002).

## RESEARCH PART B

### 5 The socio-technical landscape

The socio-technical landscape (consisting of slow trends and developments, static factors and unexpected events (Van Driel & Schot, 2005)) affects the regime and can create windows of opportunity for niche technologies. The landscape developments influencing the (opportunities for the) diffusion of micro-hydro power in Bolivia are discussed in this chapter.

#### 5.1 Increasing environmental awareness

Environmental awareness has increased worldwide over the last decades. Renewable energy sources are becoming more and more important and a lot of technological progress has been made. Starting with the Brundtland report 'Our Common Future' in 1987, through which it was recognized that the environmental problems are global in nature and that it is in the common interest of all nations that policies are established for sustainable development. The next step in the process was the establishment of the Kyoto Protocol in 1997. From 2005 onwards, 183 countries ratified the protocol (UNFCCC, 2009). Thanks to the Clean Development Mechanism and the Joint Implementation, Annex I countries (high-income countries) can meet their greenhouse gas reduction targets by the implementation of renewable energy projects in developing countries (Annex II countries). This is an incentive for foreign investments in renewable stand-alone systems in developing countries like Bolivia, which can foster the diffusion of MHP systems.

The introduction of the millennium development goals in 2000 was/is another event that might have positive impact on the diffusion of MHP in Bolivia. Ensuring environmental sustainability is one of the goals. Furthermore, electricity is seen as an important service fostering the achievement of the other goals.

#### 5.2 Financial Crisis

The financial crisis has the world in its grasp. Although it is said often that developing countries will be hit less than high-income countries, it will have its effect. Bolivia's export sector is already suffering due to a decreasing demand and prices of raw materials (oil and gas) and precious metals (gold and silver). Oil and gas are important export products for the Bolivian economy. In 2007, an estimated 11.7 billion cubic meters of gas and 9,900 barrels oil were exported (CIA World Factbook, Bolivia, 2009). The decreasing oil and gas prices will limit the government's revenues of the oil and gas fields that were re-nationalized by the government of Evo Morales. Those revenues increased drastically over the past years. Before the nationalization, 18% of the income of the fields returned to the Bolivians. Thanks to new agreements, this increased to 50 to 80%. In 2006 and 2007, the Bolivian government received respectively 1.6 billion US\$, a 40% increase compared to the previous year, and two billion US\$. These revenues were expected to grow to four billion US\$ in 2010, however, this number has been put under pressure because of the crisis (Martinez, 2007).

A part of these revenues are used for rural electrification programs. It is still unclear what the exact consequences for these programs will be, but it is possible that they will be postponed or terminated. The crisis has already hit the mining sector. Many private gold and silver mines have already been closed, and more will probably follow. The gold price dropped in 2008 from just above 1,000 US\$ per ounce, to just above 700 US\$ per ounce (Goldprice.org, 2009). Many Bolivian mines need high prices to make a marginal profit, because they do not have access to the latest technologies, and productivity is therefore low. The Bolivian government has to pay attention to the miners who will get unemployed, because they will express their problems via road-blockades and demonstrations, destabilizing the country. Possibly, this draws away financial resources from rural energy projects to the mining sector. The gold price recovered in the first months of 2009 to 900 US\$ per ounce in April. Long-term developments are uncertain though.

#### 5.3 Latin America's swung to the left and reduced influence of USA

In the last decade, a wave of social ideology has spread across Latin America. Governments in Bolivia (led by president Evo Morales), Ecuador (Rafael Correa) and Venezuela (Hugo Chávez) have turned radically to the left, away from the neoliberal economic model that had the continent firmly in its grasp for twenty years. More moderate

governments in Brazil (Lula), Argentina (Néstor Kirchner) and Uruguay (Tabaré Vázquez) are following. The common denominator of these governments is their promise for a more equal distribution of wealth and increased state control over natural resources, especially oil and gas. They move away from neo-liberal policies like the privatization of state enterprises, the liberalization of markets, and currency stabilization that had been enforced by multilateral lending institutions like the World Bank and IMF and rich country governments. Especially Bolivia undertook some of the most wide-ranging structural reform programs in Latin America and was operating almost continuously under IMF agreements from the 1980s to 2005. Privatization reached its climax during the presidency of Gonzalo Sanchez de Losada (1993-1997) who tried to reform Bolivia into a modern market economy quickly (Cadwalader, Wickersham, & Taft, 1999). However, those measures did not result in economic progress. Even the IMF was puzzled and concluded “that a country perceived as having one of the best structural reform records in Latin America experienced sluggish per capita growth, and made virtually no progress in reducing income-based poverty measures” (IMF, 2005, p. 4). (Weisbrot & Sandoval, 2006) Nowadays, economic policies have been shifting towards a focus on the nationalization of private companies, rural development, education, small-scale indigenous landownership and healthcare. (Castaneda, 2006; Denvir & Riofrancos, 2008)

At the same time, the influence of the United States of America is diminishing. The USA have always had a strong influence in national policies of Latin American countries. It has always considered the continent as its backyard and has pressed through many neo-liberal reforms in exchange for development aid. Since 9/11 however, the USA’s foreign attention has been shifted to the Middle East, while at the same time Latin America swung to the left. Now, other powers move in. Especially Chinese gained a foothold and have already spent billions of dollars for infrastructure, transport, energy and defence projects under the slogan ‘peaceful rising’. This process facilitates the shift away from neo-liberalism that dominated national policies (Hawksley, 2006; Bajak, 2008).

These developments are pressing on the existing electricity regime in Bolivia. Companies are forced to extend their focus to less developed areas with little market potential. Furthermore, the leftist government puts aside more money for rural electrification and stimulates the establishment of new programs.

## 5.4 Economic Development

In recent years, Bolivia has been experiencing a strong economic growth per capita as well as in absolute figures (see table 5.1). It is expected that the growth will continue in coming years, because the effects of the nationalization of the oil and gas reserves are not yet fully capitalized. Despite the financial crisis, the economy still grew in the first three quarters of 2008. The economic growth has been accompanied by a more equal distribution of wealth. The Gini-coefficient increased over the last five years from 44.7 in 2001 (UNDP, 2002) to 60.1 in 2006 (UNDP, 2007). These developments can have several effects on rural development. First of all, more funds might be available for rural electrification investments. Second, people in rural areas have more to spend, which makes it easier for stand-alone systems to generate sufficient income, but also makes it financially more attractive for distribution companies to expand the national grid to rural areas, because the turnover will probably increase.

**Table 5.1: Development of GDP per capita (PPP US\$) in Bolivia from 2001 to 2006. Sources: Human Development Reports (2003; 2004; 2005; 2006; 2007; 2008) and the World Bank (2009)**

Year	GDP/capita PPP US\$	Growth %	GDP (billion US\$)
2007			13.12 <sup>16</sup>
2006	3,989 <sup>16</sup>	41.5 <sup>16</sup>	11.45 <sup>16</sup>
2005	2,819	3.64	9.55
2004	2,720	5.14	
2003	2,587	5.16	
2002	2,460	6.96	
2001	2,300		8.40

<sup>16</sup> Strong growth can be explained due to effect of nationalization of oil and gas fields.

## 5.5 Exchange-rate Boliviano

The exchange-rate of the Boliviano (Bs) compared to the Euro and US Dollar has fluctuated a lot in recent years (see figure 5.1). In approximately ten years, the Bs/US\$ rate increased from just below five to just above eight with a maximum of 8.29 Bs/US\$ in January 2007. However, the Boliviano has been increasing in value compared to the US\$ and euro since respectively January 2007 and July 2008. This has its impact on rural electrification programs. Many programs are financed in dollars or euros by foreign donors. A strong Boliviano means less money to spend on the national market, resulting in smaller projects. So programs have benefitted from a weak Boliviano until approximately 2007 – 2008. Now, the Boliviano is getting stronger, resulting in tighter budgets for future development programs.

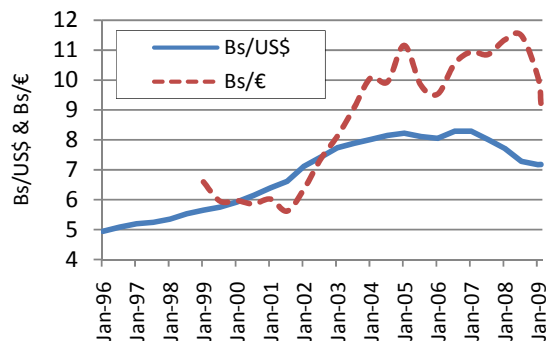


Figure 5.1: Exchange rate of the Boliviano (Bs) to the US Dollar (US\$) and Euro (€) (Oanda.com, 2009)

## 5.6 Poor Infrastructure in Bolivia

Bolivia's infrastructure is very poor. Many rural areas are (almost) inaccessible by car, boat or plane. Communication infrastructure is not developed. Many areas do not have television reception, internet or lack a telephone connection, so that they are isolated to a certain extent. Electricity coverage is also very low. Only densely populated areas are connected to large grids. If rural areas are connected, the quality of the transmission lines is low, resulting in regular power shutdowns. Stand-alone systems are independent of these transmission lines. Quality is often better, so that stand-alone systems can offer a good alternative for the national grid.

## 5.7 Internal Political Instability

Stability is relatively rare in Bolivia. Since its independence in 1825 many wars were fought with successively Peru, Argentina, Peru again, Chile, Brazil and Paraguay. After the last war was finished in 1935, internal instability continued. The period between 1952 and 1978 was characterized by revolutions and military governments. Democratic elections were introduced in 1979, but this election, as well as the election in 1981, was marked by fraud. Three successive military governments took over again, until 1982, when elections were held again. But social unrest did not disappear and is still present in Bolivia. Many governments were succeeded by radically different thinking governments, which led to a continuous change in government policies, with a complete lack of long-term vision and continuity. This is hindering the development of the country and the implementation of renewable energy projects. Many programs that once were set up were terminated by the next government. An example is the national program for MHP plants, discussed earlier. But also a biomass program initiated by ESMAP never took off.

## 5.8 Governmental Structure

Bolivia's government is seated in La Paz, the administrative capital of the country. The constitutional capital is Sucre. The country is divided in nine administrative regions called Departamentos (departments)<sup>17</sup>. The departments consist of provincias (provinces, 112 in total). The provinces are separated in secciones (sections, singular: sección, 327 in total). Sections consist of several municipios (municipalities). The government of the department is called a

<sup>17</sup> La Paz, Santa Cruz, Cochabamba, Potosí, Chuquisaca, Oruro, Tarija, Beni and Pando.



Prefectura (prefectures), with a Prefector (prefect) as head. The government of a section is called an Alcaldía, with an Alcalde (mayor) as head.

The national government is in charge of national policies, but a lot of the power has been decentralized so that the Prefecturas have become important policy making institutes. They have their own budgets, and play an important role in e.g. infrastructure and rural development. The Alcaldías can partially develop their own economic policies. They have some financial resources and often function as co-financier in rural electrification projects. However, their main role is as intermediate actor between the villages that would like to have electricity and the main institutions who can provide it.

## 5.9 Geographical conditions

Geographically, Bolivia is one of the most diverse countries in the world. The potential for micro-hydro depends on the region. The country can be divided into three zones, mainly characterized by their elevation. The Andean western part is dominated by two great parallel mountain ranges, the Cordillera Occidental and the Cordillera Oriental, with altitudes up to 6,542 meter. The two ranges enclose the Altiplano, a relatively flat area of 800 km long and 150 km wide at an elevation of 3,650 to 3,800 meter. (Encyclopædia Britannica, 2009a) The Altiplano is unsuitable for micro-hydro because of the lack of differences in altitude and the scarcity of water. The latter holds for big parts of the Cordilleras as well, although there is some potential, especially in the north-western parts of the department of La Paz.

To the north and east, the Andes descends to a rugged terrain, in Aymara called the Yungas, meaning 'Warm Valley'. These valleys lie at elevations between 1,800 and 2,900 meter and are characterized by their huge forests, rivers, fertility and their rich varied agriculture. (Encyclopædia Britannica, 2009a) These areas are especially suited for hydro power. Flat areas do not exist and small and big rivers criss-cross the area. Moreover, thanks to the fertility, many small communities have settled in these regions.

Going further downhill, one reaches the Amazon Basin that covers almost two-thirds of Bolivia and is more or less flat and therefore, despite the abundance of water, unsuitable for micro-hydro as well. (Encyclopædia Britannica, 2009a)

Figure 5.2 shows the potential of hydro-power in Bolivia. The darker an area, the higher the potential. The dark strip of land with potential corresponds with the valleys. To the left of them are the Cordilleras and the Altiplano, to the right the Amazon Basin. As can be seen in the figure, the highest potential is in the department of La Paz. Cochabamba has the second largest potential, and some parts of the departments of Tarija and Santa Cruz have a good potential as well.

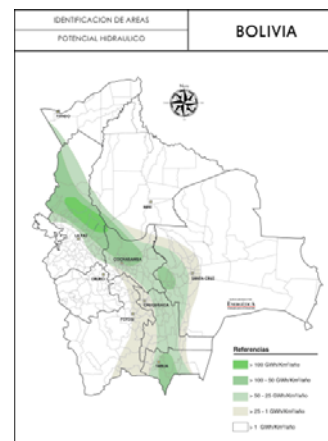


Figure 5.2: The potential of hydro-power in Bolivia (Fernandez F., 2005)

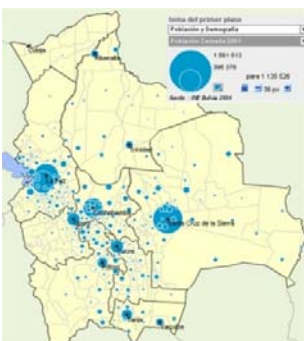


Figure 5.3: Geographical distribution of the population (Instituto Nacional de Estadística, 2009)

The areas of high potential correspond more or less with the geographical distribution of the population, as can be seen in figure 5.3. This has advantages and disadvantages. Positive is that MHP plants serve (small) communities, which are abundantly present. Negative is that the national grid will expand to relatively densely populated areas, so that micro-hydro niches protected by their distant geographical location do not exist abundantly.

## 6 The electricity regime

The socio-technical regime is shaped by the dominant technology and a set of rules and institutions related to this technology. The regime that will be analyzed in this chapter is the electricity regime. If the micro-hydro technology is going to diffuse, it has to be able to compete with the current dominant technology of this regime. The structure of the electricity regime will be discussed in this chapter, starting with a short overview of its history.

### 6.1 History

The history of the Bolivian electricity sector starts in the 19<sup>th</sup> century. The first (small) power plant was built in 1887 in Potosí, to serve the mines. One year later, La Paz followed the example of Potosí and built a steam engine. The first hydro power plant was installed in Cochabamba in 1897 and had a capacity of 160 kW. The first large scale hydro plant was built in 1909 by the Bolivian Rubber Enterprises in La Paz, consisting of three 800 kW turbines. Until the sixties of the previous century many stand-alone hydro-power systems were built, especially in the departments of La Paz, Oruro, Potosí and Cochabamba. Total installed power was approximately 120 MVA. Till then, electricity was mainly used in the mining sector, which counted for 90% of Bolivia's export and thus was very important. (Eterovic Garrett, 2002)

#### 6.1.1 1960-1995: Establishment of ENDE

The electricity sector faced many problems in the 1940s and 1950s. Power supply was unstable, the various plants were not connected and private initiative and investments were lagging behind demand. To solve these, the Empresa Nacional de Electricidad (ENDE) was established in 1962. ENDE was a governmental organization aiming at developing the electricity sector, especially in regions without private initiative. This should be done by designing and implementing new plants to close the existing gap between supply and demand. Furthermore, ENDE had to build transmission lines to connect the main plants and to construct a national grid, through which the generation would become more efficient. Lastly, distribution and the sale of electricity had to be coordinated in case this was not done by private companies yet. (Eterovic Garrett, 2002) The establishment of ENDE initiated the development of the electricity regime as it is known today, as an interconnected grid instead of a sector dominated by stand-alone systems.

From the 1960s to 1995, the electricity regime developed from a decentralized hydro-power dominated regime to a national structure in which hydro power and thermal power plants became equally important. ENDE had built many power plants, especially gas fueled plants that became very popular in the 1970s, and transmission and distribution lines. One of the main achievements of ENDE was the construction of the national grid, the Sistema Interconectado Nacional (SIN), which connected the four largest existing grids, the Sistema Central, Sistema Sur, Sistema Oriental and the Sistema Norte in 1989 (Eterovic Garrett, 2002). The SIN as it is known today can be defined as the national interconnected system of power plants, and transmission and distribution lines (see figure 6.1). The newly constructed SIN transported approximately 80% of the electricity generated. The remaining 20% was distributed via smaller grids that can be divided into three categories. Sistemas Aislados are the largest grids that are not connected to the SIN. The technology used in these grids is comparable to that used in the SIN. They only differ in the fact that the scale (number of plants, total length of transmission and distribution lines, and number of users) is much smaller. Sistemas Aislados Menores and Autoprodutores are smaller grids with a maximum installed capacity of 1 MW. The electricity generated for the Sistemas Aislados Menores is generated by electricity companies, that of the Autoprodutores by companies that need the electricity themselves. (Espinoza, 2005)

#### 6.1.2 >1995: Privatization

In the eighties and especially the nineties, a trend of privatization of state-owned enterprises holds the world in its grasp. It was endeavored to make these companies work more efficiently in order to become (more) profitable. The major gulf of privatization in Bolivia took place between 1993 and 1997 (see landscape developments, section 5.3) and changed the electricity regime drastically. Although ENDE's profit was

**Table 6.1: Facts & Figures Electricity**

<b>Sector:</b>	
Capacity installed:	499 MW
Average consumption:	423 kWh/cap/y
Source of electricity:	
Hydro:	2159 GWh/y
Gas:	2079 GWh/y
Oil:	884 GWh/y
Transmission lines:	2,400 km
Electricity import:	0 kWh
Electricity export:	0 kWh
National coverage:	65 %
CO <sub>2</sub> emission:	1.36 ton/cap/y

Sources: VMEEA (2007), CIA (2009), IEA (2009)

on average 4% annually and the organization functioned well, it was privatized as well. One of the main reasons was that international organizations and bilateral partners refused to invest in state-owned companies, so that ENDE could not attract foreign funds to invest in the expansion of the grid to rural unconnected areas. (Fernandez F., 2006)

In 1995, it was decided that all ENDE's activities had to be split up, horizontally as well as vertically (generation, transmission, distribution). ENDE's power plants were divided between three companies; Corani, Guaracachi, and Valle Hermoso Transmission lines became property of the Transportadora de Electricidad (TDE) (Eterovic Garrett, 2002). Lastly, distribution was divided between six companies, each having a geographical monopoly determined by the boundaries of the departments (Espinoza, 2005). Since 2001, the electricity sector operates as a free market (Fernandez F., 2006). Generation, transmission and distribution activities did not have to be split up in the Sistemas Aislados and smaller systems, which could continue to operate in a vertically integrated manner (Espinoza, 2005).

Nowadays 85.5% of all electricity generated in Bolivia is transported via the SIN. 53.2% is generated by thermo-electric plants (mainly gas, some oil), 46.8% by large scale hydro power plants.

## 6.2 Electricity Grid

Nowadays, the SIN connects the departments of La Paz, Cochabamba, Santa Cruz, Oruro, Potosí, Sucre and Chuquisaca (see figure 6.1) (UDAPE, 2005). The Sistemas Menores and the Sistemas Aislados are situated in the departments of Beni, Pando, Tarija, Santa Cruz and La Paz. There are projects going on to connect the smaller systems in Tarija and Beni to the SIN, the other systems will function independently for the time being.

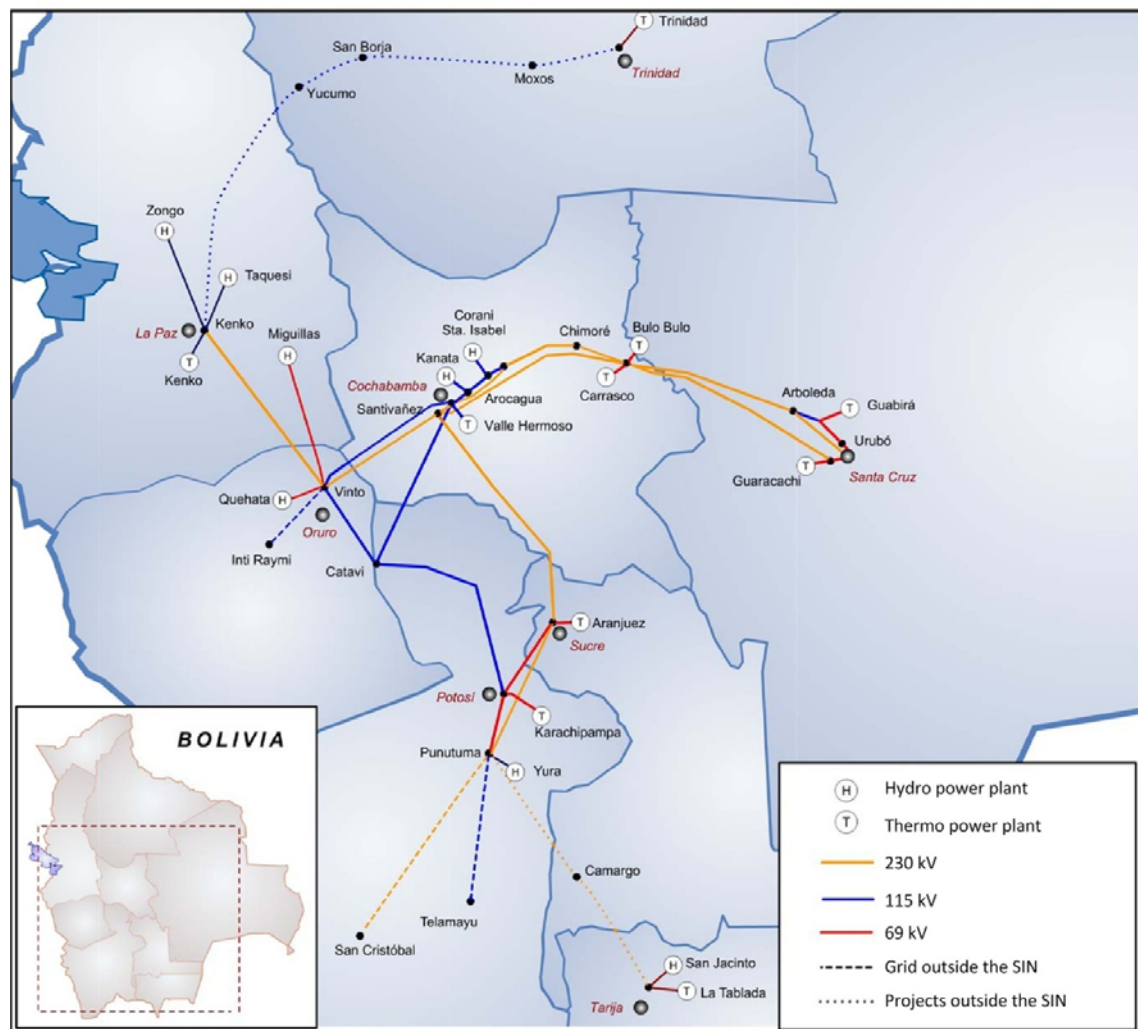


Figure 6.1: The grid of the Sistema Interconectado Nacional (SIN) (Superintendencia de Electricidad, 2009)

## 6.3 Actors

### 6.3.1 Generation, Transmission and Distribution Companies in the SIN

Since the privatization of the electricity sector, private corporations and cooperatives are responsible for generation, transmission and distribution activities. In 2007, the electricity generated and distributed via the SIN was generated by ten companies (see figure 6.2) The Guaracachi (1,256.1 GWh), Compañía Boliviano de Energía Eléctrica (COBEE), 1,144.5 GWh) and Valle Hermoso (831.2 GWh) together generated 65.9% of the total electricity generated (4,902.5 GWh). (Superintendencia de Electricidad, 2009)

Since 2005, two companies transmit electricity via the SIN. The TDE owns 62% (958.2 km) of the 230 kV high-tension cables and all 115 and 69 kV cables, respectively 669.6 and 185.3 km. The remaining grids are owned by ISA Bolivia (587 km), which entered the market in 2005 (UDAPE, 2005; Superintendencia de Electricidad, 2009). The last one receives a lot of attention, because it investigates the possibility to construct a high-tension connection with Peru. This would mean a very important step in the building of a Latin American electricity network, which till now has not been possible, because Bolivian plants operate at 50 Hz, other countries like Peru and Brazil at 60 Hz (Espinoza, 2005).

Six large companies operate in the distribution sector. Each of them has a geographical monopoly in a department. Recently, several new distribution companies started to operate in the department of La Paz to serve less densely populated areas in which Electropaz, the main distribution company in La Paz, did not operate. The four largest are incorporated in the figure below that shows all the companies operating via the SIN.

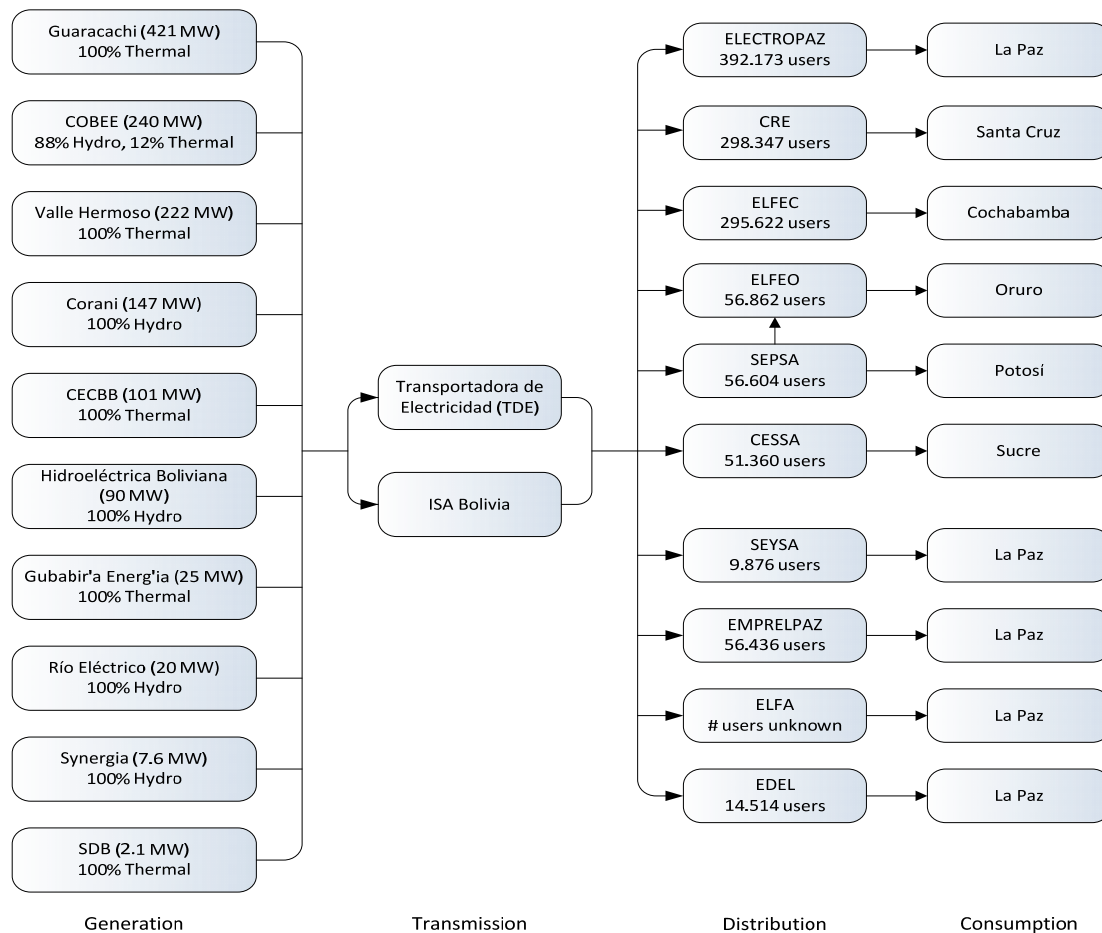


Figure 6.2: Actors operating via the SIN (Superintendencia de Electricidad, 2009, adapted)

### 6.3.2 Operators on the Sistemas Aislados

A couple dozen small independent systems exist in Bolivia. Three corporations are significantly larger than the other companies and have a generation capacity larger than 10 MW. SETAR is the biggest operator, with a capacity of 50.8 MW (16% hydro, 84% thermal) and 64,093 users divided over six separate grids all situated in the department Tarija. CRE is the second largest, with a capacity of 40.9 MW (100% thermal), 35,779 users and seven local grids in Santa Cruz and ENDE (a remnant of the previous state-owned company) is the third, with a capacity of 28 MW (100% thermal), 6,314 users and three grids in Tarija and Pando. (Espinoza, 2005; Superintendencia de Electricidad, 2009)

### 6.3.3 Policy Making

The government body responsible for the formulation of legislation and norms for the regulation of the electricity sector is the Viceministerio de Electricidad y Energías Alternativas (VMEEA – Vice-Ministry of Electricity and Alternative Energy Sources)<sup>18</sup>. It is a vice-ministry of the Ministerio de Hidrocarburos y Energía (MHE - Ministry of Hydrocarbons and Energy) situated in La Paz. Furthermore, policies are formulated by the VMEEA and programs established, especially for rural electrification programs for regions without private initiative.

### 6.3.4 Regulation

The Superintendencia de Electricidad<sup>19</sup> is the watchdog of the sector. Tariffs are regulated by the Superintendencia according to economic principles, and the quality is monitored. Furthermore, the organization hands out licenses to operate via the SIN. In the past, this was also done for small stand-alone systems which had to have a special legal status to generate electricity. However, since reforms in the 1990's (see the landscape developments), stand-alone systems smaller than 300 kW are free from those rules. Therefore, it became much easier to construct a plant. Since the electricity suppliers outside the SIN can be vertically integrated, the Superintendencia de Electricidad is not involved anymore in the small-scale sector.

## 6.4 Rural electrification

The reform of the electricity sector in the 1990s was mainly focused on the urban areas, where the market had a sufficient size to attract substantial private investment. It did not result in more private investments in rural areas, due to the perceived lack of a reasonably sized market. Due to the lack of private investment and the introduction of the popular participation law<sup>20</sup> (in 1994) and the administrative decentralization law (1995) that gave local and regional governments more power and resources to formulate and carry out regional and local policies, rural electrification is mainly carried out by prefectures and municipalities. The national government bore and bears the ultimate responsibility for rural electrification and set the theme on the national agenda through the Estrategia Nacional de Energía Rural (National Strategy for Rural Energy) in 1994. This program tried to persuade the private sector to put more emphasis on rural electrification and to formulate local needs. It aimed at increasing rural electricity coverage to 77% in 15 years. The strategy was made operational in the Programa Nacional de Electrificación Rural (PRONER, National Program for Rural Electrification) in 1997. From then on rural electrification coverage increased (see figure 6.3). PRONER was followed by the Plan Bolivia de Electrificación Rural (PLABER, Bolivian Plan for Rural Electrification) in 2002. PLABER aimed to supply 200,000 households with electricity in a five years period. Approximately 70% of its goals have been reached. (Fernández F., Rojas, & Gutierrez, 2006) In 2007, the program Electricidad para Vivir con Dignidad (Electrification to live with dignity) was started to increase rural and urban electrification coverage from respectively 33 and 85% in 2005 to 53 and 97% in 2011 and finally, after the completion of four phases to full coverage in 2030. In urban areas this should be done by densification and expansion of the SIN. Coverage in rural areas should increase using the same measures plus the installation of natural gas power stations and renewable energy sources, especially solar. However, priority is given to densification and

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<sup>18</sup> The name of the VMEEA has changed regularly in the past. It used to be the VMEEAT (Vice-ministry of electricity, alternative energy sources and telecommunications) or the VMEH (Vice-ministry of energy and hydrocarbons). In the remaining part of this text, I will only refer to the VMEEA. For more information about the VMEEA, see <http://www.hidrocarburos.gov.bo/vmeea/>

<sup>19</sup> For more information about the Superintendencia de Electricidad, see <http://www.superele.gov.bo/>

<sup>20</sup> The 'ley de participación popular' was introduced because many rural electrification projects failed because they were not demand driven and the demands and desires of the local population were not taken into account. This law encourages local actors to initiate and participate in rural electrification projects (Espinoza, 2005).

expansion. Two hundred thousand households should eventually be served with renewables, 570 thousand with traditional fuels (oil, gas, large scale hydro).

However, despite the establishment of an electrification program, the private sector is still not interested to participate in rural electrification. It is estimated that only 2.6% (9.5 million US\$) of the required funds for the rural electrification part of the first two phases of the program (2007-2016) will come from private companies, while 80% (84 million US\$) of the funds needed for urban electrification will be invested by the private sector. (VMEEA, 2007)

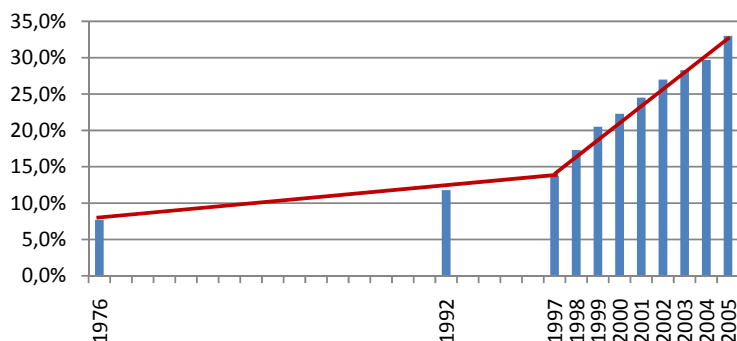


Figure 6.3: Electrification coverage in rural areas (VMEEA, 2007)

According to a study of ESMAP, rural electrification encounters a series of political and economic obstacles. The most important are that 1) political efforts in the electricity sector still focus too much on hydrocarbons; 2) the private sector lacks knowledge of the potential of rural markets; 3) the private sector lacks funding for rural electrification; 4) actors in the electricity sector do not have sufficient knowledge about renewable sources for electrification; and lastly, (5) Bolivia lacks an adequate regulatory framework. (ESMAP, 2005)

These obstacles are typical for a niche-technology trying to replace or to obtain a place within the dominant regime-technology. Established cognitive, normative and formal rules are hard to change. Perceptions and actions of actors in the regime are guided by them so that a certain blindness to variations and innovations has been created. Rural electrification ‘has’ to follow the same path as the increase of electricity coverage took place in the past. Therefore, the grid has been extended (unnecessary) to communities already served by a stand-alone system. Regime-actors do not see, or will not see because of vested interest, those systems as an alternative for large grid based electrification. Technological closure and lock-in prevent new technologies from breaking through.





## 7 The micro-hydro power niche

Niches are breeding places for new (radical) technologies to develop. As will be discussed in this chapter, micro-hydro power in Bolivia is not a radically new technology. It was already used centuries ago to generate mechanical power for the mining industry. However, it only has been used for electricity generation on small scale in Bolivia since the 1970s or 1980s. And although the technology is relatively mature, other aspects like organizational structures and financing mechanisms are far from developed. The niche-developments of MHP technology will be discussed in this and the following chapters. This chapter provides the reader with a background and a basic understanding of the Bolivian micro-hydro sector. A short overview of the history of MHP in Bolivia is given; the actors participating in the sector and their mutual relations are described; MHP programs are summarized; the case studies are introduced and the experiences of the main actors are discussed.

The key element of this study is learning processes that have taken place and/or that are still taking place within local projects and within the micro-hydro sector. By examining these learning processes, the barriers hindering the diffusion of the technology in Bolivia will come to the surface. These processes are divided into three parts. The next chapter (8) discusses learning processes within local projects. Chapter 9 analyzes learning processes by implementing organizations, and chapter 10 examines additional findings that are not (yet) learnt by Bolivian actors. The last part of the niche analysis (chapter 11) brings the other chapters together and studies intermediate, dynamic barriers to learning processes. Each of these chapters contributes to one or several sub questions. This is discussed thoroughly in the introduction of the next chapter.

### 7.1 Historical overview

The history of MHP in Bolivia can be traced back to the Spanish conquest in the 16<sup>th</sup> century. The Spaniards introduced micro-hydro in the mining industry. They built mechanical mills driven by waterpower to crush stones containing gold or silver. After the colonial era, the technology was not used anymore. It is unclear when exactly micro-hydro was used again. A record of projects dating from 1983 lists nine systems smaller than 100 kW and seventeen systems smaller than 200 kW (Ministerio de Desarrollo Sostenible y Medio Ambiente, 1996). Furthermore, 125 projects, pre-projects and ideas for small-hydro plants were identified in 1984. (Secretaría Nacional de Energía, 1996)



Figure 7.1: Ruins of the canal (left) and a millstone (right) of a Spanish mechanical micro-hydro plant

More plants were built in the 1990s. The Instituto de Hidráulica e Hidrología (IHH - Institute for Hydraulics and Hydrology) of the University of La Paz started constructing plants in 1986 and extended their program halfway this decade. Energética, a Bolivian NGO, started designing and constructing plants as well. However, very few plants were constructed in absolute numbers. The government wanted to boost the installation of systems and wrote a program to stimulate micro-hydro, the Programa Nacional de Micro Centrales Hidráulicas (PMCH – national program for micro-hydro power). The government recognized that the living circumstances in remote rural areas often were inhuman. One of the measures to improve these conditions was the establishment of an extensive program to increase electricity coverage. The blueprint of the PMCH was ready in 1996 and it became part of the program Estrategia Nacional de Energía Rural. The government saw that the enormous potential of micro-hydro was not being



utilized fully, and decided that micro-hydro should play an important role in the program. However, it was also recognized that knowledge and financial resources were lacking.

The PMCH aimed at installing 100 plants of 7 MW in total, to provide 20,000 families with electricity within 15 years. It was calculated that 17 to 21 million US\$ was needed, assuming 2,400 to 3,000 US\$/kWh installed. The Fondo de Desarrollo Campesino (FDC) would contribute 10 million US\$ (48%), local and regional governments 2.3 million (11%) and private companies and development organizations 8.6 million (41%).

The program identified four barriers. First, not enough was known about the energy demands of the local population. This should be solved by the participation of local based organizations with a lot of experience and knowledge of the areas. Second, studies should be done into the potential of sites and money should be made available for these studies. Third, funds would be needed for the actual construction, and lastly, local organizations should be able to manage and sustain the plant.

The program should be all-embracing, including technical assistance, capacitation of local organizations and the establishment of small regional maintenance companies. Unfortunately, a new government was elected in 1997 that did not see the relevance of the program and rejected it.

Despite the rejection of the program, more plants were built in the following years. IHH built on average three plants a year. Energética built some, and the government started some programs from 2002 onwards. Furthermore, small private companies constructed several plants. It is unknown however how many plants exactly were built.

## **7.2 Actor Network**

The actors participating in the implementation of MHP projects in Bolivia form a quite complex and comprehensive web. Many organizations have multiple functions and roles and only few settled long-term relations exist. Often, new actor networks have to be formed for new projects and programs. This results in dynamic and unstable relations that shift regularly. This section provides an overview of the main actors currently active in the MHP sector and their mutual relations. The actors are categorized by function. The network is visualized in figure 7.2 on page 42.

### **7.2.1 Policy & Planning**

As the law dictates: "El Estado tiene la responsabilidad de desarrollar la electrificación en poblaciones menores y en el área rural que no pueda ser atendida exclusivamente por la iniciativa privada." (Electricity Law, Art. 61). The state has the responsibility for the electrification of small communities in rural areas when private initiative lacks. The VMEEA (see chapter 6.3.3) shoulders the responsibility for rural electrification. Two micro-hydro programs were established by the VMEEA (more about this in section 7.3).

### **7.2.2 Regulation**

As discussed in the regime-analysis, the Superintendencia de Electricidad had been regulating the small-scale electricity generation sector until the reforms in the 1990s. After the deregulation of the electricity sector, the Superintendencia has not been involved anymore.

### **7.2.3 Implementing organizations**

Implementing organizations are actors that take care of the whole project cycle, from identification, design and implementation to maintenance. This does not necessarily mean that they always carry out the whole cycle. A very important role of these organizations are their coordination activities, bringing together the communities, financiers, and if necessary construction companies (given below).

#### **Instituto de Hidráulica e Hidrología (IHH)**

IHH (Institute for Hydraulics and Hydrology) is a faculty of the Universidad Mayor de San Andrés (UMSA), the university in La Paz. Two persons at the institute (a civil engineer and an electro-mechanical engineer) are specialized in micro-hydro technology and have been working on it for more than 20 years. IHH started an experiment in 1986 in San Pedro de Condo, Oruro. The result of the experiment was good, and the faculty decided to start the Programa Hidroenergético (Program for Hydro-energy) (more about this later).

### Energética

Energética is a Cochabamba-based Bolivian NGO currently specialized in solar panel technology. Its director has a lot of experience with micro-hydro and Energética has built and designed three systems and designed five additional systems from 1994 to 2001. The majority of the systems designed by Energética has never been built due to the expansion of the central grid. Because of this experience, Energética decided to concentrate on photovoltaic solar panels and recently on efficient wood stoves. Solar panels are less sensitive to grid-expansion because they are often bought by dispersed households that are financially not interesting for distribution companies. This year (2009) however, Energética will start designing four new micro-hydro plants again.

### Viceministerio de Electricidad y Energías Alternativas (VMEEA)

The VMEEA (see also chapter 6.3.3) is responsible for the electrification of rural areas that lack private initiative. Besides the formulation of several programs, the VMEEA has also established some micro-hydro projects itself. So far, four plants have been built; three are under construction and will hopefully start operating soon.

### Small private companies

Besides the three big actors mentioned above, some small private companies and individual people design and construct micro-hydro plants. Often these are companies or electrical engineers with little micro-hydro experience who are asked by a community to build a plant. They are usually asked because they are known in the region to be electrical or mechanical engineers which is often related to the ability to construct micro-hydro plants. The capabilities of these people/ companies vary to a great extent and are difficult to assess by inexperienced people.

## 7.2.4 Financing organizations

In Bolivia many organizations finance or have financed one or several MHP projects. Those organizations are international NGOs, programs of embassies, national funds or programs, local governments, etc. Descriptions of the most important financing organizations are given below, together with the actors with whom they collaborate (see also figure 7.2).

### Kreditanstalt für Wiederaufbau (KfW)

The German development bank KfW has financed a €5.1 million program established together with the VMEEA for the installation of seventeen micro-hydro plants in Bolivia. The KfW contributes 75 to 80% of the investment; the remaining part has to be financed by local governments (more about this program in chapter 7.3.).

### UNDP/GEF Small Grant Program (SGP)

The SGP is funded by the Global Environment Facility (GEF) and carried out by the United Nations Development Program (UNDP). It supports sustainable activities of non-governmental and community-based organizations in developing countries (SGP, 2009). The SGP donates maximum 35.000 US\$ a year per project implemented by IHH, with the requirement that the projects include a productive end-use facility.

### United Nations Development Program (UNDP)

The UNDP has set up a program together with the VMEEA (see chapter 7.3). The UNDP is the main financier of the program that uses a structure with co-financing. The VMEEA administers the fund.

### ProAgro/GTZ<sup>21</sup>

In 2005, GTZ started the Agricultural Development Program (ProAgro) to improve the efficiency and quality of services provided by national programs for the promotion of sustainable agricultural development. Access to modern energy sources in rural areas is one of the components of the program. This takes shape in a yearly donation (max. 10.000 US\$) to IHH for one project.

### Alisei

Alisei is an Italian NGO that started a program for rural development in 1996 in Bolivia. They have co-financed three micro-hydro projects (San Juan de Coripata, Challa Jahuirá and Inca Pucara) of the VMEEA. The investment concerned 130,750 US\$. Furthermore, Alisei has monitored the self-assembly<sup>22</sup> of two of these plants.

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<sup>21</sup> For more information about GTZ/ProAgro, see <http://www.gtz.de/en/weltweit/lateinamerika-karibik/bolivien/13654.htm>

#### Fondo Nacional de Inversión Productiva y Social (FPS)<sup>23</sup>

The FPS (National Fund for Investments in Productivity and Social Projects) is a public institution aiming at increasing the access to services to less developed regions in Bolivia. Rural electrification is one of the spearheads of its policy, besides education, health, sanitation and irrigation. Funds are available for the co-financing of micro-hydro projects and the FPS acts as one of the main financiers of a program of the VMEEA. Furthermore, technical assistance can be provided.

#### Fondo Nacional de Desarrollo Regional (FNDR)<sup>24</sup>

The FNDR (National Fund for Regional Development) is a Bolivian governmental organization aiming at local and regional development through the provision of funds for municipalities and prefectures meant to encourage the development of the private market. Besides financial support, legal and technical assistance can be provided as well. The FNDR is a minor investor in one of the programs of the VMEEA.

#### Programa Nacional de Cambios Climaticos (PNCC)<sup>25</sup>

The PNCC (National Program for Climate Change) is established in 1995 to initiate discussions and investigations about measures that could be taken and programs that could be set up to fulfill the obligations of the United Nations Framework Convention on Climate Change (UNFCCC). Besides studies and investigations about climate change, the PNCC also supports initiatives to mitigate climate change, among others two micro-hydro projects implemented by IHH and co-financed by the UNDP/VMEEA.

#### Municipios and Prefecturas

Local governments (Municipios) and departmental governments act as co-financiers in almost all micro-hydro projects. In some cases this is a requirement of the major financier of the projects, e.g. in the case of the KfW. In case a plant is built by an engineer or small private organization, local governments often act as main financier.

#### Other

A lot of additional organizations have financed one or several projects in the past, but are currently not present in the field anymore. Among them the Royal Embassy of The Netherlands, which was an important partner of Energética, the Embassy of France, JICA (Japan International Cooperation Agency)<sup>26</sup>, FCIL (Fonds Canadien d'Initiatives Locales) Canada, and Fonadal (Fondo Nacional de Desarrollo Alternativo)<sup>27</sup>.

### 7.2.5 Construction companies

Construction companies are companies that only construct plants. They do not engage in coordination processes and they do not have the capabilities to design a plant. Only a few companies in Bolivia have sufficient knowledge to construct micro-hydro plants. Two companies are identified; one is not active anymore in the field.

In the past Ingelec has built several micro-hydro plants, especially for projects of the government. Ingelec is a Bolivian company, specialized in the construction of large-scale hydro- and thermo-power plants and the installation of transmission and distribution lines. The company operates internationally, especially in Latin America. Micro-hydro however is not the core business of Ingelec and they stopped their activities in this industry a couple of years ago, because of a lack of specialized personnel. Icaro, a similar company, has taken over the place of Ingelec and is currently the only private company that is constructing micro-hydro plants.

### 7.2.6 Research organizations

The only actor identified who is doing research on micro-hydro technology in Bolivia is IHH. In the past, Pelton and Michell Banki turbines have been developed and adapted for local manufacture and to fit specific local conditions. Furthermore, IHH has done research on the construction of the civil construction parts of micro-hydro plants and has

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<sup>22</sup> With the term self-assembly is meant that the community builds the micro-hydro plant. An organization, in this case Alisei, is monitoring the process through regular visits.

<sup>23</sup> For more information about the FPS, see <http://www.fps.gov.bo/>

<sup>24</sup> For more information about the FNDR, see <http://www.fndr.gov.bo/>

<sup>25</sup> For more information about the PNCC, see <http://www.pncc.gov.bo/>

<sup>26</sup> For more information about JICA, see <http://www.jica.go.jp/english/>

<sup>27</sup> For more information about FONADAL, see <http://www.fonadal.gov.bo/>

developed its own methods. More about the development of its technologies and construction methods can be found in chapter 9.

### **7.2.7 Local organizations & users**

Operation and maintenance of micro-hydro plants is usually carried out by small local organizations. These organizations can have different structures. The most often used organizational structure is that of a Cooperativa (Cooperative) or an Asociación (Association). In these organizations, the users usually have built the plant themselves and are therefore socios (companion and co-owner). The socios own the plant and form a board that takes care of the daily administrative business. This board is elected by the socios every one or two years and can assume several functions, like president, vice-president, treasurer, secretary, administrator (often a combination of treasurer and secretary) and a 'vocal' (someone who is responsible for the communication with the socios). Besides the board, an operator has a permanent appointment and takes care of the operation and maintenance of the plant. For bigger plants, more operators (usually an electrician and a mechanical engineer) and an administrative person can be engaged as well.

Another organizational structure that exists is one with the local head of the community, the mayor, as the head of the plant, being assisted by one or two operators. Besides these two structures, all possible combinations and forms exist.

### **7.2.8 Visualization of actor network**

Figure 7.2 (next page) shows the network of the actors discussed above. In case of 'local organizations and users', only the actors involved in the project case studies (to be discussed in section 7.4) have been incorporated. The actor map of the entire Bolivian micro-hydro sector will of course be more extensive, especially because more local actors will be involved.

The red lines in the figure show historical ties. These ties can have two meanings. First, as is the case e.g. for Energética, the actor is not active anymore in the field. Second, as is the case with e.g. the regional governments and the UNDP/SGP, the actors were involved in the project, but only for a relatively short period of time, usually during the implementation of the project.

Several actors have or had a central position in the figure. The implementing organizations IHH and the VMEEA play a key-role in the diffusion of MHP projects. They are the connection between financiers, regional and local governments and local communities. Energética used to play the same role. An important difference between them however is the duration of the link with the project. As can be seen, IHH has strong linkages that continue after the completion of the project. The VMEEA on the other hand has somewhat weaker and discontinuous linkages.

Some financing organizations have direct contact with the projects as well, others have only indirect linkages. A good example of direct linkages is the UNDP/SGP. They want to include a productive end-use facility in their projects and investigate together with IHH and the local community what kind of small company fits best with the local needs.

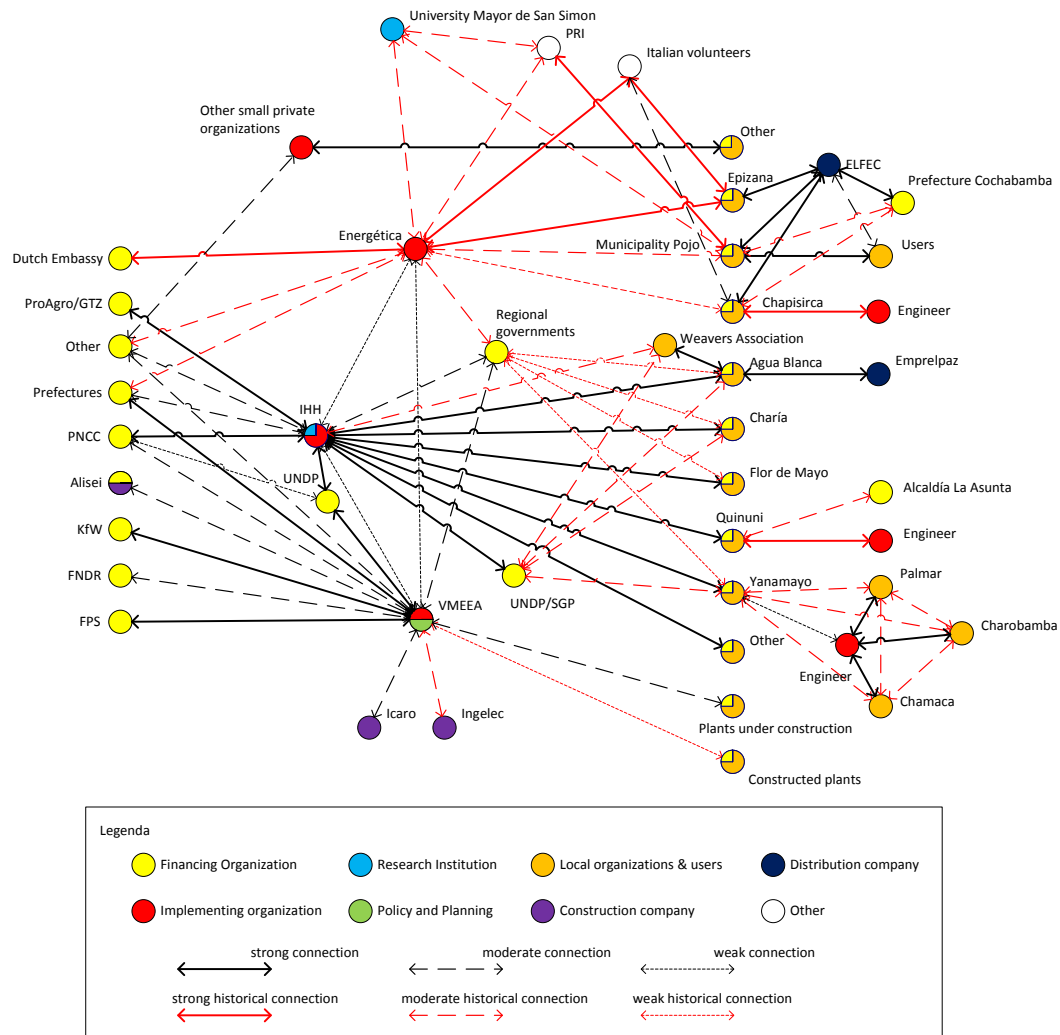


Figure 7.2: Visualization of actor network

### 7.3 Existing programs and projects

It is impossible to give an exact estimate of the number of micro-hydro plants that have been built in Bolivia. No one has an up to date list, and even the implementing organizations themselves often do not have up-to-date information about the plants they have built. As said before, it is known that there were nine systems in 1983. Besides that a list exists with the 125 (pre-) projects and ideas identified in 1984. Of these projects, 13 have been carried out although two of them do not fit the definition used for MHP (see Appendix I for a list of these projects), and 27% of the initial ideas/plants have been substituted by the national grid (Fernandez F., 2005). Furthermore, a study carried out in 2005, identified 138 plans for projects and projects in the design phase that have a capacity below 500 kW (mini-, micro-, and pico-hydro plants) (ESMAP, 2005). Nowadays, three programs exist that include MHP. 48 plants have been built under the heading of these programs. Furthermore, Energética has built three plants. Of these 51 plants, approximately 45 are still functioning. How many micro-hydro plants have been built by private organizations is difficult to estimate. Probably it will be somewhere between 15 and 40. It cannot be said how many are still functioning, but the share will be much lower than the plants built by the three programs and Energética.

Short summaries of the three programs will be given below. Appendix I shows a list of all the projects of Energética, the VMEEA and an incomplete list of the projects of IHH.

### 7.3.1 IHH: Programa Hidroenergético

IHH started the Programa Hidroenergético after its first experience with micro-hydro in 1986. The aim of the program is to increase the quality of life of people in remote, rural areas by adapting the then existing technology for local use and by offering a complete package of technical, economic and administrative knowledge and support in order to establish sustainable projects. The first years, IHH developed its own series of turbines (Pelton and Michel Banki), generators and control panels. Later on, they developed a self-assembly method for a faster and cheaper installation of the plants. According to this method, villagers have to build the civil construction parts of the plant themselves. IHH monitors the process through frequent visits. In the course of time IHH has built approximately 40 projects. In recent years, on average three to four projects a year have been built, while three to four plants are designed and are going to be built next year. The average project cycle takes two years, one for gathering data and designing the plant, one for the construction. Recently, several projects have been expanded with a productive end-use facility, like a woodcraft workshop or coffee processing plant. This has been done in order to improve the quality of life, not only by offering electricity, but also by increasing income.

Projects of IHH are financed by several organizations. In recent years, the UNDP/SGP, the PNCC, ProAgro/GTZ, the GEF, the VMEEA, and Prefecturas and Alcaldías have contributed to the investment cost.

Financing of IHH's projects:

UNDP/SGP	1 project/year	max 35.000 US\$
PNCC	1 project/year	max ± 35.000 US\$
ProAgro/GTZ	1 project/year	max 10.000 US\$
VMEEA/GEF		co-financier
Alcaldes/Municipios		co-financier
Prefecturas		co-financier

### 7.3.2 VMEEA, UNDP & Others: Programa de Electrificación Rural con Energías Renovables<sup>28</sup>

This 8.275.000 US\$ program was set up by the VMEEA and the UNDP in August 1999. The aim of the program was to eliminate barriers for the execution of rural electrification with renewable sources and to develop schemes that are sustainable and can be replicated in future projects. The aim of the project was to use public and private resources to install three micro-hydro systems<sup>29</sup> for 400 households and 3,000 solar panels.

Officially, the program ended in December 2007. By that time 3,605 solar panels, three micro-hydro and two pico-hydro systems have been installed. Currently, solar panels and micro-hydro systems are still being installed under the heading of the project. It is unclear however whether those projects were meant to be part of the program, or if they are separate projects and that it happened to be that they fit in nicely. In total, the 'expanded' project will include 6,105 solar panels, eight micro-hydro systems, seven pico-hydro systems and four designs for new micro-hydro systems. All micro-hydro projects are situated in the provinces Nor and Sur Yungas. The plants vary from 15 to 100 kW (421 kW in total) and serve 705 households. Total costs for the micro-hydro plants are 756,346 US\$.

The program started as a collaboration of the VMEEA and the UNDP, using resources from the GEF. Many organizations joined the program. Major financing partners were the Prefectura La Paz, the PNCC, the FPS, the FNDR and Alisei, and the KfW (for the designs of four other plants). Technical partners are IHH, Ingelec and Icaro.

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### 7.3.3 VMEEA & KfW

In 2002, the KfW and the VMEEA started a €5.1 million project to build seventeen micro-hydro plants. The program was officially included in PLABER (see chapter 6.4, page 34). Although PLABER was terminated in 2007, this program is still going on. The VMEEA acts as coordinator of the program, the KfW is the financier.

Organization	Investment (US\$)	%
UNDP	211,800	28%
FPS	171,275	23%
Prefectura La Paz	83,704	11%
Alisei	77,743	10%
Beneficiaries	52,400	6.9%
FNDR	42,189	5.6%
PNCC	39,008	5.2%
Other	47,836	10.3%
<b>Total:</b>	<b>756,346</b>	<b>100%</b>

Table 7.1: Total investment for the micro-hydro part of the program (KfW is not included)

<sup>28</sup> For more information, see [http://www.hidrocarburos.gov.bo/07\\_PROYECTO/proyecto.php](http://www.hidrocarburos.gov.bo/07_PROYECTO/proyecto.php)

<sup>29</sup> San José de Llojeta, Challa Jahuirá, and San Juan de Coripata

A couple of years ago, all municipalities and prefectures in Bolivia received an invitation to send in a proposal for a micro-hydro plant. The municipality or prefecture has to form a technical committee that has to investigate whether there is potential or not. Thereafter, the municipality/prefecture has to come with a final design for the plant. They can do that themselves, or call in an external party. The final design has to be submitted to the VMEEA, who evaluate and if necessary adapt the design. The KfW has to approve the design, after which an external company can be sought to construct the plant. During the construction, another company (sometimes the VMEEA is doing this itself) has to train three community members as electrician, mechanic and administrator. These three people have to manage the plant.

In principle, the plants should be micro-hydro, in this case meaning between 10 and 100 kW. However, larger, very promising initiatives are approved as well. The plants may cost 15,000 US\$/kWh and have to be situated minimal 15 to 20 km from the SIN or a Sistema Aislado. The KfW does not pay the entire investment. 80% is paid when the partner is a municipality, 75% when the partner is a prefecture. The remaining 20 or 25% has to be paid by the partner.

Till now (November 2008) two plants are being built; One plant in Pucara, Santa Cruz, which has a capacity of 100 kW and is going to serve 313 families. The other one is situated in Mallku Villamar, Potosí, and has a capacity of 28.8 kW for 85 households. Both projects face delays and are expected to be ready in December 2008. The design of four other projects is ready. Currently, a company is being sought to build those plants. Two other municipalities are making a design.

## 7.4 Case studies

To analyze learning processes in projects and the aggregation of lessons learned from projects to the global niche level, eight MHP projects are selected and studied. The projects have been chosen by their size, age, location and elevation, in order to be able to generalize findings for the whole Bolivian micro-hydro sector. The projects are situated in five different regions and in the two departments (La Paz and Cochabamba) with the best suitable conditions and the highest concentration of MHP plants. Four projects are located relatively close to each other (maximum distance is approximately 2.5 hour) in the province La Asunta (department La Paz). This is done to investigate the effect of the presence of many micro-hydro projects in the vicinity, e.g. whether there is more interaction between the projects and if so, what the results of this interaction are. The location of the case studies is shown in figure 7.3. The exact geographical coordinates can be found in the case-studies in Appendix II.

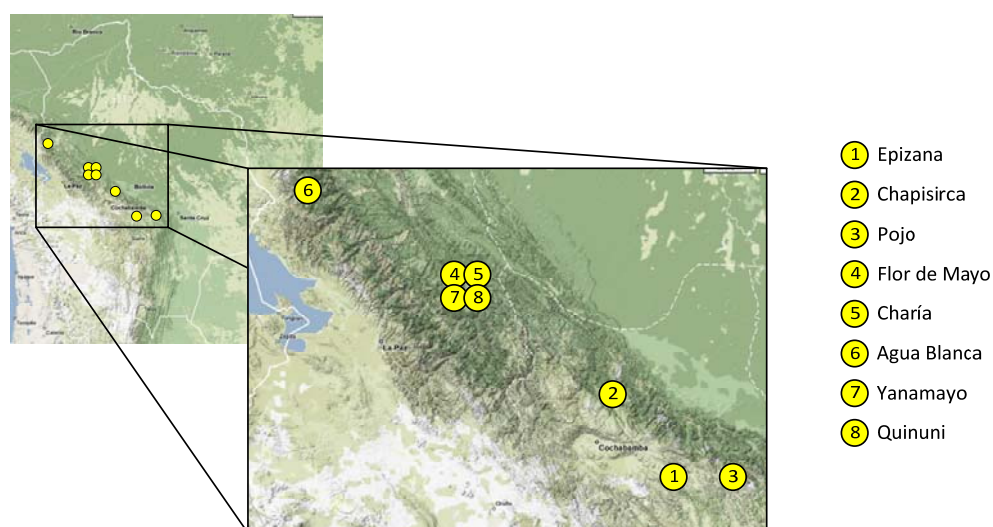


Figure 7.3: Location of case studies.



Table 7.2 summarizes some of the most important characteristics of the plants. As can be seen, the projects vary in age (0 to 19 year), size (15 to 105 kW), users (54 to 280 users), costs per kW installed capacity (1,140 to 3,745 US\$) and the technology used. Figure 7.4 shows the time-line of the projects and by whom they have been implemented. Some projects were initially designed and/or constructed by a private company or by own initiative. IHH or Energética intervened in those projects. Those interventions had different reasons. The plants of Chapisirca and Quinuni were still under construction. Those plants had to deal with a lot of design errors and had to be redesigned and rebuilt. The plant of Epizana already functioned but had to deal with organizational, technical and financial problems which could not be solved locally. The plant in Yanamayo had become too small and a new plant had to be built.

In this section a short summary of the eight case-studies is given. A more elaborate description can be found in Appendix II.

**Table 7.2: Characteristics of eight case-studies**

#	Location	Year	Size (kW)	# Users	Costs US\$/kW	Main donor	Head (m)	Flow-rate (l/s)	Turbine <sup>e</sup>
1	Epizana	1990	105	280	3,745	INER & Alcaldía	150	100	M-B
2	Chapisirca	1996	40	55	2,908	Dutch Embassy & Alcaldía	50.2	250	M-B
3	Pojo	2001	100	200	2,543	Dutch Embassy & Prefectura	43.9	200	P
4	Flor de Mayo	2001	15	54	1,639	UNDP/SGP	60.6	??	P
5	Charía	2004	20	92	1,996*	UNDP/SGP	59.2	53	P
6	Agua Blanca	2005	30	92	1,140* <sup>†</sup>	UNDP/SGP	175.2	30	P
7	Yanamayo	2007	28	109	1,145* <sup>‡</sup>	UNDP/SGP	13.7	423	M-B
8	Quinuni	2009 <sup>¥</sup>	34	120 <sup>¥</sup>	1,338 <sup>¥</sup>	PNCC, UNDP/VMEEA	??	??	P

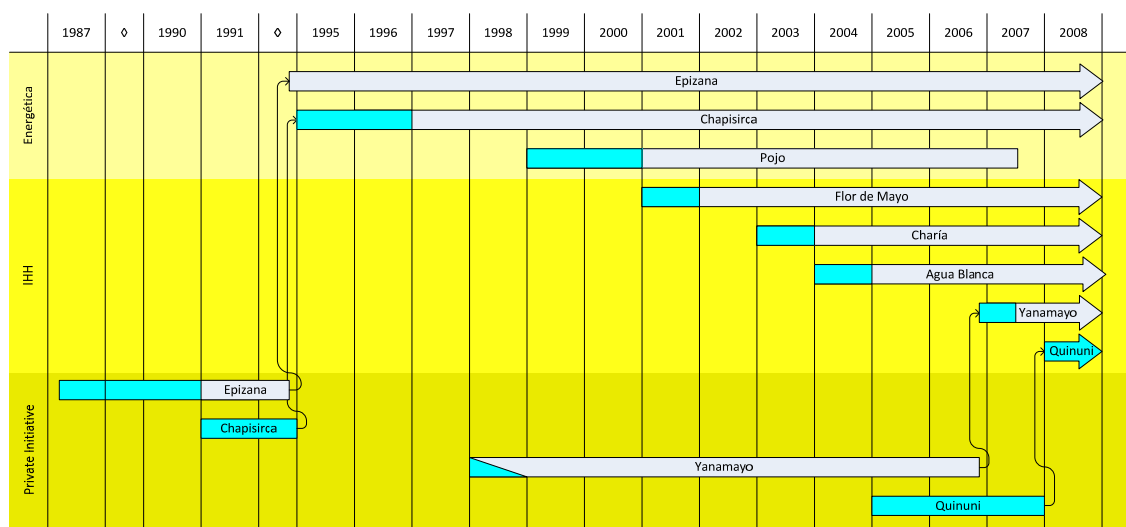
<sup>e</sup> Michell Banki (M-B) or Pelton (P);

<sup>‡</sup> low costs because use of existing construction;

\* including productive end-use facility: 2410, 1407, 1303 US\$/kW;

<sup>¥</sup> expected;

<sup>†</sup> low costs because no canal was required.



**Figure 7.4: Time-scale of the case-studies**

Construction Phase  
Plant in Operation

### 7.4.1 Epizana

The micro-hydro plant in Epizana serves the villages Epizana and Totorá. It was built by a group of Italian volunteers between 1987 and 1990 and replaced a 40 year old 20 kW plant. The capacity of the plant became too small between 1992 and 1994. New users could not be connected anymore. Energética intervened between 1994 and 1996. They replaced light bulbs by fluorescents, adapted the construction works to decrease loss of water and rearranged the distribution network. Furthermore, the tariff had to be corrected for inflation, which was never done. This problem was to recur regularly.



In 1997, the national grid was extended to both villages by the distribution company ELFEC. It turned out that the local organization, the Cooperativa San Francisco, could compete with ELFEC because the tariff was much lower. Things changed however in 2006, with the introduction of the Tarifa Dignidad, a subsidy of 25% for small users (< 70 kWh/month) of the SIN. This affected the competitiveness of the micro-hydro plant. The number of users decreased from 322 to 280, income declined by 25%.

In general, the plant is functioning well. The Cooperative is a stable organization and works relatively professionally.

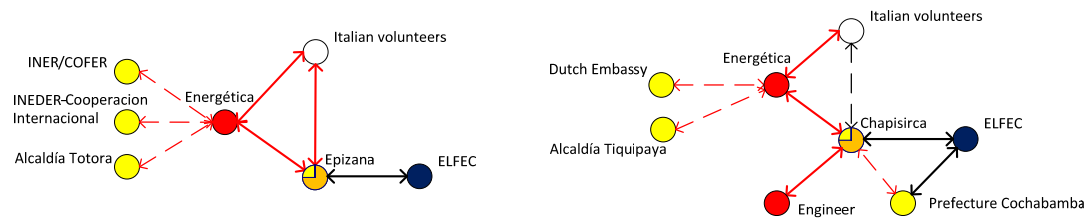


Figure 7.5: Actor network of Epizana (left) and Chapisirca (right)

### 7.4.2 Chapisirca

Chapisirca is a village of about 200 households in the mountains north of Cochabamba. In 1991, a micro-hydro expert told the population that it was possible to build a 25 kW plant for only 7,000 US\$. The project failed, despite fierce attempts and a total investment of 40,000 US\$. In 1996 Energética intervened and redesigned and rebuilt the plant, with the help of Italian volunteers.

In 2007, ELFEC extended the grid to Chapisirca and connected the relatively rich part of the village. The number of users dropped from 130 to 55 and the plant start suffering losses. The municipality makes up the deficit.

The plant is managed poorly. The function of operator is part of the mayoralty, but the mayor does not have sufficient knowledge and does not maintain the plant very well.

### 7.4.3 Pojo

In 1997 the municipality of Pojo decided to build a micro-hydro plant with an integrated irrigation system. Energética and the University of Cochabamba were asked to design the electro-mechanical part of the system and the PRI (Program for Rural Irrigation) designed the civil construction part. The PRI however did not have sufficient knowledge about micro-hydro systems and did not manage to build a well functioning canal system. The result was that the plant functioned poorly. The inlet and canal were obstructed during large parts of the year, and stones could enter the penstock and destroyed the turbine blades several times.

Moreover, the plant was making losses because it was seen as a social project and not all costs were passed on to the users. The deficit was made up by the municipality. However, after the turbine broke down again in 2007, the mayor decided to join a grid-based rural electrification program and to dismantle the plant.

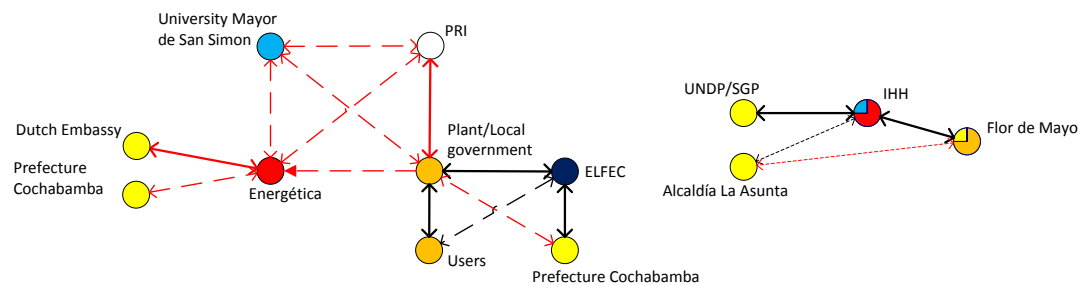


Figure 7.6: Actor network of Pojo (left) and Flor de Mayo (right)

#### 7.4.4 Flor de Mayo

The plant in Flor de Mayo was built between 2000 and 2001 by IHH and mainly financed by the UNDP/SGP. The plant still functions well, but new inhabitants cannot be connected anymore because the village has grown fast and users consume more electricity than expected. In recent years, the operator lacks technical knowledge. Different persons have fulfilled the function and knowledge was not always passed on.

The plant has brought about a lot in the village. The inhabitant realized that they can achieve a lot when they work together. After the completion of the plant, a bridge and road were constructed connecting the village to the main road and a drinking water installation has been installed. Moreover, the community came with the idea to use the electricity generated during daytime for a productive end-use facility. This idea has been carried out elsewhere, in subsequent projects of IHH, because not enough money was available anymore to invest in a productive end-use activity in Flor de Mayo.

#### 7.4.5 Charía

The construction of the plant in Charía was finished in 2004. It was one of the first projects in which IHH and the UNDP/SGP included a productive end-use facility, namely a small coffee and banana processing enterprise. This was not successful though, because the community was not interested in the cultivation of coffee and bananas and preferred to keep growing coca. Moreover, the enterprise did not have enough entrepreneurial knowledge and lacked starting capital to purchase coffee and bananas.

The plant functions well. During a period of extreme drought in 2007 water shortages occurred, but this was an exception. The organization managing the plant has relatively much financial knowledge. Tariffs are corrected for inflation and profits are made that are saved for future replacements.

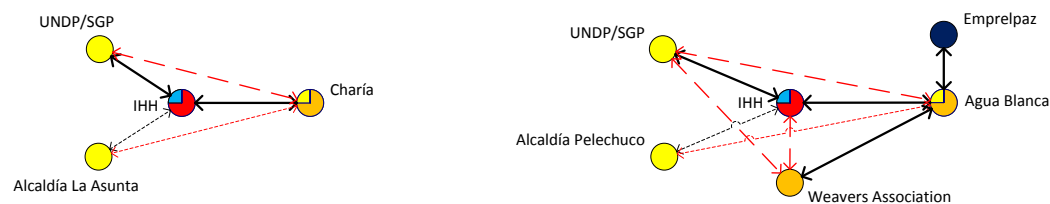


Figure 7.7: Actor network of Charía (left) and Agua Blanca (right)

#### 7.4.6 Agua Blanca

IHH constructed a 30 kW plant in Agua Blanca in 2005, financed by the UNDP/SGP. The project included the facilitation of a weavers association with electrical equipment. Till now, this has not resulted in increased income or profits. Entrepreneurial knowledge and starting capital are lacking. Technical problems occurred during the first two years. The vibrations of the turbine and generator caused both to break loose. After two years, IHH had solved the problem.

In 2008 Emprelpaz extended the grid to the village. The whole distribution network was installed except the connections to the houses. However, the community decided not to accept a connection to their houses and continue to use the micro-hydro plant. They were proud that they had built the plant themselves and the community believes that it fosters the development of the village if one does not lose their money to an external company.

#### 7.4.7 Yanamayo

In 2001 a pico-plant of approximately 2 kW was installed in Yanamayo by the villagers with the help of a German engineer living nearby. This plant was inefficient, but was otherwise functioning well. The capacity became too small after several years though and the community asked IHH to build a bigger plant. The initial plan was to construct a large system generating electricity for four villages, that all had one or several pico-plants built by the same engineer. However, there was not enough money available and only one micro-hydro plant could be built.

Construction works ended in 2007. A large part of the penstock was destroyed in January 2008 by a landslide. Repair took three months. Now the plant is operating well. The carpentry end-use that was included by IHH and the UNDP/SGP has not gotten off the ground yet.

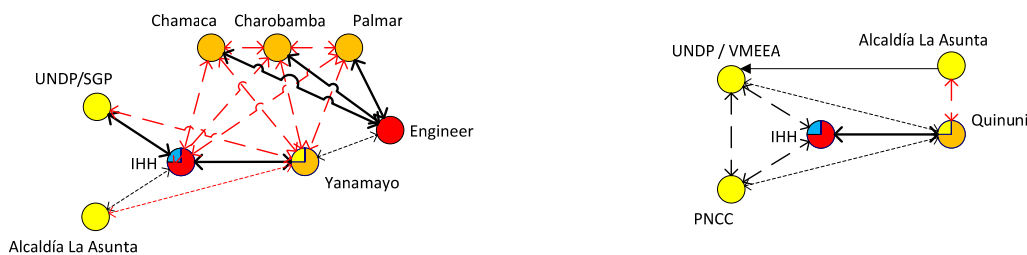


Figure 7.8: Actor network of Yanamayo (left) and Quinuni (right)

#### 7.4.8 Quinuni

In 2003 the inhabitants of Quinuni decided to construct a micro-hydro plant, following the example of many other villages in the vicinity. A Bolivian expert was asked to make a design and to construct the plant. It turned out that the 'expert' did not have any micro-hydro knowledge at all. After several years of construction and reconstruction, the plant still did not work. IHH became involved in 2007 and redesigned and reconstructed the system. Financing problems were the next hindrance. The PNCC and the VMEEA which administers the funds of the UNDP did not agree about the conditions of the payment. Moreover, the conditions of both organizations changed regularly. The VMEEA decided to part with the project after threats to go on hunger strike (a quite standard measure in Bolivia). The PNCC has the power to decide now. Hopefully, construction works will be finished in April 2009.

### 7.5 Expectations

As discussed in section 2.2.1, Strategic Niche Management scholars have described three internal niche processes that are of crucial importance for the development of a sound niche-construction. Those are 1) the articulation of expectations, 2) the building of social networks, and 3) learning processes. Expectations are a means for the construction of a shared (research) agenda which is very important to get everyone working in the same direction. Furthermore, it is important "to attract resources such as financial, managerial resources, actors, knowledge and expertise" (Mourik & Raven, 2006, p. 19). How the expectations are formulated in the MHP niche in Bolivia is described in this section.

#### 7.5.1 Expectations at the global niche level

The expectations of actors operating at the global niche level are influenced heavily by the past. The number of plants installed over the last decades has fallen short of expectations. Programs have not been carried out or the expectations had been pitched too high. Nowadays, many actors do not nourish much hope that things will change in the near future. In general, they do not have high hopes for a sudden fast diffusion of MHP in Bolivia.

Energética lost all its hopes several years ago. After the cancellation of such-and-such a project the organization decided to quit its micro-hydro projects. The continuously changing policies and lack of transparency caused too much trouble to successfully carry out projects. This year (2009) Energética will give MHP a chance again. The organization is going to design four new projects, although they are quite skeptical whether these plants will ever be built, because the local communities have not found financial resources yet for the construction-phase. The director of Energética, Miguel Fernández<sup>30</sup>, believes that MHP only has a future when an all-embracing program is started facilitating all aspects necessary for the building up of a proper functioning sector. This program should encompass sufficient financial funds, training facilities for local communities and engineers, systems to exchange knowledge and information, and so on.

Although IHH has been successful over the last two decades, they do not have much hope that they will be able to expand their number of projects or that they can build larger plant. Although the demand is huge, IHH lacks

<sup>30</sup> Miguel Fernández is also the author of the Programa Nacional de Micro Centrales Hidráulicas

resources and does not want to collaborate with the VMEEA if this means that they cannot work under their own conditions (full-project implementation). According to IHH, micro-hydro can have much more success if the liberal reforms carried out in the 1990s (see landscape analysis) are reversed and organizations are permitted again to carry out the whole project cycle, not just one part of it. If this would be allowed, the different phases will fit more closely and projects will be more successful.

The expectations of the VMEEA are moderate. Although financial resources are available, not much has been achieved in the past. The project in cooperation with the UNDP has almost been fulfilled and more plants have been realized than expected, although the construction of some plants has not been finished yet. On the other hand, the program carried out in collaboration with the KfW has been facing delays. The program started in 2002, but the first plant was still not realized in November 2008. This has dampened the expectations of the VMEEA and it has led to feelings of disappointment and irritation of many other actors in the field. Contrary to IHH and Energética, the VMEEA holds on to the liberal regulations and believes that the sector functions best the way it is doing at the moment.

Financing organizations have not lost their interest in MHP so far. The UNDP/SGP has been active in the sector for many years and probably will continue to finance one project a year. The same holds for ProAgro/GTZ. Local and regional governments do still act as co-financiers because they believe that micro-hydro is a very good means for rural electrification. Moreover, the KfW has started a € 5.1 million program with the VMEEA to foster the implementation of micro-hydro plants.

The expectations among construction companies differ. Ingelec stopped its micro-hydro activities because it is not their core-business and they do not see sufficient opportunities for the near future. On the other hand, Icaro entered the industry because the company sees enough chances to make profit.

From the above can be concluded that one cannot speak of the leveling and alignment of expectations among the global niche actors. Expectations are not influenced to a great extent by each other, which might hamper networking and the coherence of the learning processes of the different actors.

### **7.5.2 Expectations at project level**

Expectations within the project are usually very high in the beginning. How they develop depends on the progress of the project. In case the construction goes by without many problems, expectations remain high. However, several projects (e.g. Chapisirca, Pojo, and Quinuni) have shown that the spirit can go down after several years of delay and disappointment. The presence of successful examples is in these cases very important to hold or maintain the belief in the technology.

The presence of successful examples is furthermore very important for the initial enthusiasm of the local population. Although all communities without electricity welcome micro-hydro projects heartily, this enthusiasm will even be higher in villages where the opportunities of the technology are known.



## 8 Learning processes within local projects

The second internal niche process as can be found in SNM-literature is learning. In this study, the analysis of learning processes is divided into three separate parts; 1) learning processes within local projects, 2) learning processes by Bolivian implementing organizations, and 3) an analysis of additional findings.

This chapter deals with the first category that links to learning within projects at the local project level. Learning processes that have taken place in the past and/or that are still taking place are derived from the eight case-studies and categorically described. The second category relates to learning processes in the global niche. These will be discussed in chapter 9. These two sections will provide the main contribution for the answer to the first and second sub-question of this study, namely *'What barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia?' and 'How does learning contribute to overcoming these barriers?'*. Barriers will be derived from learning processes. This provides insight in the way learning helps to overcome barriers. At the same time, barriers can be identified. Lastly, a reflection on the functioning of the micro-hydro niche is carried out by the author (chapter 10), leading to several additional findings, i.e. lessons not learnt by the system's actors. This chapter will be the main input in the fourth sub question *'What additional lessons for the diffusion of micro-hydro power can be learned from implemented projects?'*. All three chapters will contribute to the third sub question *'What factors foster and impede learning processes?'*. Moreover, this sub question will be given extra attention in chapter 11 that discusses the dynamic barriers to the diffusion of knowledge. The allocation of chapters to sub questions is not that black-and-white though. It is done to give an indication of the main purpose of the particular chapters. But each of them will contribute to each sub question in one way or the other.

The learning processes are described using Douthwaite's learning cycles described in chapter 2.2.3. These cycles consist of four phases; (1) the practical experience, (2) making sense, (3) drawing conclusions and (4) taking action. The numbers in the text refer to these phases. The learning processes are categorized into the five broad barrier categories (market, financial/economic, technological, institutional and social, cultural and behavioral) given in chapter 3. Within those five categories more specific themes are used under which the learning cycles in the relevant case-studies are described. For example, the first learning cycles described fall in the theme 'Expansion and Competition with the Grid' in the category 'Market'. Within this theme, learning cycles in Epizana, Pojo, Chapisirca and Agua Blanca are described because those projects had/have to deal with this specific topic. The barriers that were/are addressed by the various learning processes are categorized in terms of the same five categories as well. This is indicated with a letter (M = market, F = financial/economic, T = technological, I = institutional, and S = social, cultural, and behavioral). Furthermore, the level (landscape, regime or niche) where the barrier stems from is mentioned behind as well. The barriers are mentioned separately in a bar below the learning processes.

### 8.1 Market related learning processes

#### 8.1.1 Expansion and Competition with the grid

The expansion of the large electricity grids in Bolivia, the SIN and the Sistemas Aislados, is currently making progress. Expansion and densification of the grids is seen by policy makers as the best way to increase the electricity coverage in rural areas and is therefore the priority of the government. Plans for expansion are usually not communicated in advance to organizations and institutions planning and implementing stand-alone systems for rural electrification. Furthermore, the presence of such systems is not seen as a reason not to expand the grid. Because of these trends, micro-hydro plants often have to compete with the grid. The plants in Epizana, Pojo, Chapisirca and Agua Blanca face(d) this problem. All plants chose a different strategy in order to deal with this barrier, leading to different results and different lessons learned.

Epizana – Learning Cycle 1:

(1) In 1996 ELFEC extended the SIN to Epizana and Totorá, the two villages that are connected to the micro-hydro plant in Epizana. The first thought of the Cooperativa San Francisco was that it was impossible for a relatively small micro-hydro organization like theirs to compete with the national grid. (2) Therefore the Cooperative concluded that there were two options; the first one was to continue the operation of the plant and sell the electricity generated to

ELFEC and thus collaborate; the second option was to sell the equipment and use the money for another purpose that would benefit the development of the region, like investments in regional agricultural development. (3) ELFEC however did not want to buy the electricity generated by the Cooperative, making the organization choose the second option. (4) A study was started in collaboration with Energética to identify the best future investment.

#### Epizana – Learning Cycle 2:

(1) The study about the future investment strategy of the Cooperative was not yet finished when ELFEC started operating. It turned out that ELFEC's tariff (0.90 Bs/kWh, minimum use of 12 kWh/month) was much higher than that of the Cooperative (0.40 Bs/kWh, min: 25 kWh/month). The micro-hydro plant would be financially more attractive than ELFEC for people consuming more than 14 kWh/month. Moreover, ELFEC did not install a three-phase distribution network like the micro-hydro plant has, but a single-phase network. The wheat mills in the vicinity of Totora could therefore not shift to ELFEC, because their machines have to use three-phase current. (2) This created opportunities. The mills guaranteed a demand of 2,400 kWh/month and many people would probably choose the electricity of the Cooperative based on financial grounds. (3,4) Therefore it was decided not to sell the plant and continue the operation.

#### Epizana – Learning Cycle 3:

(1) But although the majority of the inhabitants of both villages should stay with the Cooperative from a rational financial point of view, about half of the users moved to ELFEC. The main reason was that they could not grasp the negative financial consequences of the shift and it was expected that ELFEC was technologically superior and would have less power failures. (2) The Cooperative lost a significant part of its income. It seemed impossible to prevent a bankruptcy in the long term if the situation would not change. (3) The Cooperative however decided to wait a couple of months before taking a final decision. They believed that many users would return after a while, if it became clear that ELFEC's bills would turn out to be much higher than those of the Cooperative had been. (4) Furthermore, it was decided to emphasize the financial benefits of their plant to the users.

As the Cooperative expected, many users returned because of the high tariff applied by ELFEC and because ELFEC did have regular power failures as well, although less than the micro-hydro plant. In the end, only 80 users had left the Cooperative. Some had financial reasons because they consumed less than 14 kWh/month, some because they wanted to minimize the chance of power failures and were financially not able to be connected to both organizations, others because they were biased through the size of the company and its plants.

#### Epizana – Learning Cycle 4:

(1) In 2006, the Tarifa Dignidad was introduced by the government, meaning that users of the national grid consuming less than 70 kWh/month would receive a 25% reduction of their bill. This meant that the tariff of ELFEC decreased from 0.80 to 0.60 Bs/kWh for small users. The then tariff of the Cooperative was 0.50 Bs/kWh. (2) This changed the financial situation dramatically. The micro-hydro plant then became only financially more beneficial for users consuming more than 23 kWh/month. Many used less and shifted to ELFEC. The number of users dropped from 322 in 2005 to 280 in 2008. This led to a considerable reduction of the Cooperative's income. It decreased from approximately 85,000 Bs/year in the period 2003-2005 to ± 64,000 Bs/year in 2006 and 2007. (3) The Cooperative had to increase its competitiveness, otherwise it would go bankrupt. Reducing the tariff to strengthen its financial competitiveness was not an option; neither to reduce the minimum tariff. To reduce costs, the Cooperative decided that one should work more efficiently. Furthermore, its technological competitiveness had to be increased. (4) Two actions were undertaken. A new automatic billing system was bought to reduce costs. In the past, income had been collected by an external company. The new system would save a lot of time and money. Second, a study is being undertaken to buy a new more efficient turbine using less water, in order to prevent power failures during the dry periods. Funds for the purchase of this turbine are being sought. GTZ possibly wants to invest in a new turbine.

#### Pojo & Chapisirca – Learning cycle 1:

(1) The plants in Pojo and Chapisirca function(ed) poorly. Both installations faced many power failures due to obstructions of the canal caused by large amounts of sediments in the river (Pojo), a broken turbine because small stones were able to hit and destroy the blades (Pojo) or the lack of water during large parts of the year (Chapisirca). Furthermore, both plants made financial losses. The plant in Pojo was seen as a social project. The users could

consume unlimited amounts of electricity for 20 Bs/month. The users in Chapisirca used too little electricity so that the plant's income was not sufficient. Furthermore, users got away easily when they did not pay. (2) Because of these problems users did not have electricity during large parts of the year and the local governments had to contribute large sums of money to keep the plants functioning. (3) Adapting the plants' design was in both cases not an option, because no money was available. Another opportunity to solve the problem presented itself. Both communities could join the rural electrification program of the department of Cochabamba. ELFEC would extend the grid to both places and the local Cooperatives had to hand over the local grid to the distribution company. (4) Both communities seized the opportunity. ELFEC expanded the grid using funds of the government. The plant in Pojo was dismantled. The plant in Chapisirca kept functioning, because ELFEC would only expand the grid to the most densely populated and the most prosperous part of the village. The other part of the village is still using the micro-hydro plant.

Pojo– Learning cycle 2 – unfinished:

(1) ELFEC installed a single-phase transmission- and distribution network to Pojo. Several months after the dismantling of the micro-hydro plant, the local government made plans for the modernization of the agrarian sector in the valley. However, to use agrarian machinery like mills, a three-phase distribution network is needed. The hydro-plant did have one, while ELFEC did not. (2) The dismantling of the plant and the shift to ELFEC made it impossible to industrialize the agrarian sector and thus hindered the development of the valley. (3) Afterwards the local government regretted the dismantling of the machine. It was financially impossible however to re-install the plant.

Chapisirca – Learning cycle 2 – unfinished:

(1) The number of users of the plant in Chapisirca decreased from 130 to 55 after the national grid was expanded. (2) The income of the plant decreased dramatically. Besides the lower number of users the biggest consumers like the hospital, school, market place and the wealthier people were not connected anymore. Moreover, fewer people were able to help maintain the system. (3) The mayor of Chapisirca has plans to build a small pasta-factory to foster the development of the valley and to increase the plant's income. However, the plans are far from fully developed yet and it is questionable if it will ever be built, considering problems like the lack of capital and knowledge about marketing and business administration.

Agua Blanca – Learning cycle 1:

(1) In the winter of 2008, Emprelepaz expanded the national grid to Agua Blanca and surrounding villages. A distribution network was installed, including street lighting, but without connections to the houses yet. The implication of the connection to the central grid would be that the plant in Agua Blanca would have to compete with the central grid. It is shown in Epizana and several other plants built by IHH that this is possible. However, the organization in Agua Blanca was still very young and inexperienced. Moreover, due to technical problems the plant had had financial losses in the first years and was trying to build up some money reserves. This would be very difficult when the plant had to compete with Emprelepaz. (3) The local cooperative identified three options; Quitting, which would mean the dismantling of the plant; Competing with Emprelepaz; Or completely ignoring the grid by refusing a connection collectively. (4) The community chose the last option. It was possible to collectively refuse the grid due to strong community ties and because the villagers had constructed the plant themselves and were very proud that they made it happen, despite all the technical problems in the first two years. Furthermore, the community had invested a considerable amount of money in the (construction of) the plant and the villagers did not want to give their money to an external company, but wanted to keep it inside. They believed that this was best for the development of the village. A last important factor was the difference in tariffs. The tariff of Emprelepaz would be considerably higher (0.50 Bs/kWh plus a basic rate of 22 Bs compared to 0.40 Bs/kWh plus 10 Bs) which made the decision easier.

Agua Blanca – Learning cycle 2:

(1) The users of the plant consumed more electricity than was expected and power failures occurred regularly. To solve this problem, a bigger generator was bought and installed, leading to an excess of electricity. (2) The excess of power in combination with the expansion of the national grid by Emprelepaz made the community realize that they could expand their grid as well and act as a small electricity distributor for the region. (3,4) The Cooperative consulted IHH to discuss the possibilities. Currently, a first investigation is being conducted.



The learning cycles described above show a number of different barriers to the diffusion of micro-hydro technology. First, they show a bias towards the dominant regime-technology. Cognitive rules and path-dependence make the users and institutions blind for alternatives for expansion and densification of the grid. The opportunities of micro-hydro plants, like the presence of a three-phase distribution network, are neglected or even worse. Micro-hydro plants are not seen as a real alternative for electricity generation and are therefore not seen as a reason not to expand the grid.

S	Bias towards regime-technology by users	Regime
I	Bias towards regime-technology by government	Regime
I	Neglect of advantages of micro-hydro technology	Regime

Moreover, the regime-actors, especially the distribution companies do not want to collaborate with actors in the micro-hydro niche. Plans are not communicated, policies are not made transparent and one does not want to incorporate stand-alone systems in their networks. No coordinating institution exists to regulate such issues. The last issue is also hindered by the strict legislation. It is quite hard to become an electricity generator operating via the SIN and distribution companies themselves are not allowed anymore to generate electricity since the liberal reforms in the 1990s.

I	Lack of intention of regime-actor to cooperate with niche-actors	Regime
I	Liberal reforms hinder collaboration between niche and regime	Landscape
I	Lack of coordinating institution	Regime/Niche

The political swing to the left in Latin America (see landscape influences, chapter 5.3) also affects the competitiveness of micro-hydro plants. Through the sudden emphasize of access to services for the poorest part of the population far-reaching measures have been taken. One of those is the subsidy provided by the government to distribution companies, through which they can operate below the marginal costs. Moreover, negative externalities, e.g. environmental pollution, are not taken into consideration in the tariffs. These are far higher for large scale hydro and gas and oil powered plants. These factors hinder the operation and diffusion of micro-hydro plants considerably.

M	Disturbed competitiveness due to market-distorting subsidies	Landscape
M	Non-consideration of externalities	Regime

Lastly, micro-hydro plants often perform worse than the central grid in technological terms.

T	Weak technological performance of micro-hydro plants	Niche
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## 8.2 Financial/economic related learning processes

### 8.2.1 Adjustment of tariffs

A well known problem of organizations managing a rural stand-alone system is the neglect to adjust tariffs in step with inflation. If this is not done, the tariff is no longer a representation of the actual costs and the financial sustainability of the plant comes under pressure. Several plants made this mistake.

Epizana – Learning cycle 1:

(1) 1994 was the first year that the Cooperative of the plant in Epizana ran at a loss. (2) The profit was already diminishing since the tariff was set in 1990 to 0.25 Bs/kWh, because the plant was not managed in a financially sustainable way in the long-run. (3) At first instance, the Cooperative did not fully realize how to solve the problem. From 1994 to 1996 Energética became involved in the project and concluded that the neglect to adjust the tariffs was the main problem. They suggested that the tariff should be raised to 0.47 Bs/kWh, in order to cover all the costs, including depreciation. Furthermore, they recommended correcting the tariff each year by the inflation-rate. (4) The

tariff was adjusted in 1996 after another year of losses, although not to the 0.47 Bs Energética had recommended, but to 0.30 Bs/kWh. The users own the plant and have to vote for tariff changes. They did not agree to the recommended 0.47 Bs/kWh, because it would have hit them too hard financially.

Epizana – Learning cycle 2:

(1) The marginal adjustment of the tariff alleviated the problem for the next two years. However, the Cooperative did not pass on the full effect of the inflation in the next years and losses were again made from 1999 to 2001. (3) After the recommendations of Energética, the cause of the losses was now clear to the board of the Cooperative. The tariff had to be adjusted again (4) and the board managed to convince the users of the necessity and the tariff was changed in 2002 to 0.50 Bs/kWh. The income and profit increased immediately.

Pojo & Chapisirca – Learning cycle 1 – unfinished:

(1) The organizations in Pojo and Chapisirca have both never adjusted the tariff and face(d) financial losses. (2) The local governments bear/bore the losses of the plants because they recognize(d) that the electricity generated and distributed was too important for the villagers to dismantle the systems. (3) It is unknown whether the organizations realized that the ignorance of the adjustment of the tariff with inflation is (one of) the main causes of the problem. The plant in Pojo was seen as a social project and the villagers had unlimited access to electricity for 20 Bs/month. The tariff in Chapisirca had never been adjusted since the construction of the plant in 1996. For both cases, no action was undertaken to strengthen the financial situation of the plants. The tariffs were not adjusted, leading to the (partial) dismantling of the plant and the expansion of the national grid.

Flor de Mayo – Learning cycle 1 – unfinished:

(1) Since the plant in Flor de Mayo has been in operation, the Association has the aim to save 1,000 US\$ each year to build up a reserve for future replacements. This was done in the first years, but the financial situation of the plant does not allow putting aside this amount of money anymore. (2) As a result, the Association might not have sufficient financial reserves to be able to purchase components for future replacements. Because a new generator had to be bought in 2007, reserves are already quite small. (3) The tariff has not been adjusted since the beginning of the project. On the other hand, costs increase because of inflation and because the wage of the operator was increased in both 2007 as well as in 2008 with 50 Bs, from 200 to 300 Bs per month. However, this problem is not fully recognized by the Association and nothing has been done yet.

Charía – Learning cycle 1:

(1) The organization in Charía has the same financial aim as the Association in Flor de Mayo: save 1,000 US\$ each year. This was possible without difficulties, despite the fact that profits were diminishing since the installation of the plant in 2004. (2) This did not lead to problems immediately. In 2007 almost 2,800 US\$ could be saved. On the other hand, it would lead to problems on the long run. (3) This was recognized by the local organization and (4) the tariff was adjusted in 2008 from 0.60 Bs/kWh to 0.70 Bs/kWh. It is expected that this will sustain the healthy financial situation of the plant.

The above analysis brings out that inadequate financial management is a barrier that regularly hinders a proper functioning of a micro-hydro plant. In general, the tariff of a micro-hydro plant is not corrected on a yearly basis for inflation. In some cases, tariffs are adjusted when the plant has losses, however financial knowledge often lacks and one does not realize which factors cause the losses. Another barrier for a successful functioning is that not all costs are passed on to the users. One of the case-studies for example (Pojo) was seen as a social project by the mayor of the town. Approximately two-fifth of the actual costs was passed on to the users, the remaining was paid by the municipality. Those plants cannot survive in the long-run and will probably be replaced by the grid or just dismantled.

F	Inflation is not passed on to the users	Niche
F	Not all costs are passed on to the users	Niche
F	Project seen as social venture	Niche

Participation and involvement of beneficiaries in development projects is a topic discussed often in the last decades. However, it does not only have advantages. In the case-study of Epizana, the carrying out of a sound financial management is in first instance made impossible by the users, who lost sight of the common interest and voted against the adjustment of the tariff in for their own short-term interest.

### 8.2.2 Billing system

The majority of the micro-hydro plants collect the electricity bill manually, because their organizations are too small for an advanced system. The Cooperative in Epizana however decided to buy a computer-controlled system because the large number of users (280) made it impossible to administer everything manually.

Epizana – Learning cycle 1:

(1) The administration and processing of the payments of the users of the plant in Epizana was done manually in the past. Members of the board and technicians of the Cooperative had to visit every house to take the meter readings and note down the electricity consumed and to calculate to money due. Considering the high number of users (400 at the time), this was a time consuming process. When people did not pay, or did not pay in time, this was administrated manually as well. (2) Due to this effort, the technicians did not have sufficient time to maintain the plant regularly, leading to inadequate maintenance. (3) Energética analyzed the problem and concluded that the billing administration could be carried out more efficiently. (4) They purchased software to administer the payments by computer. This led to a considerable saving in time and the technicians were able to make more time available for their main duty.

Epizana – Learning cycle 2:

(1) The computer-controlled system saved time, but not as much as the Cooperative and Energética had hoped. (2) The administration of the payments was still a very time consuming process and weighed down heavily on the capacity of the Cooperative. (3) The reason for the somewhat disappointing result of the new system was that the secretary still had to take the meter readings every month. Furthermore, the data had to be entered into the computer system manually. (4) The Cooperative decided to change the system. The secretary did not pass by all the houses to take the meter reading anymore, but the users had to report the electricity consumed themselves. This would be entered into the computer and the users would receive their bill immediately. The Cooperative checks the meter readings once a year.

Epizana – Learning cycle 3:

(1) The tariff of the Cooperative changed in 2002, through which the settings of the system had to be changed. However, the Cooperative was not able to do this, and neither was Energética. (2,3) The billing software became useless, because it could not be adapted through the lack of sufficient knowledge about the software. Everything had to be done manually again, because external expertise was hard to find. (4) It took several years until the system could be adapted and functioned again.

Epizana – Learning cycle 4:

(1) The competition with ELFEC and the introduction of the Tarifa Dignidad forced the Cooperative to increase its efficiency. The billing system was carried out together with an external company that charged a small fee (0.50 Bs per user per month) for its services. (2) This small fee weakened the competitive position of the Cooperative, (3) but it would take too much time to do the administration themselves, considering the existing software. (4) Therefore, new software was recently acquired to administer the payments more efficiently without the intervention of an external party. This will probably lead to a cost-reduction and will strengthen the competitive position of the Cooperative.

Summing up, the learning processes show that relatively large micro-hydro plants need an appropriate billing system to reduce the labor involved in collecting the payments. Computer systems however involve a great deal of software and local organizations often lack the capabilities to handle these programs.

T	Labor-intensive billing system	Niche
T	Lack of knowledge of software system	Niche

### 8.3 Technological related learning processes

#### 8.3.1 Lack of local technical capabilities

Flor de Mayo – Learning cycle 1 – unfinished:

(1) In 2007 the generator of the plant in Flor de Mayo broke down. (2) It could not be repaired and the Association had to buy a new one for 3,000 to 3,500 US\$. This investment reduced the financial reserve of the organization drastically. (3) The reason for the breakdown of the generator was the lack of knowledge of the operator. The first operator was given a technical course by IHH. However, in the meantime, the operator had changed a couple of times and not all knowledge was passed on. The current operator does not have the capability to maintain the plant, which led to the breakdown.

Chapisirca – Learning cycle 1 – unfinished:

(1) After the construction of the plant in Chapisirca was finished, an electrical- and a mechanical operator were instructed to maintain the plant. However, after a couple of years both left the villages and were not succeeded. (2) The necessary capacity was not filled and the village became dependent on experts from Cochabamba. This regularly resulted in long power failures, because of the remote location of the village. (3) The Cooperative realizes that more local knowledge is necessary to sustain the plant. However, one does not know how to obtain it.

Pojo – Learning cycle 1 – unfinished:

(1) Two engineers maintained the plant in Pojo. Both however had limited knowledge and could not carry out major reparations. (2) Because this lack of knowledge, engineers from Cochabamba had to come when the plant was broken. (3) Usually, this took more than two weeks in which the community did not have electricity. These delays were one of the arguments to dismantle the plants.

In a nutshell, local communities often do not have sufficient technical capabilities to sustain and maintain a micro-hydro plant. Usually, one or several operators have been trained, but this knowledge is in many cases not transferred properly to the next operator. Once the knowledge had been lost, it is impossible to restore it, because no training facilities exist.

T	Lack of technical capabilities	Niche
T	Lack of knowledge transfer	Niche
T/I	Lack of training facility operators	Niche

Micro-hydro experts are thinly spread in Bolivia. Places with a plant are in nature located in remote areas, otherwise the grid would have been expanded to them. Therefore, it usually takes a lot of time if an engineer has to come from a big city for local repairs.

T	Lack of micro-hydro experts in rural areas	Niche
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### 8.3.2 Three-phase systems

Epizana – Learning cycle 1:

(1) Before the intervention of Energética, the plant in Epizana did not have enough capacity to connect all villagers. (2) One of the reasons was that the power generated was much lower than it should be. (3) Energética studied the causes and found that the three-phases of the distribution network were unequally loaded through which losses occurred. The operator had no idea that it is important to load each phase equally. (4) The users were re-distributed over the three phases and Energética educated the operator about the system.

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T	Lack of technical capabilities to maintain three-phase system	Niche
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### 8.3.3 Water shortage

Epizana – Learning cycle 1:

(1) In the areas around the micro-hydro plant the cultivation of potatoes has increased over the last decade. The fields around the plant require relatively large amounts of water, which is scarce during the dry season. To irrigate their fields, the farmers use water from the small artificial lake of the micro-hydro plant. (2) This results in a water shortage for the plant, leading to power failures, especially during day-time when the farmers use the water. (3,4) The Cooperative decided to talk with the farmers about other solutions. Those were not found, and the farmers continued to use the water. This resulted in several arguments between both sides.

Epizana – Learning cycle 2:

(1) After several years, still no solution was found and (2) power failures continued to exist during periods of drought. (3,4) The new president of the plant decided to start an investigation in cooperation with the university of Cochabamba about the purchase of a new, more efficient turbine, leading to a reduction of the water consumption. This study was still going on during the site-visit. Meanwhile, the Cooperative was in consultation with GTZ about funds for the purchase of the new turbine.

Chapisirca – Learning cycle 1 – unfinished:

(1) The plant in Chapisirca does not function at all in July and August due to a shortage of water. Often, there is not enough water in June and September as well. (2) Despite this shortage, nothing is done to repair the canal in places where it is leaking considerably. Because the valley faces economically difficult times, the users do not want to spend time repairing the canal, but prefer to work on their fields. The operator does not have time either, because he has to maintain his field, and fulfill his function as mayor of the place.

Summing up, water shortages remain a big problem for micro-hydro plants. Some regions face long periods of droughts. In other cases, conflicting interests with agriculture result in water shortages.

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T	Power failures due to shortage of water	Niche
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I	Conflicting purposes of the available water	Niche
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A key factor for the success of small plants is the participation of the beneficiaries. When they have other competing interests, it will become hard to maintain the plant.

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I	Poor participation of beneficiaries due to competing interests	Niche
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## 8.4 Conclusions

In this chapter, learning processes that have been taken and/or still are taking place in local projects have been investigated. Several (sequences of) learning cycles have been analyzed and the barriers underlying these cycles have been identified. These barriers provide a part of the answer to the sub question: *‘What barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia?’*. The involved learning processes contribute to the sub question *‘How has learning contributed to overcoming these barriers?’*. The aim of this section is to summarize the learning processes and barriers that have been found and to draw conclusions to answer the sub question: *‘What factors foster and impede learning processes?’*

What barriers hinder the diffusion of micro-hydro power? The majority of the barriers identified are institutional and technological barriers (both nine). The identified institutional barriers often stem from regime or landscape factors or have a ‘global niche character’ and thus cannot be removed in local projects. Technological barriers cannot be solved because of the lack of local technological capabilities.

How has learning contributed to overcoming barriers? Table 8.1 summarizes the number of (sequences of) learning cycles<sup>31</sup> per project. Starting with the number of learning cycles, it is clear that the organization in Epizana has experienced the most cycles, followed by Chapisirca and Pojo. The same plants have the highest number of sequences of learning cycles. The thirteen learning cycles in Epizana are subdivided into five sequences. Chapisirca has experienced four sequences, Pojo three, and the other case studies less than three. The age of a plant is a very important determinant for the number of (sequences of) learning cycles. Except for Agua Blanca, the older a plant is, the more learning cycles have been identified.

The quality of the (sequences of) learning cycles is another story though. All learning cycles in Epizana have been completed, which is an indication of an existing problem-solving (barrier removing) capacity within the organization. The other plants have experienced a lot of unfinished cycles, meaning that the barriers have not been removed yet. Furthermore, the organization in Epizana has a high number of learning cycles per sequence. Consecutive learning cycles are an indication of the capacity to adapt and re-adapt a system or technology. Adaptations are evaluated and improved, so that the overall quality improves.

**Table 8.1: Summary of learning processes in the eight case studies**

	Epizana	Chapisirca	Pojo	Flor de Mayo	Charía	Agua Blanca	Yana-mayo	Quinuni
<b>Date of implementation</b>	1990	1996	2001	2001	2004	2005	2007	2009
<b># learning cycles</b>	13	5	4	2	1	2	-	-
<b># sequences of learning cycles</b>	5	4	3	2	1	1	-	-
<b># completed learning cycles</b>	13	1	1	0	1	2	-	-
<b># completed sequences of learning cycles</b>	5	0	0	0	1	1	-	-

While the number of learning cycles highly depends on the age of the plant, there should be other factors influencing the quality of the learning processes<sup>32</sup>, because no big differences exist between the other plants. The most important distinguishing characteristic of the plant in Epizana in comparison to the other plants is the organizational continuity. Because the plant is relatively large for a micro-hydro plant in Bolivia (105 kW) and has a high number of users (280), it generates enough income to engage three people fulltime. These people have been working for the plant for five to fifteen years and have gained a lot of experience and knowledge. Organizational continuity is thus an important factor that fosters the existence and completion of (sequences of) learning cycles. The presence of people who have the possibility to spend all their time and energy into the plant is another prerequisite.

The majority of the learning cycles described have been categorized as market (10 cycles), financial/economic (10) and technological (7) related cycles. Financial/economic related learning cycles have been completed most often.

<sup>31</sup> A sequence of learning cycles is formed if two or more cycles follow each other, so that a process of adaptation and re-adaptation is created.

<sup>32</sup> Here, the quality of a learning process is seen as a combination of finished learning cycles and the existing of sequences

Market relating learning cycles are often hard to complete because the barriers provoking the learning processes are often induced by regime or landscape factors and/or have an institutional character. Local projects cannot influence these factors so that no action can be undertaken to remove these barriers. Market related learning cycles (as well as market related barriers) do only exist in projects outside the La Asunta area. Because the national grid will not be expanded to this area due to the cultivation of coca, a protected niche is created in which the technology can develop more quietly. Technological learning cycles are often unfinished because local communities lack the technological capabilities to solve the existing problems.

So locally, learning can help overcoming barriers if communities have the means to do so. Very often though, the barriers origin from the global niche or the socio-technical regime or landscape. Factors influenced by the global niche cannot be influenced by local projects. One of the reasons is the top-down approach of the VMEEA, through which especially institutional factors keep hindering the diffusion of MHP. A better interaction between the local project level and the global niche will improve this considerably.

## 9 Learning Cycles by Bolivian implementing organizations

Besides learning at the local project level, discussed in the previous chapter, learning takes also place in the global niche. As discussed in section 7.2, the implementing organizations play a very important role in the realization of micro-hydro projects. They are at the centre of the actor-network and thus play a crucial role in learning processes at the global level. Their learning cycles will be discussed in this section, again by referring to Douthwaite's learning cycles with the numbers (1), (2), (3) and (4). The barriers are indicated in the same way as in the previous section.

### 9.1 Market related learning processes

#### 9.1.1 Allocation of financial resources

IHH – learning cycle 1 – unfinished:

(1) A lot of financial resources are available for the implementation of MHP plants in Bolivia. The program of the Bolivian government and the KfW has the disposal of €5.1 million euro. The other program of the government, the Programa de Electrificación Rural con Energías Renovables, has a budget of more than 756,000 US\$ and IHH can invest 80,000 to 100,000 US\$ on a yearly basis. (2) The problem is that the money of IHH is divided into smaller parts and cannot be used entirely within one big project. Therefore, IHH is stuck in the implementation of small projects (max. ± 40 kW) while the market regularly asks for bigger projects, see e.g. the case of Yanamayo. (3) This would not be a problem if the VMEEA would fill the existing gap and takes care of the construction of the larger plants and IHH would construct the relatively small plants. Unfortunately, the government has until now not proven to be fully capable of carrying out such a program fluently and without delays. Furthermore, the government's projects are more expensive than those of IHH, among others through inefficient construction methods and bureaucracy (see section 10.3.3).

To sum up, financial resources are not entrusted to organizations with capabilities. The most skilled organization does not have access to large parts of the funds available, so that less skilled organizations have more financial resources.

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M Misallocation of financial resources

Niche

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### 9.2 Technological related learning processes

#### 9.2.1 Flow measurement

IHH – learning cycle 1:

(1) The quality of the measurement of the flow rate of a river is one of the key determinants for a successful functioning micro-hydro plant. Data of several years has to be available to assure that years with limited rainfall does not result in water shortages and power failures. (2) Data of small rivers is often not available and lengthy measurements have to be carried out, often hindering a smooth and quick project implementation. (3) IHH tries to build plants in cycles of two years, using the first year for measuring and designing. Obviously, this is not enough to get an accurate insight in the long-term river flow rate. (4) This was solved by estimating the flow rate very carefully using measurements of one year and by using the memories of elderly inhabitants to find out how that particular year relates to previous years.

IHH – learning cycle 2:

(1) The method described above allows building the plant in two years, but cannot prevent that water shortages occur in periods of extreme drought. (2) This happened for example in Charía in 2007. The plant had functioned without any problem for three years, but the extreme conditions of the winter could not be covered with IHH's method. (3) IHH realized that the way of measuring can lead to problems. (4) To solve these problems, a new method was used in Agua Blanca, using the flow rate measurements and data of the available regional rainfall. A computer program combined both to calculate the minimum flow rate of the river. The next couple of years have to show whether this program increases the accuracy or not.



Recapitulating, the lack of data of river flow rates is sometimes leading to water shortages and thus power failures. It is very hard to give an accurate estimation with measurements of only one year. New methods are being developed, but it is uncertain yet whether those will improve the situation.

T	Lack of data of flow rate of small rivers	Niche
T	Lack of methods to accurately measure flow rate in short period of time	Niche

### 9.2.2 Canal construction

IHH – learning cycle 1:

(1) Over the years, IHH has gained a lot of experience with canal construction techniques. In the past, they used to use concrete canals that are cheap and can be built with local materials. (2) Concrete canals turned out to have several disadvantages though. They require a lot of construction efforts and obstructions will occur easily in areas with vegetation and gravel. Furthermore, a lot of maintenance and repair works are required as the canal becomes older. IHH learned that micro-hydro plants should be simple and should require as little maintenance as possible in order to increase the sustainability of the plant. This contradicts with concrete canals. (3,4) Over the years, IHH started to use tubes in some areas. They are used e.g. in the La Asunta region because of the abundant presence of tropical vegetation. Experiences with tubes are very good. Construction efforts are reduced, which is important for IHH's self-assembly method (see section 9.3.3) which already weighs heavily on the local population. Furthermore, the price-difference is reduced to a marginal difference in case of long distances with a small water flow (small diameter).

Energética – learning cycle 1:

(1) Energética has experienced the same problems as IHH. (2) Their plants all have a concrete canal. (3) The canals in Epizana and Pojo are only covered at some places, so that a lot of vegetation can enter. This is not causing problems in Epizana because the operator cleans it three times a day. In Pojo however, the canal was obstructed regularly. (4) To solve obstruction problems, the canal in Chapisirca was covered almost completely.

Energética – learning cycle 2 – unfinished:

(1) The coverage of the canal reduced the problem, but did not solve it entirely. (2) Moreover, other problems appeared. Water losses occur in Chapisirca due to cracks in the canal.

It can be concluded from the above analysis that the canal forms a problematic part of a micro-hydro scheme. Concrete canals have a low sustainability and require a lot of maintenance. Moreover, they will be obstructed regularly when they are not covered. Tubes on the other hand are more expensive and cannot be built with local materials.

T	Low sustainability of concrete canals	Niche
T	Obstruction of open canals	Niche
T	High costs of tubes to be used as canal	Niche

### 9.2.3 Turbine & control system development

IHH – learning cycle 1:

(1) In its first project in 1986 IHH used a Michell Banki T3 turbine developed by the Swiss SKAT. (2) The turbine did not fit the local conditions perfectly. (3) Therefore, IHH decided to develop a turbine themselves for the next project. This would reduce costs and IHH would have the disposal of a turbine that perfectly fitted the local conditions. (4) A Pelton D12 (diameter of 12 cm) was developed for the generation of 12 V direct current. It was made of one piece of aluminum and was suited for small (pico-)sites.

IHH – learning cycle 2:

(1) The first turbine turned out to be successful. (2,3) Using this experience, IHH decided to develop a whole series of Pelton turbines, so that they would have the disposal of a turbine for each specific site. (4) A Pelton D20 was the second turbine that was developed. It has a capacity of 25 kW delivering alternating current (AC). The turbine had four injections and was suited for a maximum flow-rate of 50 l/s and a maximum head of 80 m. In the following years all kind of Pelton turbines were developed, with diameters of 12, 20, 26 and 33 cm and with different blade designs. IHH started experimenting with materials, resulting in the use of a stainless alloy. The developed Pelton turbines covered sites with flow rates ranging from 6 to 200 l/s and heads ranging from 20 to 150 m, generating power in the pico-range to 250 kW.

IHH – learning cycle 3:

(1) Pelton turbines can only be used at sites with a lot of altitude differences. (2) A lot of places in Bolivia do not have such differences and (3) have to use other types of turbines. (4) To cover those sites as well, IHH started a program to develop a series of Michell Banki turbines for sites with medium head and flow rate. It resulted in four turbines covering flow rates from 50 to 600 l/s and heads from 3 to 80 m.

IHH – learning cycle 4:

(1) Besides turbines, IHH experienced that electrical control system bought abroad did not fit the turbines developed by IHH and the local conditions perfectly. (2) Because a Bolivian manufacturer was not available, (3) IHH decided to design the control system themselves. (4) Now IHH has a system that ensures a stable and steady electricity supply. The system is appropriate for single- and three-phase systems. It uses a dump load for the excess of electricity generated and is adjustable for electrical, mechanical and mixed output. The system can be used up to 100 kW.

To summarize, the lack of cheap, locally produced equipment fitting specific conditions is still a problem in Bolivia. IHH has solved the problem themselves, but the other organizations still buy equipment from abroad. This is expensive, time consuming and leads to problems if the equipment breaks down. The plant in Chapisirca e.g. has been waiting several months for a new electrical control system that has to come from Italy.

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T	Lack of appropriate technology	Niche
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#### 9.2.4 Lack of local technological knowledge

VMEEA – learning cycle 1 – unfinished:

(1) The program of the VMEEA and the KfW, described in chapter 7.3.3, prescribe that the municipalities have to make the design for a micro-hydro plant themselves. The design will be evaluated by the VMEEA and the KfW and has to be approved before funds will be assigned. This approach has hindered the progress of the program considerably. (2) Communities lack the knowledge to design a plant. Proposals made by community members do usually not have any chance to be approved. Furthermore, municipalities do not know where to find an engineer or organization capable of designing a scheme. If they do know, they often do not have sufficient financial resources to pay for the design. (3) The VMEEA has recognized that this approach is not working the way it should. In the future, money will be made available to contract out the designing. The problem how to find an experienced person or organization to make the design still remains. Furthermore, it is unclear when the policy will change.

To conclude, the program of the VMEEA does not fit the local capabilities. The VMEEA does not seem to be able to empathize with local communities. This is a serious barrier for the further diffusion of the technology.

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I	Badly thought-out approach to implement MHP in local communities	Niche
I	Local inability to contact micro-hydro experts	Niche

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### 9.2.5 Lack of technological construction capabilities

Technological knowledge of MHP is scarce in Bolivia. Only few people and organizations have sufficient capabilities for the construction of micro-hydro plants. On the contrary, many people think that they can build a system because the technology looks quite simple. This is leading to many failed projects that put the technology in a bad light.

Energética – learning cycle 1 – unfinished:

(1,2) Energética had to deal with incapable engineers or organizations twice. The plant in Chapisirca had to be redesigned and rebuilt completely. The place of the turbine house was chosen wrongly and the canal had to be extended. Another problem occurred in Pojo. The construction of the civil parts of the plant was done by an organization promoting agricultural development. This organization was experienced in the construction of irrigation canals, but did not have any knowledge about micro-hydro schemes. Despite Energética's strong objections regarding the design of the civil construction works the construction continued. Eventually this led to the dismantling of the plant.

IHH – learning cycle 1 – unfinished:

(1) IHH has the same experience with the project in Quinuni as Energética had in Chapisirca. (2) An incapable engineer convinced the community about his skills and designed and built a plant. The plant still did not function after several reconstructions. (3) IHH had to redesign the plant completely. Unfortunately, this was not the first time that IHH had to intervene in such a way. Other communities made the same mistake, leading to the same result.

The above analysis brings out that communities do often not have any technological knowledge of micro-hydro schemes. They hear success-stories from other villages and if there is a small river in the vicinity, the construction of a micro-hydro plant should be simple according to them. It is quite easy for a convincing engineer to persuade a community to let him construct the plant. Because the community lacks the technological know-how, they cannot judge whether the engineer is capable or not. Moreover, no certification or rating system (or something like that) exists which can guide them in making their decision.

I	Presence of incapable engineers	Niche
I	Lack of certification system / rating system	Niche
I	Low-tech appearance of technology	Niche
T	Lack of local technical knowledge	Niche

### 9.2.6 Extension of existing structure

IHH – learning cycle 1:

(1) Several plants that were analyzed became too small after several years. (2) One of the disadvantages of MHP plants is that it is difficult and expensive to extend an existing system. (3) Often, the whole system has to be re-built. (4) IHH did an experiment in Yanamayo and tried to use the existing infrastructure. The penstock of the old system was used for one injection of the turbine, while a new penstock was installed for the other injections. Normally, one penstock is used and the water stream is split just before the inlet of the turbine in case of multiple jets. The advantage of this new approach is that a smaller penstock can be bought. This reduces the costs considerably, considering the high costs of a penstock. IHH was satisfied with the result and will use this technique in new projects as well.

T	It is difficult to expand a micro-hydro plant	Niche
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## 9.3 Institutional related learning processes

### 9.3.1 Three-phase distribution network as prerequisite for development

IHH – learning cycle 1:

(1) In the past IHH used to install single-phase distribution networks to reduce costs (three-phase networks are more expensive) and because they thought that no one needed a three-phase network. (2) However, several communities started to complain that the lack of a three-phase network hindered their economic development. The best examples are Flor de Mayo and Charía. The inhabitants of both villages would like to start a carpentry workshop and a metal workshop, but both require a three-phase connection which is not available. (3) IHH learned from this experience and (4) established a carpentry workshop with a three-phase connection nearby the plant in Yanamayo.

IHH – learning cycle 2:

(1) The lack of a three-phase network in the village itself was still not solved though, (2) so that the establishment of other productive end-use facilities in Yanamayo was still not possible. (3) IHH learned that despite of the higher costs of a three-phase network they had to install one. (4) This is first being done in Quinuni. This project should reveal whether communities really will make use of it.

Energética – learning cycle 1:

(1) Energética had already experienced the importance of a three-phase distribution network in Epizana and Pojo. (2) In Epizana it is used by wheat mills and a metal workshop. In Pojo it would have been used for the development and mechanization of the agrarian sector, if the project still would have functioned.

Summing up, a three-phase distribution network is a prerequisite for industrial and economic development. Machinery cannot be used if it is absent. However, a three-phase network is often not installed because it is more expensive than a single-phase network.

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I	Absence of three-phase network as barrier for economic development	Niche
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### 9.3.2 Collaboration with distribution companies operating on the central grid

Energética – learning cycle 1 – unfinished:

(1) Energética had to deal with distribution companies operating on the SIN regularly in the past. When the NGO started with a micro-hydro project, ELFEC and the Prefectura de Cochabamba were asked about their grid-expansion plans to determine whether it was necessary to build a plant or not. (2) Despite this effort, the majority of the plants designed by Energética were never built because the grid was extended nevertheless, despite promises not to extend the grid to those villages. (3) It turned out to be impossible to consult with ELFEC and the Prefectura, so that needless efforts were undertaken and the local communities had wasted a lot of money for the design.

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I	Lack of transparency of grid-expansion policies	Regime
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### 9.3.3 Construction method

IHH – learning cycle 1:

(1) During the last twenty years IHH has developed a self-assembly method for the installation of micro-hydro plants. The organization noticed that the high initial investment for micro-hydro schemes is often a barrier (2) because it is hard to obtain financial resources. (3) IHH had confidence in the capacities locally available and (4) decided to start a program in which the villagers themselves build the plant using as much local materials as possible and in which IHH monitors the construction process by regular visits in which mistakes are corrected and problems discussed.

This method has gradually been developed using twenty years of experience in approximately 40 projects.<sup>33</sup> Nowadays it consists of six phases: 1) Pre-investment-phase, in which measurements are carried out, the scheme is designed and the local community is prepared for the construction, among others by the establishment of a local organizational structure; 2) Funding-phase, in which financial donors have to be found; 3) Construction-phase, in which the local community builds the plant; 4) Training-phase, in which the whole community is educated about technical, organizational and financial issues; 5) Transfer-phase, in which the responsibility of the project is transferred from IHH to the local organization; and 6) Evaluation and Assistance-phase, in which IHH evaluates the functioning of the project, normally after three or four months and in which the community can ask IHH for (mainly technical) assistance.

As said before, this whole process has gradually evolved and is still evolving. It started with the involvement of users in the construction works and it has expanded to what it is right now. In recent years, the evaluation-phase has been introduced. Several projects are evaluated after three or four months. The evaluations however are still quite superficial and according to the author should be held at a later stage, because usually not much has changed over three months. Long-term evaluations are not held. Furthermore, some projects are extended by the establishment of a productive end-use facility. This however is still in a development phase. Many things go wrong and a lot of knowledge has to be acquired yet. More about this in the next theme.

The self-assembly method has several advantages. First of all, it reduces costs, because no construction company has to be involved and local manpower is for free. Moreover, cheap local materials are used. Table 9.1 shows the average costs per kW installed for the case-studies plus some additional plants. The average investment per kW for plants of IHH is 1,438 US\$. Energética needs 2,726 US\$ per kW installed, while the VMEEA invests 4,284 US\$ per kW. A one-way ANOVA analysis of the investment per kW installed between the projects of IHH and the VMEEA gives a p-value of 0.01, meaning that the difference is significant. Moreover, it should be mentioned that the plants of IHH are relatively small while the VMEEA has several plants of 100 kW. The average investment of the VMEEA of plants smaller than 40 kW is 5,304 US\$/kW. The table also shows that the investment in Epizana was relatively high. This is because no local materials were used and the technology used (including the small artificial lake) is quite complex (see case-study). This is an important factor that increases the investment.

**Table 9.1: Average investment per kW installed for different organizations. Investments for projects of the VMEEA are prospected values.**

VMEEA	Size	US\$/kW	IHH	Size	US\$/kW	Energética	Size	US\$/kW
San Jose de Llojeta	100	2,422	Flor de Mayo	15	1,639	Pojo	100	2,543
San Juan de Coripata	100	1,992	Charía	20	1,996	Chapisirca	40	2,908
Challa Jahuirá	95	983	Agua Blanca	30	1,140	<b>Average</b>		<b>2,726</b>
Santiago Siete Lomas	30	2,145	Yanamayo	28	1,145			
Inca Pucara	15	3,036	Quinuni	34	1,338			
Pucara	100	4,215	Camata	25	1,367			
Mallku Villamar	28.8	4,668	<b>Average</b>		<b>1,438</b>			
Kanamarca	28	5,216				<b>Other</b>	<b>Size</b>	<b>US\$/kW</b>
Sta. Rosa de Challana	31	4,503				Epizana	105	3,745
Cieneguillas	15	6,226				<b>Average</b>		<b>3,745</b>
San Miguel del Bala	15	6,975						
San Jose de Uchupiamonas	21.7	9,025						
<b>Average</b>		<b>4,284</b>						

Furthermore this approach increases the identification with, and appropriation of the technology by the local community leading to a higher sustainability of the project. On the other hand however, the construction of a plant by socios can result in social differences between socios and users that move to the village after the completion of the plant. The socios in Flor de Mayo see the other users as somewhat inferior, because they have not contributed to

<sup>33</sup> This development took place in multiple learning cycles. It appeared to be impossible to reconstruct all the separate cycles. Therefore, the development of the construction method is described differently from the way in which the other learning cycles were documented.

the construction. In Agua Blanca socios that did not benefit from the productive end-use facility argued with users that did benefit about the amount of labor they had to contribute. They did not agree that everyone had to contribute the same, while some gained more than others.

Lastly, the local administration and independence from external organizations strengthen the social structure of the community. Spoken in the terminology of Korten, IHH has achieved a high degree of fit between program design, beneficiary needs, and the capacities of the assisting organization (Korten, 1980, p. 496). Moreover, IHH is following Korten's sequence of learning to be effective, efficient and to expand in the right order. First, the organizations learned to construct proper functioning plants with their own technology (learning to be effective). Thereafter, a method has been developed to reduce the input in terms of money and to build plants with local materials (learning to be efficient). Now, IHH should learn how to expand their program by building bigger plants, or more plants a year. The VMEEA on the other hand started in the last phase, without knowing how to construct a proper functioning plant with reasonable resources. This is not working out.

To summarize, the initial investment of micro-hydro plants is large. Often it is hard to obtain sufficient financial resources. The costs of a plant are even higher when no local materials are used.

F	High initial investment of micro-hydro plants	Niche
F	Neglect to use local materials	Niche
IHH's construction method reduces costs and increases participation and feelings of ownership, increasing the sustainability of the project. This is often lacking in other projects. However, it can go hand in hand with the creation of social differences.		
S	Lack of ownership-feelings	Niche
S	Creation of social differences through the self-assembly method	Niche

### 9.3.4 Establishment of productive end-use facility

IHH – learning cycle 1:

(1) The inhabitants of Flor de Mayo asked IHH if it was possible to do something with the electricity that is generated during day-time. (2) During the training that IHH gave them in 2001, they saw the difference between peak-hours and the rest of the day. (3) IHH decided to do something with this experience in the next project, because no money was available anymore in Flor de Mayo. (4) A productive end-use facility was included in the project in Camata (not included in the case-studies) from 2001 to 2003. A small coffee- and locota- (a kind of chili) processing plant was built so that the villagers could process and sell their own coffee and locota and thus add value to their coffee-beans.

IHH – learning cycle 2:

(1) The project was continued in Charía in 2004. The same equipment was used as in Camata to process coffee and bananas. Both products grow in the region, although coca was the main source of income. The future of coca was uncertain though. The Bolivian government wanted to eradicate the cultivation to please the USA and ensure development aid. (2) IHH wanted to anticipate this development and hoped that the inhabitants would start growing coffee and bananas more intensively. (3) This however was a mistake. The community was not interested at all in the cultivation of coffee or bananas. Both would never be able to replace the income earned with coca. After one year, the facility was closed. IHH learned in this project that one should join an already existing structure or activity and that one should not try to create a whole new industry. (4) This lesson was used in the project in Agua Blanca in 2005.

IHH – learning cycle 3:

(1,2) IHH and the community of Agua Blanca decided to equip an already existing weaving organization with electrical machines. The organization used locally produced llama- and alpaca-wool to process artifacts for tourists manually on a very small scale. The weavers were given looms and washing- and painting machines. (3) This structure did not however flourish either and (4) a new attempt was made in the next project in Yanamayo.

IHH – learning cycle 4 – unfinished:

(1) The last attempt was carried out in Yanamayo in 2007. (2) Besides the micro-hydro plant a woodcraft workshop was installed to make furniture and to teach the students of the secondary school a handicraft. Many people in the La Asunta area would like to have a woodcraft workshop because they have to buy low quality furniture from La Paz, while the tropical area has plenty of high quality wood. (3) In this project, IHH decided to shift the focus from income generating activities towards non-financial activities. The future has to reveal whether this approach will work out or not.

The establishment of a productive end-use facility can increase the sustainability of a micro-hydro plant significantly. Using electricity for a productive end-use during daytime increases the financial income of a plant while the capacity of the plant does not have to be increased. The learning cycles described above show however that although IHH adapted its strategy over and over, they did not achieve to establish a successful productive end-use facility. Several things went wrong in the projects. First of all, a blue print approach was used in the project in Charía. Exactly the same project was started as in Charía. This resulted in a misfit between the community and the program. This happened several times. The critical fit between the means by which the beneficiaries were able to define and communicate their needs and the processes by which the IHH and the UNDP/SGP made decisions lacked. The UNDP/SGP wanted to install productive end-use facilities, while the local communities wanted carpentry workshops. (Korten, 1980, p. 496) Another common denominator is the lack of entrepreneurial skills and knowledge about business processes. Local communities do not know how to manage a small firm, how to put their product into the market, how to find and use distribution channels, etc. Furthermore, the projects lacked capital to buy the raw products, whether it was coffee, locota, bananas or wool.

However, it cannot be a surprise that IHH is not able to establish successful productive end-use facilities. Its core business is research into micro-hydro technology and the implementation of micro-hydro projects. The implementation of productive end-use facilities, including knowledge transfers, guidance to explore the market and find distribution channels and the provision of starting capital is not their specialization. Therefore, it should be better that the establishment of productive end-use facilities is done in collaboration with a specialized external organization.

I	Lack of entrepreneurial skills to establish productive end-use facility	Niche
I	Lack of knowledge about business processes	Niche
F	Lack of starting capital	Niche

### 9.3.5 Lack of awareness of programs

VMEEA – learning cycle 1 – unfinished:

(1) In 2002, the VMEEA sent letters to municipalities and prefectures to announce the joint program of the KfW and to investigate the local demand. Local and regional governments had to send in project proposals if they wanted to participate in the program. This approach however has not led to many requests. Worse still, a shortage of projects exists despite the enormous demand for rural electrification projects. (2) Especially local governments are not aware anymore of the opportunity offered. (3) The VMEEA is aware of this lack of awareness, but has not taken steps to improve the situation till now (November 2008).

I	Lack of awareness of opportunities	Niche
I	Ineffective communication between global niche and project level	Niche

## 9.4 Social, Cultural and Behavioral related learning processes

### 9.4.1 Differences in Work Ethic

IHH – learning cycle 1 – unfinished:

(1) The experience of many projects has shown that MHP projects in more distant, remote villages are more successful and can function more independently than projects in areas closer to urban areas. (2) According to IHH, the reason is that people living in remote areas are less used to receiving help from the government or NGOs and (3) therefore are used to solving their problems themselves and working harder. Communities located closer to urban areas have a more dependent attitude and lack the work ethic needed to build and sustain a micro-hydro plant.

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S	Dependence on development programs leads to reduced self-initiative	Niche
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### 9.4.2 Social cohesion to reduce electricity consumption

Energética – learning cycle 1:

(1) A couple of years after the installation of the plant in Epizana, it became too small to serve the whole community. (2) New users could not be connected and power failures occurred regularly. (3) Energética investigated the causes and (4) started an information campaign to create awareness and to change the electricity consuming behavior of the users. Moreover, the population was urged to distribute the electricity consumption more evenly over the day.

Other cases exist in which the community itself solved the problem through social control. Before the installation of the larger plant, inhabitants of Yanamayo together decided that no one was allowed to use more than two energy-saving light bulbs. More or less the same happened in Agua Blanca before the installation of the bigger generator, where the villagers decided to spread the use of showers. Not everyone took a shower in the morning anymore, but showered in the evening or sometime else during the day. Through this behavioral change, the peak load was reduced and consumption spread more equally over the day.

For both cases it was very important that the users had built the system themselves and that IHH had educated them about the main principles behind MHP. This had created a general understanding of the functioning of the technology, and what went wrong when too much electricity was consumed. Furthermore, the communities had the drive to continue the operation of the plant because they are proud of the system they have built. This is possibly the reason that the community in Epizana needed an external intervention and was not able to solve the problem by themselves.

## 9.5 Conclusions

In this chapter, learning processes by Bolivian implementing organizations have been investigated. Several (sequences of) learning cycles have been identified and the related barriers have been discovered. As in the previous chapter, a part of the answer to the first three sub research questions will be given in this section. The barriers found in this chapter are a part of the answer to the first sub question: *'What barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia?'*. The involved learning processes contribute to the second sub question *'How has learning contributed to overcoming these barriers?'*. The aim of this section is to summarize the learning processes and barriers that have been found and to draw conclusions to answer the third sub question: *'What factors foster and impede learning processes?'*

The majority of the barriers found in this chapter are technological and institutional barriers. Almost all learning cycles described in this chapter that are provoked by these barriers can be categorized as technological (13 learning cycles identified) or institutional (14)<sup>34</sup> related learning processes. Only two cycles have been identified in the social, cultural and behavioral category, one in the market category and none financial/economic related learning process has been identified. It depends on the organization whether the learning cycles are completed (and the barrier is thus removed) or not. IHH shows several sequences of technological related learning cycles, which indicates that the organization has a lot of technological capabilities. On the other hand, only one (unfinished) learning process has

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<sup>34</sup> Assuming that IHH's learning process under the heading 'construction method' (section 9.3.3) is covered in five learning cycles.



been identified by the VMEEA. The majority of the institutional related learning processes have been taken place by IHH as well and only few by other organizations. In general, institutional learning cycles are completed when they have a strong technological character ('three-phase distribution networks as prerequisite for development' and 'construction method'). If this technological component is absent, the cycles are in general not finished. This indicates that the technology is already mature and that IHH knows how to handle micro-hydro systems. On the other hand, other aspects of the technological system are still underexposed. In these areas a lot of progress can still be made. Thus the degree to which *learning contributes to overcoming barriers* depends on the type of barrier and the organization. The implementing organizations differ to a great extent in the number of learning cycles that they have been gone through and their barrier-removing capacity. Energética is hard to compare with IHH and the VMEEA, because the NGO quitted their MHP operations several years ago. IHH and the VMEEA on the other hand are active in the sector for many years now. IHH has shown that learning in previous projects contributes to overcoming barriers in future projects. This is however not the case for projects of the VMEEA.

*'What factors foster and impede learning processes?'* IHH has shown that it is very important to implement sequences of projects and to be permitted to carry out the whole project cycle. Both factors create a kind of continuity in which learning processes can take place. Furthermore, it is crucial to go through Korten's learning phases in the right order.

## 10 Analysis of additional findings

Besides the learning cycles described in the previous sections, some additional findings have been found by the author. These findings related to the sub-question 'What additional lessons for the diffusion of micro-hydro power can be learned from implemented projects?'. They are analyzed and described in this section.

### 10.1 Additional financial/economic findings

#### 10.1.1 Plant size

A micro-hydro plant needs a certain number of users to generate enough income to be financially sustainable. The plant in Epizana has 280 users (105 kW) and moreover is situated in a relatively developed area where the users consume a relatively large amount of electricity. This plant is able to employ four persons full time and to save enough money for future replacements. In comparison, the plant in Charía has 92 users (20 kW) and is not able to employ personnel full-time. Flor de Mayo on the other hand has only 54 users (15 kW) and is not even able to save 1,000 US\$ a year for future replacements. What is the minimum size to be able to financially sustain a plant? This is hard to say and will depend on local characteristics. The average income for example in the La Asunta region is much higher thanks to the cultivation of coca than the average income in Chapisirca. Therefore, the demand in La Asunta will be higher and/or the tariff can be higher. For example, the users in Charía use approximately 46 kWh per month, while the users in Chapisirca consume on average between 10 and 15 kWh.

But although characteristics will vary per region, it is possible to estimate the future financial situation of a plant, especially by someone having a lot of experience and knowledge about the region.

The following (simplified) formula can be used:<sup>35</sup>

$$\# * ([\bar{U} - U_b] * T/\text{kWh} + T_b) + I = W + C_{O\&M} + S + X$$

#	Number of users	W	Wages
$\bar{U}$	Average use per user	$C_{O\&M}$	Cost of Operation and Maintenance
$U_b$	Base use	S	Savings target
T/kWh	Tariff per kWh	X	Financial surplus
$T_b$	Base tariff		
I	Additional source of income		

On the left hand side, the income is described by multiplying the number of users # by the average income per user, which is composed of the use per kWh multiplied by the average use minus the minimum use, and the base tariff. Any additional incomes I are added. All costs are incorporated in the right hand side, consisting of the wages (W), operation and maintenance costs ( $C_{O\&M}$ ), the savings target (S) and the financial surplus (X). If the financial surplus is positive, a financial healthy situation exists. If it is negative but smaller than the savings target, there will be some profits, but not enough to set aside enough money for big replacements. Lastly, if X is negative and larger than S, losses will be made on the normal operation of the plant.

Using the data derived from the case studies in combination with experiences from IHH, it can be assumed that the average consumption is 20 to 30 kWh/month. For the sake of simplicity, it will also be assumed that all users are consuming the minimum amount of electricity or more. Furthermore, it is assumed that one operator is engaged with an income of 4,000 Bs a year. The other functions are occupied by volunteers. According to IHH, a saving target of 1,000 US\$ a year ( $\pm 7,250$  Bs/year<sup>36</sup>) reflects the required long-term replacement costs. Lastly, the tariff is set to 0.50 Bs/kWh with a minimum of 10 Bs/month (= 20 kWh) for a relatively poor region and to 0.70 Bs/kWh for a relatively rich region. For a relatively small plant (smaller than 40 kW) maintenance costs will be somewhere between 6,000 Bs to 7,500 Bs a year, excluding large replacements.

Using this data, the following graph can be derived:

<sup>35</sup> The formula has been drawn up by the author

<sup>36</sup> 2008 exchange rate: 7.253 Bs/US\$ (CIA World Factbook, 2009)

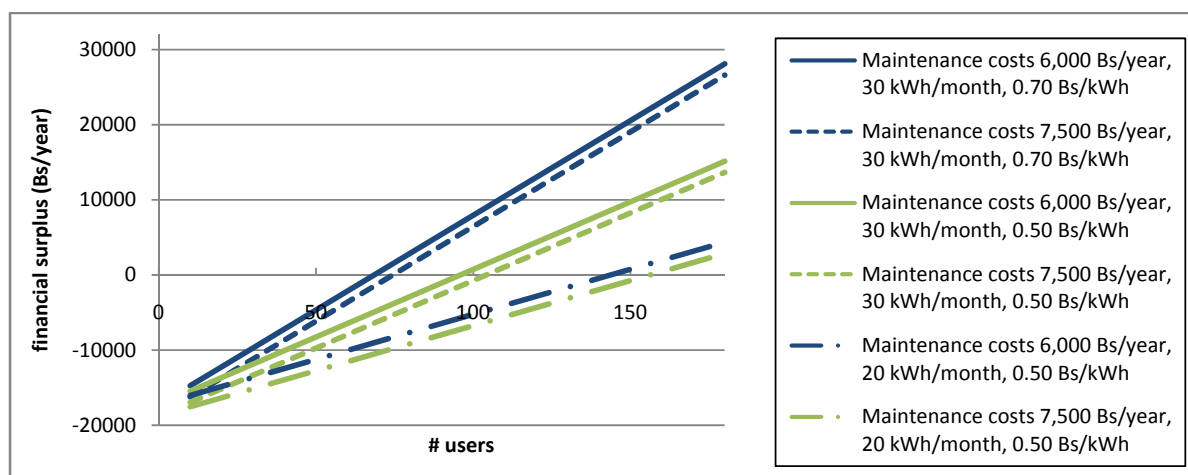


Figure 10.1: Financial surplus in relation to the number of users of a plant

The graph shows that around 100 users are needed with an average consumption of 30 kWh/month and a tariff of 0.50 Bs/kWh to manage the plant in a financially sustainable way and to make it possible to save 1,000 US\$ a year. If the tariff is raised to 0.70 Bs/kWh around 70 users are needed. So in areas like La Asunta where the tariff can be set higher, the minimum number of users should be around 70, while in other areas like Agua Blanca, it should be around 100. Table 10.1 shows a summary of the graph.

Table 10.1: Summary of figure 10.1

1,000 US\$ saving	30 kWh/month 0.70 Bs/kWh		30 kWh/month 0.50 Bs/kWh		20 kWh/month 0.50 Bs/kWh	
	Maintenance	Users needed	Maintenance	Users needed	Maintenance	Users needed
YES	6,000	68	6,000	96	6,000	144
	7,500	74	7,500	104	7,500	156
NO	6,000	40	6,000	56	6,000	83
	7,500	46	7,500	64	7,500	96

This explains why the Cooperative in Charía is able to save enough money, while the Cooperative in Flor de Mayo is not able to do this.

F	Micro-hydro plants for very small communities are not financially sustainable	Niche
F	Micro-hydro plants in poor areas need ± 150 users to be financially sustainable	Niche

### 10.1.2 Incorporation of depreciation in the tariff

In none of the cases depreciation is included in the tariff, although some plants manage to save 1,000 US\$ a year for future large replacements. The question arises if it is theoretically possible to build a plant using a loan and put aside enough money for repayments? Michele Koper already showed in her master thesis that it would be possible for the plant in Epizana to do this by the then number of users and a three-fold increase of the tariff, or by doubling the number of users and a tariff increase from 0.50 to 0.80 Bs/kWh. But the case of Epizana is quite special. Despite the size of the plant, the investment per kW was high (3,745 US\$/kW). On the other hand, the plant has a lot of users (280), but not that many users per kW installed capacity. The next analysis shows if it would have been possible for the plant in Charía.

The plant in Charía started operating in 2004. Data is gathered for the period 2004 to 2008. From 2009 onwards the data is based on the following assumptions:

In 2008 there are 76 socios and 16 users (data given). The number of users increases by a factor 1.015 a year (expectation IHH). The maximum number of users is 120.

The tariff for socios and users is the same. The tariff in 2008 is 16 Bs for 25 kWh/month and 0.70 Bs for each additional kWh (given). The average monthly consumption in 2008 is 44 kWh (given) and it is assumed that everyone consumes the minimum amount of electricity. The consumption per user is assumed to grow with 1.5% a year (expectation IHH). The wage of the operator in 2008 is 350 Bs/month (given). It is assumed that the additional costs are 7,000 Bs/year. Furthermore, 1,000 US\$ has to be saved for future replacements (expectation IHH).

The inflation rate is assumed to be 5.80%, which is the average of the last 15 years (1993 to 2007) (IMF, 2009). However, because inflation is a very uncertain factor, it is allowed to vary on a yearly basis by 5%, so that it will be between 0.80 and 10.80%, with a mean of 5.80%. The exchange-rate of the Boliviano and the US Dollar is fixed to 7.25, which is the 2008 rate.

All money-values are corrected for inflation on a yearly basis. Because the interest rates vary each year, the net present value (NPV) and internal rate of return (IRR) are calculated 2,000 (in some cases 7,500) times, using a Monte Carlo simulation. Of these 2,000 (or 7,500) values the mean, the standard deviation and a 95% confidence-interval are calculated.

Table 10.2 shows the NPVs (for a fixed lending rate of 7%<sup>37</sup>) and IRRs for the years 20 and 30. Twenty to 30 year is normally considered to be the lifespan of a micro-hydro plant. The 95% confidence interval of the NPV for both years is negative for the given lending rate. It should be possible however to pay back a loan of 5.57% (the IRR) over 30 years. Commercial institutions will not provide such a loan, but maybe it is interesting for institutions like the IMF, UNDP or World Bank. However, one should not forget that a construction like that will encompass a lot of bureaucracy that is likely to increase costs. More details of the CBA are given in Appendix V.

**Table 10.2: Results of the CBA of the plant in Charía**

Plant	Year 20		Year 30	
NPV - Mean	-138,917.65	Bs	-58,030.25	Bs
	-19,153.13	US\$	-8,038.50	US\$
NPV - Standard Deviation	10,677.43	Bs	20,645.22	Bs
NPV - 95% conf. interval	-160,272.50	& -117,562.79	Bs	-99,593.70 & -17,012.81
				Bs
IRR - Mean	1.59%		5.59%	
IRR - Standard Deviation	0.62%		0.54%	
IRR - 95% conf. interval	0.34%	& 2.84%	4.51%	& 6.66%

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F      Micro-hydro plants cannot be financed with a commercial loan      Niche

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### 10.1.3 Economic Growth and Electricity Consumption

Villages in regions characterized by a lot of economic activity will probably attract a lot of families and will grow faster than villages in regions with less economic development. This results in more households that would like to connect to the hydro-grid. Often, this will result in a too small capacity of the plant, because the designers did not take into account the growth of the villages. This can be seen in the case-studies of Charía, Flor de Mayo and Yanamayo. Designers of micro-hydro schemes should include the economic development of a region in their forecast for the growth of the village and related, the (future) capacity needed.

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T      Limited possibilities to increase capacity of micro-hydro plants      Niche

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<sup>37</sup> This is chosen randomly. The prime lending rate in Bolivia over the last 15 years has been 36% and over the last five years 18% (NationMaster, 2009). The interest rate and the prime lending rate do not have a high correlation. The correlation statistic of both variables between 1987 (the year after a period of hyperinflation) and 2005 is 0.51, which is moderate.

## 10.2 Additional technological findings

### 10.2.1 Canal / penstock construction

More attention should be paid to the construction of the canal in case it is built on a steep mountain slope. In many cases, excessive rainfall in combination with logged vegetation will cause erosion of the mountain slope through which the canal can subside. This happened in Yanamayo and resulted in reconstruction works during three months, in which it was not possible to use the plant. In Pojo the canal had to be repaired several times due to landslide as well and the same will possibly occur in Quinuni. The first cracks were already visible above parts of the slope that had subsided.

This problem can quite simply be solved by planting trees alongside the canal (in case a tube is used, otherwise the vegetation will cause obstructions) or by using piles to prevent the canal slipping away.

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T	Erosion of mountain slopes destroy the canal and/or penstock	Niche
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## 10.3 Additional institutional findings

### 10.3.1 Organizational Continuity

It is very important for an organization managing a micro-hydro plant to assure that knowledge created and experiences gained remain in the organization. Many micro-hydro organizations in Bolivia use an organizational structure in which the users are also the owners and in which the board (except the operator) of the plant is elected every one or two years by the owners. This means that the persons filling the positions in the board of a plant change very often. The case studies have shown that in these cases often a lot of knowledge and information is lost. The administration of the plant is often not structured and parts are thrown away after a new board is chosen. Furthermore, the members of the new board are not introduced very well into their functions and have to learn the bits and pieces of the job themselves. The plant in Epizana is the only plant visited that engages several persons, including an administrator. This organization is a lot more structured and professional. A continuing process of successive learning cycles takes place because people occupy a function for a longer period of time and get the possibilities to innovate. All other organizations do not show many successive learning cycles, because the wheel has to be reinvented every one or two years again, and people cannot build on the knowledge that is already created.

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I	Discontinuous learning cycles through frequently changing management	Niche
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### 10.3.2 Staff Policy

Besides organizational continuity, it is also important that the right people are appointed for the right position. Members of the board of a plant must have the ambition to sustain the plant and to let it be successful. Operators must have at least some technical knowledge and must see the maintenance of the plant as (one of) their core business. The organizations of Chapisirca and Pojo show how it should not be done. In Chapisirca the function of operator is included in the mayoralty. Unfortunately, the mayor does not have any technical knowledge and maintenance is very poor. The mayor in Pojo was also the president, treasurer and secretary of the plant. The plant was not his core business and was not managed in a financially sustainable way. This maybe could have been avoided by a more devoted person. The major lesson learned: Choose the right person for the right position.

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I	Unsuitable people with responsibility	Niche
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### 10.3.3 Hampering legislation

In the 1980s and 1990s many liberal market reforms are enforced in Bolivia's electricity sector. One of those reforms included the implementation of tenders for the construction of micro-hydro plants and the division of the project cycle for projects carried out by private organizations. It is not possible for one organization to carry out the whole implementation process. The phases of design, implementation, capacity building and technical maintenance should be carried out by different parties. This is leading to many frustrations and delays in the micro-hydro sector. Energética for example is not allowed to both design and construct schemes. The government faces the same problem, because they have to call for tenders and cannot implement the projects themselves. Because the different phases of the project cycle are carried out through different actors, they do often not link up. The implementing

organization does not agree with the design and wants it to be changed. Maintenance engineers do not understand the system built, because e.g. they are not familiar with it, etc.

The only organization that is able to get around this legislation is IHH, because as being part of a university, they do not have to call for tenders and can carry out the whole project cycle themselves. This is one of the main reasons for their success.

## 10.4 Additional social, cultural, and behavioral findings

### 10.4.1 Observability as driving force behind diffusion

Everett Rogers already mentioned observability as one of the attributes an innovation needs to foster a widespread diffusion. Observability, especially the visibility of successful projects, is also very important for MHP projects. Communities in regions with a lot of proper functioning plants like La Asunta know about the opportunities of the technology and have the desire to build a system themselves. Charía asked IHH to build a system because Flor de Mayo, the village clearly visible on the opposite mountain slope, had a micro-hydro system. Quinuni asked an engineer to build a plant because all surrounding villages did also have one, and the villagers of Yanamayo constructed a pico-plant after the example of three nearby villages.

Examples of functioning plant do also strengthen the expectations of the technology. Quinuni and Chapisirca experienced more or less the same problem: An in-experienced engineer built a plant that never functioned. The inhabitants of Quinuni had a firm conviction that it is possible to build a proper plant because they had plenty of good examples. Therefore, they kept trying and did not give up. The villagers in Chapisirca on the other hand did not have examples and lacked the belief in the technology, so that they gave up and only continued after five years and serious convincing efforts of the provincial government and Energética to start again.

Furthermore, due to the absence of MHP in some regions, communities do not know about the opportunities of the technology. For many programs they have to apply themselves. However, if a lack of awareness exists the community will not apply and opportunities for new successful projects are lost.

I	Lack of visible successful examples	Niche
I	Lack of awareness of opportunities of technology	Niche

### 10.4.2 Behavioral change and electricity consumption

It is very hard to predict the amount of electricity that is going to be consumed. The starting position usually is the behavior of the community before the electricity system was introduced. Important parameters are the amount of kerosene, diesel and biomass used for the generation of electricity, heating purposes and cooking, the number of candles and batteries used, etc. Furthermore, external determinants are important, like television reception. However, several project show that the users consume far more electricity than expected. The capacity of the plant in Agua Blanca was too small within two years, because almost all users bought an electric shower (5,400 W). The same holds for the plant in Flor de Mayo. Some villagers bought a refrigerator with deepfreeze ( $\pm 1,000 - 1,500$  W) and five computers were purchased for the primary school. In Epizana, the users did not realize that the plant also has a limited capacity and that it is not possible to use an unlimited amount of electricity (see section 9.4.2).

## 10.5 Conclusions

The main aim of this chapter is to give an answer to the fourth sub question: *'What lessons can be learned from implemented projects?'*. It has been found improvements can be made in all categories. The most important findings are summarized:

It has been found that it is impossible for a local community to use a commercial loan for the construction of a relatively small plant (20 kW) with  $\pm 100$  users in a relatively rich area with an initial tariff of 0.70 Bs/kWh and an initial investment of 325,000 Bs. The analysis also shows that plants in poor areas with an average consumption of 20 kWh/month/person and a tariff of 0.50 Bs/kWh needs to have at least 150 users to be able to save enough money for big future replacements (1,000 US\$). Plants in richer areas need at least 70 users.

Another aspect that should be given more attention according to the author is the incorporation of the economic prospects of the region and possible behavioral change associated with climatological conditions into the forecast of the future electricity consumption, which determines the size of the plant. It is often seen now, that villages in economically growing areas attract many new inhabitants, so that the plant quickly becomes too small. Electricity consumption in cold areas will probably increase due to behavioral change. Users will most likely buy electric showers that use a lot of electricity.

Other aspects that are important for a successful functioning of a micro-hydro plant are a solid construction of the canal and penstock. Both have to withstand erosion. The existence of success stories and examples of proper functioning plants are very important for the confidence and belief in the technology, especially when problems occur. Lastly, it is very important for the local organizations to elect or engage people with the right capacities and to have a structure in which persons can exercise their jobs for a longer period of time, so that people have time to innovate.

# 11 Networking and barriers to dynamic niche processes

The principle idea of this study is that barriers cause problems that induce learning processes that change the initial situation so that the ground of the barrier and the barrier itself are removed. Through this process the niche-technology develops and a technological trajectory is shaped. Factors impeding this process are seen as intermediate barriers to the development of the niche. These barriers are discussed in this chapter. Seven phases<sup>38</sup> in the development of the niche were identified in section 2.3 and are shown again in figure 11.1 for the sake of clarity, together with a rearrangement of the most important actors of the network shown in figure 7.2, so that they fit into the original figure. The projects are not shown in a chronological order for the sake of clarity. The global niche is divided into two parts; the global niche and the regional niche. This is done because many actors in the Bolivian micro-hydro sector do not operate at a 'global' level, in the sense of 'worldwide', but only at a regional level. The distinction between regional and global provides more clarity about the role of the different actors. More about this in the methodological reflection (section 12.3).

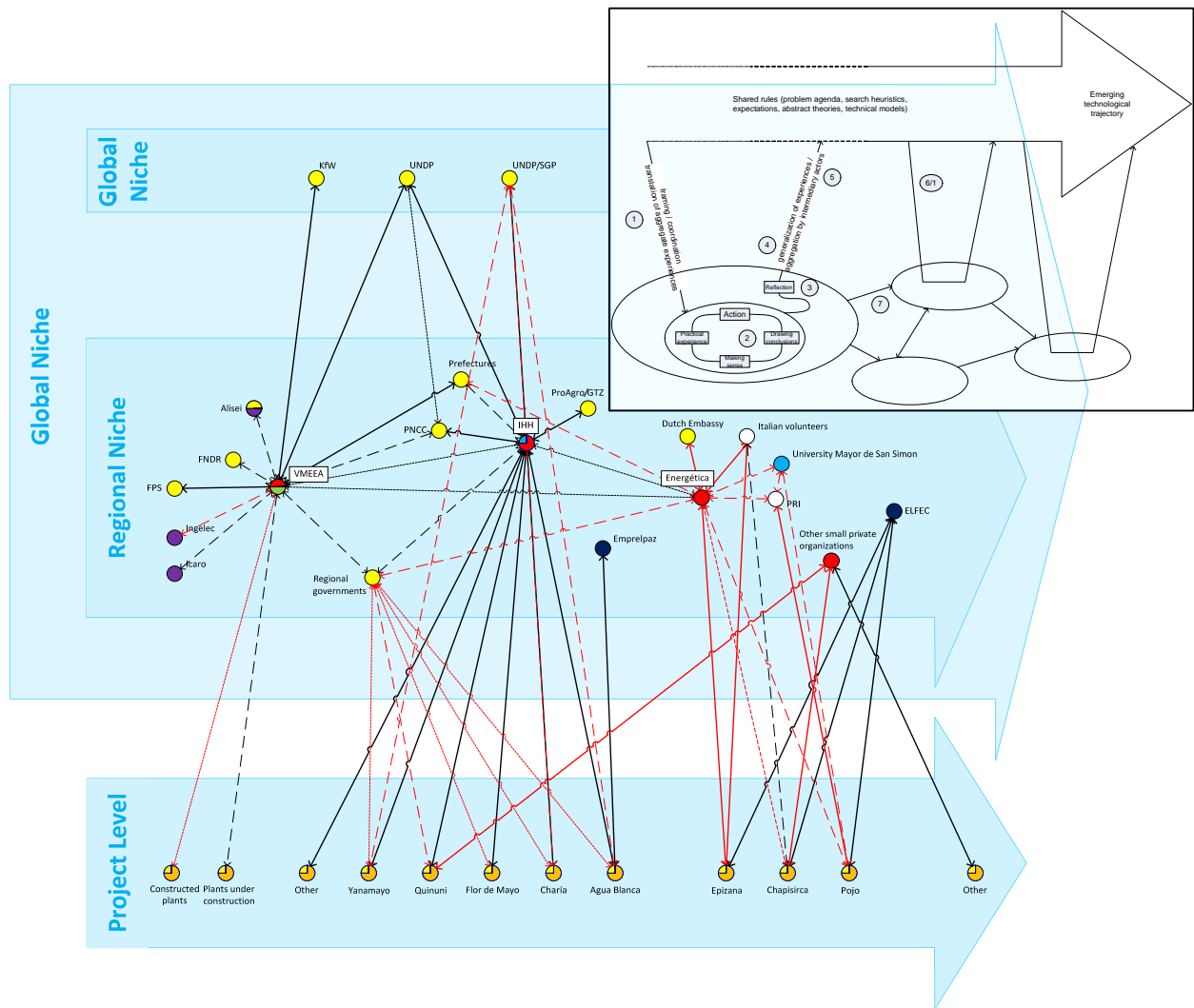


Figure 11.1: Emerging niche trajectory carried by local projects

<sup>38</sup> The seven phases are (1) framing and coordination activities, (2) learning selection, (3) evaluation, (4) generalization, (5) aggregation, (6) framing and coordination activities again and (7) inter-project learning.



The most remarkable in the figure above is the prevailing vertical orientation of the linkages between the actors. Strong longitudinal links do almost not exist. The implementing organizations act on their own and developed their own technological trajectory. Locally, lessons can only be shared via actors in the regional niche, which is very inefficient. The effect of this vertical orientation and the functioning of the seven stages will be discussed below, in order to provide an answer for the fourth sub-question '*What factors foster and impede learning processes?*'.

#### **11.1.1 (1,6) Framing and coordination activities**

The extent to which an implementing organization uses lessons learned aggregated in the regional niche depends largely on the organization itself. IHH is the best example of how lessons learned in the past can be used for the framing of a new project. Many experiences of previous projects are used to improve the next project, e.g. in case of the productive end-use facilities. This is however not the case for all actors. The VMEEA contracts out large parts of their projects. Projects are carried out by different actors. Lessons learned in one project of the VMEEA by a certain actor are not passed on to the next actor carrying out the following project, so that a discontinuous process is created.

Moreover, due to the lack of longitudinal linkages at the regional niche level, lessons learned are not shared with the other implementing organizations, so that each actor only uses its own lessons learned for framing and coordination activities.

#### **11.1.2 (2) Learning selection (learning within projects)**

As can be seen in chapter 7.5, the number of learning cycles differs greatly between projects. The organization in Epizana is the only one that shows several sequences of consecutive learning cycles. Some of the other case studies have two successive cycles as well, but never more than two. The plant in Epizana is the oldest of the selected projects, but this is not the main factor that fosters consecutive a learning process. Probably the most important factor is the organizational structure of the plant. All other case-studies do not have an organization with a complement of staff that lasts for more than two years. The majority of the projects is too small or the users too poor to generate sufficient income to engage a person for an administrative-function fulltime. Therefore, people are elected for one or two years, after which another person is elected. Information transfer is often very poor, so that the newly elected management has to start from the beginning again. The management in Epizana on the other hand has been engaged for a much longer time (five to twenty years) so that the conditions are created for consecutive learning. Organizational continuity is thus a very important factor to foster learning processes.

#### **11.1.3 (3,4,5) Evaluation, generalization and aggregation**

To what extent generalization and aggregation of lessons learned at the local project level to the regional or global niche occurs does mainly depend on the implementing organization. IHH has a wide and deep network of plants they constructed in the past. The relation between the organization and the local communities is very strong during the construction-phase, and continues to exist because IHH provides technical assistance after the completion of the projects. The communities have the possibility to call or come by and they make use of this service often, so that IHH is updated regularly about the condition of the plant and other existing problems. Moreover, evaluations are held three to four months after the completion of the projects in which difficulties are discussed and communities can bring up new ideas. Furthermore, engineers of IHH visit the villages regularly when they are in the region. Those conversations were often the beginning of new developments, like the introduction of productive end-use facilities, the change from single-phase to three-phase networks and the evolution of the self-assembly method. Those new developments are carried out in new projects, through which learning cycles are created spanning multiple projects.

However, this is not always the case. Energética has also been involved to a great extent in their projects (Chapisirca, Epizana and Pojo) and visited them regularly. However, since the decision was made to specialize in photovoltaic solar panel technology and to move away from MHP those contacts lessened and fade away slowly. This same is happening with projects of the VMEEA. Sometimes the project is visited after its completion to provide trainings. In other cases, this is contracted out and contact is lost. Those developments hinder the aggregation of learning processes, which cannot diffuse because the local communities do not have the means to communicate their findings and lessons learned to the regional niche themselves.

Aggregation to the regional or global niche is the first step, but it is not sufficient to create an emerging technological trajectory. Therefore, the lessons learned have to be aggregated to the whole regional or global niche through longitudinal network processes, in this case especially between the implementing organizations. This however does not take place. Figure 11.1 shows that the three big implementing organizations have only weak connections and the small private organizations operate completely independently. IHH avoids cooperation with the VMEEA as much as possible, because collaboration is seen as very ineffective and hindered by bureaucracy. The lack of networking in the regional niche is one of the main problems in the micro-hydro sector in Bolivia. Different organizations do not share their aggregated lessons. It can be said that not one niche-trajectory develops, but several, each implementing organization working on one. This can e.g. be illustrated by the installation of three-phase distribution networks. Energética used to implement them in the projects because they had already learned the importance for industrial development. IHH saw this many years later and had to discover it themselves, despite of the fact that the knowledge was already somewhere available.

#### **11.1.4 (7) Inter-project learning**

The same impediment for the spread of lessons learned that exists in the regional niche does also exist at the local project level: No longitudinal linkages exist between projects. Although some of the case studies are located very close to each other (the smallest distance is a twenty minutes' walk between Charía and Flor de Mayo) not one of them communicates with each other or with other micro-hydro plants. Though internal relations are very strong and a culture of collaboration exists within the communities, they are quite close to external parties and collaboration between different communities does not occur, apart from exceptions.

Avner Greif (1994) brought up an explanation of this phenomenon. Developing countries can be categorized as collectivist societies. People in collectivist societies learn to be dependent on the members of the same group. As a consequence, economic and social interactions in collectivist societies are restricted to small groups with strong inward ties. On the contrary, outward ties are very weak. Non-members of the group are seen as dangers to the equilibrium that has been formed in the group. So trust is created within communities but mistrust between them (Rapley, 2007). This has been illustrated in all case studies. The four plants in the La Asunta region do in general know what is going on in the nearby villages, and they know if problems exist with the electricity supply. The inhabitants of Flor de Mayo for example all could tell that the plant in Charía had to deal with power failures the previous winter (2007). They did not know what exactly was wrong and they did not take the initiative to help the Cooperative in Charía. The management of the plant in Charía on the other hand did not even consider asking assistance of villagers of Flor de Mayo.

Mutual rivalry did also come forward in the case studies of Epizana and Pojo. Energética asked the management of the plant in Epizana if they would like to assist the new board of the plant in Pojo by giving some courses. The organization in Pojo refused those courses because they did not want inhabitants of Epizana to interfere in their business. Both places are capital of a province, and it was impossible for the people in Pojo to accept assistance from the other capital. Both managements never contacted each other.

Those stories probably apply for many micro-hydro plants in Bolivia. Because mistrust between villages exists, no knowledge is exchanged directly and one cannot learn from each other's experiences.



## 12 Conclusions

In this final chapter, the research question will be answered and the methodology used will be discussed. Furthermore, recommendations will be given to promote a further diffusion of micro-hydro power in Bolivia and to improve upon the research framework used in this study for the purpose of further work on this subject.

### 12.1 Research Conclusions

The objectives set at the beginning of this study were: *'The identification and analysis of barriers to the diffusion of micro-hydro power for rural electrification in Bolivia'* and *'the investigation of how learning processes contribute to the removal of barriers to the diffusion of micro-hydro power for rural electrification in Bolivia'*. The research question that was deduced from these objectives was formulated as *'How do barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia, and how can learning help to overcome these barriers?'*. This question will be answered on the basis of the four sub questions.

#### 12.1.1 Barriers hindering the diffusion of micro-hydro power for rural electrification

The first sub question is: *'What barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia?'*. In this study it was found that especially institutional and technological barriers hinder the diffusion of micro-hydro power. Financial/economic barriers were found relatively often as well. Local projects as well as implementing organizations come across these proximate (directly related) barriers most often. The most important ones are summarized in this section. A list of all barriers identified is given in Appendix IV.

Competition with electricity from the central grid is a barrier for many micro-hydro schemes. The grid is in some cases technologically superior, but the tariff is usually higher. The introduction of the Tarifa Dignidad (25% reduction of the electricity bill for small users of the central grid) in 1996 changed the situation considerably however. Due to the subsidy many plants are not able to compete anymore against the grid. A strong bias towards the regime technology exists within the government. Moreover, actors operating in the regime do usually not want to cooperate with niche-actors.

The high initial investment necessary for a micro-hydro plant is another obstacle for widespread diffusion. Many organizations do not make use of local materials to reduce costs. But even the cheapest schemes cannot be built profitably with a commercial loan, so that communities are dependent on national or international funds. Money is available for at least 100 40 kW plants if they are built by the most efficient organization (IHH). The funds however are distributed unequally. It is very hard for the most skilled organization to find funds, while other organizations have money for the implementation of plants but do not have the technological capacity to make full use of it.

Financial knowledge often lacks in local organizations. The tariff is rarely being adjusted for inflation. The financial position of many plants is weak and several are not self-supporting. In the last case, local governments have to bear a part of the costs. This gives often rise to the dismantling of the plant and/or the expansion of the central grid.

Technological knowledge is locally often not available. Plants are dependent on organizations or companies in the big cities. It often costs a lot of time to get repairs done. No training facilities exist to increase the local capabilities. Technological knowledge acquired in the introduction course that is usually part of the implementation process often diminishes over time because it is not passed on properly to the next operator.

Many small implementing organizations do not have the technological capabilities to build a micro-hydro scheme. Some even lack the understanding of the basic principles. Promises made by these organizations can almost never be fulfilled. Often the plants will never be finished, or will be dismantled in a couple of years because of technological malfunctioning. Nothing is done to stop the activities of these organizations and no institution exists to guarantee the quality of the implementing organizations.

Lastly, no institution exists that coordinates and monitors the activities in the field. Knowledge of the demand for micro-hydro plants and information about the functioning of existing plants is scarce. The activities of implementing organizations are not attuned and many lessons have to be learned twice. Locally, communities do not know the

opportunities of the technology and are not aware of possibilities to install a plant. On the other hand, many implementing actors are not aware of the local demand. The government is not able to fill this gap.

### **12.1.2 Contribution of learning to overcoming these barriers**

The second sub question reads: *'How has learning contributed to overcoming these barriers?'*. The research framework used assumes that barriers should be overcome by means of learning. Locally, knowledge should be created in (sequences of) learning cycles by local organizations. Some evidence of learning was found in the projects investigated, but the extent of learning varied across projects and organizations. It was found that the number of (sequences of) learning cycles highly relates with the age of the plant. Old plants show a lot of learning cycles, while newer plants face considerably less cycles. Complete (sequences of) learning cycles are relatively rare however in the eight case studies investigated and does not correspond with the age of the plant. Only one plant (Epizana) shows multiple completed sequences of learning cycles. In this project, barriers are actually solved, and learning does contribute to the removal of barriers. Conversely, all incomplete cycles refer to still existing barriers. It is also shown that many financial/economic learning cycles are completed locally, while technological and market learning cycles are often unfinished. Local communities lack the technological capabilities to solve technological learning cycles. Market factors often cannot be solved because of their global or regime character. Local actors cannot influence these factors.

The extent to which learning takes place by the implementing organizations at the global niche varies per organization. IHH has gone through many technological and institutional (sequences of) learning cycles. Many barriers, especially technological and institutional barriers, have been removed in this process. The VMEEA on the other hand has not completed a single cycle. Barriers in their programs remain and the programs do not evolve. Energética showed some success, but quitted their micro-hydro activities several years ago due to institutional barriers mainly stemming from the regime and global niche that could not be removed.

To summarize, this study found evidence that learning does help to overcome barriers, for example in the case study of Epizana and within the program of IHH. However, many projects and organizations fail to develop their project or program through learning.

### **12.1.3 Factors fostering and impeding learning processes**

This leads us to the third sub question: *'What factors foster and impede learning processes?'*. Several factors have been identified as being (partial) causes of hampered learning. These can be seen as intermediate barriers to the diffusion of micro-hydro power in Bolivia. Barriers that do not directly cause a problem (like the proximate causes discussed in section 12.1.1), but that form the wider context of the proximate barriers. Moreover, several factors have also been found that foster learning processes. All these factors will be discussed in this section.

Within local projects, discontinuity in the local organization is the most important barrier to achieving and completing (sequences of) learning cycles. The board of the majority or the organizations is elected every one or two years. Each election goes hand in hand with a loss of information, because the knowledge that is needed to manage a plant often is only available in a tacit form and is not passed on well. The organization in which the most learning cycles take place, Epizana, is also the organization with the most experienced people whom moreover have a full time engagement. Learning should increase the local capabilities and knowledge over time. However, some organizations are not able to sustain the level of knowledge that is acquired during the initial training. The level of knowledge diminishes over time. The performance of these plants will decrease over time.

The lessons that are learned locally are not dispersed to plants in the vicinity. As in many collectivist cultures, Bolivian communities have very strong inward ties. However, mistrust exists between communities, so that information and knowledge is not shared. Because the lack of direct linkages between projects, intermediate actors play a very important role in the diffusion of knowledge. Implementing organizations are in the best position to gather, use, generalize and spread lessons learned. In Bolivia, IHH and the VMEEA are or should be the central actors in this process. Energética used to play the same role before they quit their micro-hydro activities. The quality of the process of aggregating, generalizing and using the lessons learned depends on the organization. IHH manages to adapt and improve its program with almost each new project. Strong continuous ties with the local communities are very important in this process. IHH is able to keep these ties because they provide technical assistance as long as the

project functions. Moreover, the institute is allowed to implement the whole project cycle, from design to implementation and further to maintenance. It is not legal for private organizations to do this, so that projects of other programs are carried out by a consortium of actors. Because none of the actors is involved in overlapping phases, the continuity is low and different parts do not fit. IHH's integrated approach results in a higher learning ratio and closer ties with the local community through which trust is created.

The VMEEA contracts out large parts of the implementation project and has therefore weaker linkages with the communities. Moreover, the involvement of the vice-ministry is always of a temporary nature. The VMEEA withdraws after the completion of the project. Contact with the community is lost, which hinders generalization and aggregation activities. One does not know how the projects function or how they can be improved. Moreover, different projects are carried out by different actors. Because knowledge created and experiences gained are not passed on, framing and coordination activities hamper. The small implementing organizations do not have any linkages with the other actors in the field and do not contribute to the generation of knowledge at all.

Besides that IHH receives a lot of input through the linkages with local projects, they also have the capacity to adapt and improve their projects. Input from generalization and aggregation activities is only useful when it is used for improvements. The case studies that were implemented by IHH show that the adaptability of the organization is enormous. The interviews conducted with the VMEEA did not give the same impression.

Lastly, the social network between the global niche-actors involved in the Bolivian micro-hydro sector is weak. Strong linkages between the central actors, the implementing organizations, do not exist, nor does a system to share and distribute knowledge. Because the lack of these ties, each implementing organization is building its own technological trajectory. The lack of cohesion in the actor field impedes the extent to which learning processes occur, and their quality.

#### **12.1.4 Additional lessons learned from implemented projects**

The last sub question reads '*What lessons can be learned from implemented projects?*'. Many more things can be concluded from the analysis carried out, that are not directly related to learning processes experienced by the actors themselves. The most important findings are summarized.

It has been found that it is impossible to profitably construct a small plant by using a loan. The analysis assumed a 20 kW plant with  $\pm 100$  users in a relatively rich area with an initial tariff of 0.70 Bs/kWh and an initial investment of 325,000 Bs. The combination of a variable inflation rate of 5.80% (+/- 5%) and a lending rate of 7% gives a net present value between -99,600 Bs and -17,000 Bs after 30 years (95% confidence interval). The interest rate of a commercial loan will be much higher than 7% however. The analysis also shows that plants in poor areas with an average consumption of 20 kWh/month/person and a tariff of 0.50 Bs/kWh needs at least 150 users to be able to save enough money for big future replacements (1,000 US\$). Plants in richer areas with an average consumption of 30 kWh/month and a tariff of 0.70 Bs/kWh need at least 70 users.

Other aspects that should be given more attention according to the author are the incorporation of the economic prospects of the region and possible behavioral change associated with climatological conditions into the forecast of the future electricity consumption, which determine the size of the plant. It is often seen now, that villages in economically growing areas attract new inhabitants, so that the plant quickly becomes too small. Moreover, the consumption per capita will increase in these areas, accelerating the capacity problem. Behavioral change will probably occur in cold areas. Users will most likely buy electric showers that use a lot of electricity. This results in an enormous peak load in the early morning hours and can lead to capacity problems as well.

Other aspects that are important for a successful functioning of a micro-hydro plant are a solid construction of the canal and penstock. Both have to withstand erosion. Regular maintenance will increase the lifespan of a plant considerably. Also, the existence of success stories and examples of proper functioning plants are very important for the confidence and belief in the technology, especially when problems occur. Lastly, it is very important for the local organizations to elect or engage people with the right capacities and to have a structure in which persons can exercise their jobs for a longer period of time, so that people have time to innovate.

### 12.1.5 Conclusions

To conclude: *'How do barriers hinder the diffusion of micro-hydro power for rural electrification in Bolivia and how can learning help to overcome these barriers?'* Technological and institutional barriers hinder the diffusion of micro-hydro power for rural electrification most, before financial/economic barriers, social, cultural and behavioral barriers and market barriers. Because of these barriers, plants function poorly. Learning can help to overcome these barriers (see e.g. Epizana and IHH), but learning processes are hindered by intermediate factors. The main intermediate factors are the lack of continuity within local organizations and during the implementation process, as well as the lack of local technological capabilities to initiate and sustain learning, and the weak social network that impedes the diffusion of knowledge between projects, between projects and the global niche, and between actors in the global niche.

## 12.2 Policy recommendations

One of the most important intermediate factors underlying the barriers discussed is the weak social network and the lack of knowledge flows in the micro-hydro power niche. A better dissemination of knowledge and lessons learned will strengthen the micro-hydro niche considerably and will improve the quality of micro-hydro projects. Ideally, the solution would be in the direction of the establishment of a national platform for knowledge sharing and collaboration. This could be initiated by the government, and include organizations specialized in agriculture and the establishment of productive end-use facilities as well. This is in an ideal situation though. The previous years have shown that this will be very hard to achieve. Actors have different views on strategies for the implementation of projects and are hesitant about changing these. A more realistic first step should be to bring together the main actors (implementing organizations, financing institutions, government) in order to create some trust and later on to carefully sketch the outlines of a widely supported plan or program. In order to do this, a more or less neutral actor that has not been involved deeply in programs in the past, should take the initiative. Otherwise, an international organization can possibly act as an intermediary. In the end, an initiative like this should result in an all embracing program like the Programa Nacional de Micro Centrales Hidráulicas in 1996. This new program should put more emphasis on the incorporation of all existing actors and on the dissemination of knowledge in comparison with the old program.

Otherwise, it should be worthwhile for Bolivian implementing organizations to start international collaborations for knowledge sharing. A lot of knowledge and experience is available in Peru, where hundreds of micro-hydro plants have been installed.

On a local level, it is easier to conclude concrete recommendations. Local organizations should be stimulated to make tacit knowledge more explicit, by administering financial matters more thoroughly, create minutes of meetings and make small annual reports. Many organizations will keep using a structure in which the board changes every one or two years. Knowledge transfer will be easier when things are made explicit. Moreover, there should be an overlap in functions when people are replaced by others, for some time. This will facilitate the new board considerably. Besides this, organizations should get the possibility to receive a technical or organizational/financial training if the operator or board changes.

To foster the exchange of lessons learned between projects, a regional solution has to be sought. The case studies show that communities do not want to exchange knowledge and experiences directly with other communities, but that they are willing to do this with an external organization they trust. This creates opportunities to establish a regional platform for knowledge and experience sharing in areas with a number of plants, managed by an intermediary. A structure like this can be strengthened if this person or organization is a micro-hydro engineer who can solve technical problems. This can simplify the creation of trust.

To foster generalization and aggregation activities, evaluations of projects should be conducted frequently. It is recommended that an institution evaluates plants after a couple of years. IHH is already carrying out evaluations after three or four months. It is recommended to expand this evaluation program. It would improve the diffusion of knowledge in the global niche if these evaluations are made public.

### 12.3 Methodological Reflection

In this study, a framework is used in which Strategic Niche Management (SNM), Douthwaite's learning selection and Korten's learning approach are integrated in order to analyze learning processes that should foster the development and diffusion of micro-hydro power systems in Bolivia. This framework is incorporated in a multi-level perspective (MLP) that provides a broader contextualized view of the setting in which the technological trajectory has to develop and of the factors influencing this process.

This approach is an innovation. It is the first time that a combination of these three learning frameworks has been used to analyze the dissemination of a technology in a developing country. As elaborately discussed in this study, innovations need adjustments and readjustments before a certain level of maturity is reached. The implementers will experience barriers, and will have to evaluate the origin of these barriers before conclusions can be drawn for the improvements, which should lead to action. In this final section, the perspective of Douthwaite's cumulative learning cycles is applied to the methodological framework used in this study as a tool by the author to reflect on the research process and framework:

First of all, the MLP has been found a very useful concept to analyze the niche processes. The socio-technical landscape provides valuable insights into the reasons underlying changes in the regime, but also in the niche. This last aspect is according to the author not sufficiently incorporated in MLP literature. It has been found that the landscape directly influences niche developments as well as regime developments, while in literature emphasis is put on landscape factors influencing the regime, and regime factors influencing the niche. The analysis of the socio-technical regime has been found to be inevitable. In the author's opinion, it is impossible to analyze niche developments and formulate recommendations without having a notion of the regime. Regime-actors will influence niche developments, and/or will participate in the niche. Furthermore, the historical regime-developments give insight into current processes and help to understand the sector and its dynamics over time.

Secondly, SNM is claimed to be a management tool that should serve to manage, guide and direct the development of a technology and its diffusion. A general complain about the method is that it is until recently only used as a descriptive tool to analyze innovation processes in the past in a qualitative manner. This also holds for this study. It has been used to describe which barriers exist and what factors foster or impede learning processes in the (recent) past. SNM is not yet a tool to direct and stimulate those learning processes. But still it has been found a useful method for the understanding of key processes for the diffusion of a technology. This understanding can be transformed quite easily into recommendations.

The lack of quantitative analysis in SNM is seen by the author as a more important flaw. Maybe one has been too rigorous in the transformation from the somewhat more quantitatively orientated Systems of Innovations approach to the more dynamic Socio-Technical Systems approach. One should not be reserved with quantitative analyses because of the static aura that surrounds it. Figures can describe dynamics as well. The incorporation of quantitative examinations, for example Social Network Analysis (SNA), Cost-Benefit Analysis (CBA) or comparative statistical studies between varieties of the technology of different organizations can be valuable to underpin SNM. CBA and a comparative statistical study have been carried out in this study, but as an ad hoc solution. Future studies should incorporate these aspects in advance.

Furthermore, SNM has been used here to study a mature technology, while it originally has been developed for radical innovations. This has not been considered as a hindering factor. Financially and institutionally, many lessons still have to be learned yet and the level of performance of micro-hydro plants can still improve considerably. So it has been found that SNM can be used to study the implementation and diffusion of mature technologies of which the shape of the implementation process, as well as institutional and organizational issues have not been crystallized out yet. This situation will probably occur frequently in developing countries, when a developed technology has to be adapted to fit the specific local circumstances.

Fourthly, SNM originally has been developed to study and model the development of innovations in high-income countries. It has been used as a method to study the development and diffusion of new technologies in developing countries before by several authors, mainly in master theses. This study is the first of its kind that uses the concept of



the global niche and the local project level in the context of a developing country. This concept focuses on the consequences of the performance of individual projects for the emergence of a technological trajectory, while SNM-scholars previously focused on success and failure in individual projects. The precise definition of a global niche is still vague though. SNM scholars refer to the global niche as an emerging field or community, with global, abstract and generic knowledge (Geels & Deuten, 2006; Geels & Raven, 2006; Raven, et al., 2007). Geels (2007) refers to Law and Callon (1992) who used the concept of local and global networks. According to them, 'global networks consist of actors at some distance to local projects, but provide resources (finance, political support, technical specifications) (...). The global network refers to sponsors and a community level.' (Geels, 2007, p. 639). Upon inquiry with Rob Raven, an SNM-scholar, it appeared that the global niche refers to actors at some distance, but also to actors at a worldwide level, like research institutions. The lack of this distinction has been found to be confusing for the use of the concept in developing countries. Differences between high-income countries are fading and the western world becomes more interconnected, so that it can be imagined that differences between a regional or national level and a worldwide level become smaller. This does not hold for developing countries though. Many actors in the Bolivia micro-hydro sector do not have access to the worldwide niche. This can also be stated the other way around. Many lessons learned in local Bolivian projects will never find their way to the worldwide niche. Therefore, the introduction of an additional level between the global niche and the local project level is proposed. This should encompass a regional or national niche. This distinction has already been visualized in figure 11.1, page 77. Making use of three levels will reduce confusions and will provide a better understanding of the actual network processes in developing countries.

Furthermore, the concept used put a lot of emphasis on learning cycles at the local project level, but ignores the learning cycles that should occur within organizations at the global niche. In this study, this is expressed in chapter 9, where learning cycles by Bolivian implementing organizations have been described. Another point of interest is the assumption in the model that once lessons learned at the local project level are generalized and aggregated, these contribute to the whole emerging field. In order to achieve this however, a solid social network is needed. This is of course emphasized in SNM as one of the three internal niche processes, but not specifically in the concept of the global niche and the local project level.

But besides the theoretical adjustments discussed above, one should wonder whether a concept specifically designed to describe and analyze processes in western countries should be used in developing countries at all. As described before, western high-income countries in general have individualist cultural beliefs, while developing countries in general can be categorized as collectivist societies. People in collectivist societies learn to be dependent on the members of the same group. As a consequence, economic and social interactions in collectivist societies are restricted to small groups with strong inward ties. On the contrary, outward ties are very weak. Non-members of the group are seen as dangerous to the equilibrium that has been formed. (Greif, 1994) So trust is created within communities but mistrust exists between them (Rapley, 2007). This can explain the lack of ties between local micro-hydro power projects in Bolivia. Knowledge can only be exchanged indirectly, via actors in the global niche. According to SNM, it has to be generalized and aggregated first, before it can be used for framing and coordination activities. The specific context and details will be removed, although those can be very valuable for projects in the same geographical region with a more or less similar culture. The impossibility of direct linkages between projects in collectivist cultures cause the model not to fit. If one uses SNM to analyze transition processes in developing countries, cultural structures should be incorporated explicitly and thoroughly, in order to create a better understanding of the local specific circumstances.

Lastly, the implementation of Douthwaite's and Korten's theory have been found very useful and clarifying. Douthwaite's learning cycle concept provides insight in the processes that users of a technology are going through and that eventually lead to an intervention and an adaptation of the technology or a change in the way of use. In this study however, it has been found that it is very hard to precisely reconstruct this process of four steps. The final result of the adaptation is what matters to the users, not the process underlying this change. In general, this process will be forgotten after a couple of weeks, months or years. On the other hand, it is not absolutely necessary to do this if one is not investigating the adaptation process itself. In this study, the outcome of the learning cycles has been of greater importance than the precise description of the process itself. The process is useful though to get a general insight in the process of change, so that the researcher get a better idea of the motives behind the adaptation.

Korten's emphasis on institutional change has been a valuable addition to Douthwaite's technological learning. It places the technology in a broader perspective, so that it fits the SNM approach better. The three stages of the learning process defined by Korten have been valuable as well. They partially explain the difference between the success and failure. However, these stages should be incorporated more in future research.



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## Case studies

### Epizana

Energética (1994)

Energética (1996)

Instituto Nacional de Estadística (2009). Censo de Población y Vivienda 2001. Consulted on February 02, 2009, <http://www.ine.gov.bo/geoclip/launchmap.php>

Interview President Cooperative San Francisco (12-09-2008)

Interview Manager Cooperative San Francisco (11-09-2008)

Interview Operator Cooperative San Francisco (18-08-2008)

Interview Miguel Fernández F., director of Energética (05-08-2008)

Koper, M. (2005) Decentral, Renewable Energy Systems in Rural Bolivia. 'Evaluation of case studies and a framework for effective project design'. Thesis Master of Science, Eindhoven: Eindhoven University of Technology.

Kublank (1992)

### **Chapisirca**

Interview Mayor Chapisirca / Operator Cooperative (03-10-2008)

Interview President Cooperative (03-10-2008)

Fernández F., M. (1997) Optimización en Epizana, Errores y Reconstrucción en Chapisirca. Cochabamba: Energética.

### **Pojo**

Interview Administrator of the Municipalidad Pojo (19-09-2008)

Interview with person in charge of electricity matters of Municipalidad Pojo (19-09-2008)

Interview Miguel Fernandez F., director of Energética (07-11-2008)

### **Flor de Mayo**

Conversations with population (10-10-2008)

InformeFinal Microcentral Hidroeléctrica Flor de Mayo, August 2001, IHH, La Paz

Interview President Association (12-10-2008)

Interview Treasurer Association (12-10-2008)

Website UNDP/SGP: [http://sgp.undp.org/web/projects/3630/microcentral\\_hidroelectrica\\_comunidad\\_flor\\_de\\_mayo.html](http://sgp.undp.org/web/projects/3630/microcentral_hidroelectrica_comunidad_flor_de_mayo.html) (09-02-2009)

### **Charía**

InformeFinal Charía, October 2004, IHH, La Paz

Interview President Microempresa (10-10-2008)

Interview Treasurer) Microempresa (10-10-2008)

Presentación Microcentral Hidroeléctrica y Planta Deshidratadora de Platano y Procesadora de Café Charía, July 2004, IHH, La Paz

### **Agua Blanca**

InformeFinal Agua Blanca, August 2005, IHH, La Paz

Interview President Association (31-10-2008)

### **Yanamayo**

InformeFinal Yanamayo, October 2007, IHH, La Paz

Interview President Association (14-10-2008)

### **Quinuni**

Interview Mayor Quinuni (13-10-2008)

Interview José Luis Monroy (IHH) and Dirigente Quinuni (06-10-2008)



# Appendices



## Appendix I Micro-hydro power projects in Bolivia

### Programa Hidroenergético (IHH)

Table I.1: Projects Programa Hidroenergético (incomplete list). Projects in bold are used as case-study.

#	Project	Department	Province	Constr. Started	Constr. Finished	Investment	Flow (l/s)	Head (m)	Power (kW)	Beneficiaries (#)	Main Financier	State
1	San Pedro Condo	Oruro	Avaroa		1986		125	60	40	100	Emb. Francia	N.O.
2	Poroma				1988							
3	9 de Abril		Sud Yungas		1991							
4	Keuiña Pampa	Cochabamba	Carrasco		1992							
5	Pocomayo	La Paz	Muñecas		1992							
6	Pongo I	La Paz	Murillo		1994		28	50	12	20	FCIL Canada	O
7	Pongo II	La Paz	Murillo				14	60	7		JICA	O
8	Pongo III	La Paz	Murillo		1995		12	85	8		Emp. Dueri	O
9	Choro	La Paz	Caranavi		1996		50	50	24	70	FCIL Canada	O
10	Unduavi	La Paz	Nor Yungas		1998		180	13	15	62	FCIL Canada	N.O.
11	San Pedro	La Paz	Caranavi		1998		120	25	25	60	PPD/PNUD	O
12	Pelechuco	La Paz	Saavedra		1998							
13	Tumupasa	La Paz	Iturrealde		1998							
14	La Cascada	La Paz	Sud Yungas		1999							
15	Santa Rosa de Quilo Quilo	La Paz	Nor Yungas		1999							
16	Chojña	La Paz	Caranavi		1999							
17	18 de Mayo	La Paz	Caranavi		1999							
18	Quehuiña Pampa	Cochabamba	Carrasco				180	45	43	85	Emb. Holanda	O
19	Leque	Cochabamba	Tapacarí				120	8	5	44	FCIL Canada	O
<b>20</b>	<b>Flor de Mayo</b>	<b>La Paz</b>	<b>Sur Yungas</b>	<b>2000</b>	<b>2001</b>		<b>65</b>	<b>25</b>	<b>13</b>	<b>48</b>	<b>PPD/PNUD</b>	<b>O</b>
21	Covendo	La Paz	Sur Yungas		2002		240	14	20	120	FCIL Canada	O
22	Taipiplaya	La Paz	Caranavi				120	25	25	67	PPD/PNUD	O
23	Camata	La Paz	Muñecas	2003	2004	343,041 Bs	30	170	27	110	PPD/PNUD	O
<b>24</b>	<b>Charía</b>	<b>La Paz</b>	<b>Sur Yungas</b>	<b>2003</b>	<b>2004</b>	<b>392,423 Bs</b>	<b>58</b>	<b>54</b>	<b>20</b>	<b>120</b>	<b>PPD/PNUD</b>	<b>O</b>
25	*Asunta	La Paz	Sur Yungas				800	40	160		Fonadal	O
26	†Irupampa	Chuquisaca	Zudanés						18	50		O
27	†Korimayu	Cochabamba	Tacopaya						8	25		O
28	†San Julian	Cochabamba	Chapare						5	18		O
29	Angostura	La Paz	Inquisivi		2004							
30	Agua Blanca	La Paz	Franz Tamayo	2004	2005	342,400 Bs	30	185	30	88	PPD/PNUD	O

31	Poroma	La Paz	Larecaja	2005	2006	499,038 Bs	150	50	40	80	PPD/PNUD	O
<b>32</b>	<b>Yanamayu</b>	<b>La Paz</b>	<b>Sur Yungas</b>	<b>2006</b>	<b>2007</b>	<b>292,343 Bs</b>	<b>350</b>	<b>22</b>	<b>32</b>	<b>110</b>	<b>PPD/PNUD</b>	<b>O</b>
33	San José	Tarija	Padcaya	2006	2007	50,000 US\$	200	18	18	70	PNCC	
34	Munaypata	La Paz	Inquisivi	2006	2007		180	18	18	70	GTZ Proagro	O
35	Nogalani	La Paz	Sur Yungas				100	50	26	85	PPD/PNUD	U.C.
36	Palmeras	La Paz	Sur Yungas	2008	2009 <sup>‡</sup>		150	35	28	82	PNCC	U.C.
<b>37</b>	<b>Quinuni</b>	<b>La Paz</b>	<b>Sur Yungas</b>	<b>2008</b>	<b>2009<sup>‡</sup></b>		<b>180</b>	<b>28</b>	<b>30</b>	<b>110</b>	<b>PNCC</b>	<b>U.C.</b>

\*Reconstruction of plant

O: In Operation

<sup>†</sup> Equipment provided

N.O.: Not in Operation

<sup>‡</sup> Expected

U.C.: Under Construction

## Programa de Electrificación Rural con Energías Renovables (VMEEA)

Table I.2: Projects Programa de Electrificación Rural con Energías Renovables. Projects in bold are used as case-study

#	Project	Department	Province	Constr. Started	Constr. Finished	Investment (US\$)	Flow (l/s)	Head (m)	Power (kW)	Beneficiaries (#)	Main Financier	State
1	San Jose de Llojeta	La Paz	Sud Yungas	2003	2004	242,187			100	355	GEF / UNDP	O
2	San Juan de Coripata	La Paz	Nor Yungas	2004	2005	199,214			100	160	GEF / UNDP	O
3	Challa Jahuira	La Paz	Sud Yungas	2003	2003	93,351			95	80	GEF / UNDP	O
4	Santiago Siete Lomas	La Paz	Nor Yungas	2005	??	64,343			30	60	GEF / UNDP	U.C.
5	Inca Pucara	La Paz	Nor Yungas	2008	2008	45,540			15	80	GEF / UNDP	O
6	Palmeras*	La Paz	Sur Yungas	2008	2009 <sup>‡</sup>		150	35	28	82	PNCC & UNDP	U.C.
<b>7</b>	<b>Quinuni*</b>	<b>La Paz</b>	<b>Sur Yungas</b>	<b>2008</b>	<b>2009<sup>‡</sup></b>		<b>180</b>	<b>28</b>	<b>30</b>	<b>110</b>	<b>PNCC &amp; UNDP</b>	<b>U.C.</b>

\*These projects are carried out by IHH, but also mentioned by the VMEEA as part of the program.

<sup>‡</sup> Expected

O: In Operation

U.C.: Under Construction

## Projects VMEEA & KfW

Table I.3: Projects VMEEA & KfW

#	Project	Department	Province	Constr. Started	Constr. Finished	Investment (US\$)	Flow (l/s)	Head (m)	Power (kW)	Beneficiaries (#)	Main Financier	State
1	Pucara	Santa Cruz	Pucara	2007	Dec 2008 <sup>‡</sup>	421,550 <sup>‡</sup>			100	313	KfW	U.C.
2	Mallku Villamar	Potosí	Colcha "K"	2008	Dec 2008 <sup>‡</sup>	134,450 <sup>‡</sup>			28.8	85	KfW	U.C.
3	Totorapampa I	La Paz	Inquisivi			1,235,289 <sup>‡</sup>			350	942	KfW	A
4	Kanamarca	La Paz	Inquisivi			146,056 <sup>‡</sup>			28	70	KfW	A
5	Sta. Rosa de Challana	La Paz	Guanay			139,592 <sup>‡</sup>			31	50	KfW	A
6	Cieneguillas	La Paz	Irupana			93,388 <sup>‡</sup>			15	30	KfW	A
7	San Miguel del Bala	La Paz	S. Buenaventura			104,618 <sup>‡</sup>			15	50	KfW	D
8	San Jose de Uchupiamonas	La Paz	S. Buenaventura			195,835 <sup>‡</sup>			21.7	100	KfW	D

<sup>‡</sup> Expected

U.C.: Under Construction

A: Approval

D: Design

## Projects Energética

Table I.4: Projects Energética. Projects in bold are used as case-study

#	Project	Department	Province	Constr. Started	Constr. Finished	Investment (US\$)	Flow (l/s)	Head (m)	Power (kW)	Beneficiaries (#)	Main Financier	State
1	Tables Monte	Cochabamba	Chapare									N.B.
2	<b>Chapisirca</b>	<b>Cochabamba</b>	<b>Tiquipaya</b>	<b>1994</b>	<b>1996</b>	<b>116,320</b>	<b>200</b>	<b>43.9</b>	<b>40</b>	<b>55</b>	<b>Dutch Embassy</b>	<b>O</b>
3	Independencia	Cochabamba										N.B.
4	<b>Epizana</b>	<b>Cochabamba</b>	<b>Carrasco</b>	<b>1994</b>	<b>1996</b>	<b>393,250</b>	<b>100</b>	<b>150</b>	<b>105</b>	<b>280</b>	<b>INER/COFER</b>	<b>O</b>
5	Postrervalle											N.B.
6	<b>Pojo</b>	<b>Cochabamba</b>	<b>Carrasco</b>	<b>1999</b>	<b>2001</b>	<b>254,285</b>	<b>250</b>	<b>50.2</b>	<b>100</b>	<b>200</b>	<b>Dutch Embassy</b>	<b>N.O</b>

O: In Operation

N.B.: Not Built

N.O.: Not in Operation



**Thirteen projects being part of the 1984 (125 projects) list that have been carried out**

#	Project	Department	Investment (US\$)	Power (kW)	Beneficiaries (#)
1	La Cascada	La Paz	95,000	40	120
2	La Asunta	La Paz	385,000	150	200
3	San Isidro	La Paz	87,600	40	67
4	San José de Llojeta	La Paz	242,187	100	355
5	Challa	La Paz	78,400	40	60
6	Santa Rosa de Quilo Quilo	La Paz	85,000	40	72
7	Chojña	La Paz	50,000	16	63
8	Colonia 18 de Mayo	La Paz	40,000	18	50
9	Todos Santos	Oruro	420,000	300	450
10	Camata	La Paz	140,000	75	200
11	Tumupasa	La Paz	90,000	40	180
<b>12</b>	<b>Epizana</b>	<b>Cochabamba</b>	<b>393,000</b>	<b>105</b>	<b>330</b>
<b>13</b>	<b>Chapisirca</b>	<b>Cochabamba</b>	<b>131,791</b>	<b>45</b>	<b>103</b>

## **Appendix II Case studies**

In this section, the eight case studies are described in detail. Each case study can be read separately. But if one is not completely acquainted with the Bolivian micro-hydro sector, it is recommended to read chapter 7 'The micro-hydro power niche' first.





## Epizana

17°39'04.75"S, 65°10'47.10"W

<b>Capacity:</b>	<b>105 kW</b>
<b>Costs:</b>	<b>393,250.- US\$</b>
<b>Users:</b>	<b>280</b>
<b>Turbine:</b>	<b>Michell Banki</b>
<b>Start Date:</b>	<b>1990</b>
<b>Organization:</b>	<b>Energética</b>

## Background

Epizana is a small village (127 households) at an elevation of 3,126 meter in the sección Totorá. Because of the main road from Cochabamba to Santa Cruz is crossing Epizana and another road to Sucre splits off, the village is visited frequently and there are some restaurants and hotels, a medical post and a truck repair company.

The micro-hydro plant in Epizana also serves Totorá, the capital of the sección, 14 kilometer southwards, and two very small communities in between, Koluyo and Moyapampa. Totorá is an old colonial village, visited quite regularly by tourists. Approximately 700 families live here. The village is the administrative capital of the region, and serves as its educational centre. There is also a hospital.

## Project Description

### Implementation

Between 1987 and 1990, a new micro-hydro power plant was built in Epizana, replacing a 40 year old 20 kW plant. Although the period of construction seems to be quite long (three years) it was actually very short for that time. In the 1990s, it took often four to five years. Although the local population was not involved that much in the construction, it was possible to work with a large workforce thanks to the visit of an Italian group of volunteers.

### Expectations

Expectations were high among the villagers in Epizana and Totorá. The new plant would have a capacity large enough to supply many more people with electricity than was possible in the past.

### Technology

The plant uses a 105 kW Michell Banki turbine and a three-phase generator. Frequency and voltage are controlled by regulating the water inflow. Net head of the plant is 150 m and the maximum flow-rate is 100 l/s. A small artificial lake stores the water temporarily. The canal has a length of 700 m. The three-phase transmission lines have a length of 14 km. The low-voltage distribution network consists of three-phases as well.

Some technical problems have taken and are still taking place. There is a shortage of water in the dry months

September, October and November. Not because of a too small flow rate of the river, but because farmers use the water in the small artificial lake to irrigate their potato fields. This is leading to conflicts regularly.

Power failures occur frequently, especially when it rains or when there is a lot of wind. In case of the latter, the three phases can come into touch with each other, causing a short-circuit. Furthermore, heavy loaded transformers connected to the mills and the hospital, are sometimes overloaded, causing power failures as well.

Furthermore, a transformer in one of the small villages between Epizana and Totorá broke down. It was not possible to replace it, considering the high costs (3,000 US\$) and the small number of users in the village (five). The users have moved to ELFEC (later more).

### Organization

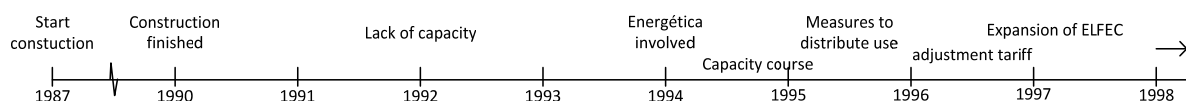
The plant is managed by the Cooperativa de Servicios Eléctricos San Francisco, Ltda, a company that is established by the users of the plant. Four people are working for the enterprise; the general manager (working already five years for the Cooperative), the secretary, the operator (15 years) and the plant assistant, who is doing all kinds of jobs. In 1996, Energética proposed an organizational reform, adding an employee responsible for the distribution network. This job used to be employed, but was vacant at the time. However, the direction of the plant did not see the necessity of an additional person.

The direction consists of a president and a vice-president. Both are elected by the users for a two years' period. The users are shareholder of the Cooperative.

### Intervention of Energética

The first two years, the plant operated without any problems. After two years however, the first problems arose. The capacity of the plant turned out not to be sufficient to cover the demand. In 1992 a study showed that the average maximum demand per hour (between 20.00 and 21.00h) was 84 kW, while the actual maximum output was somewhat lower than 100 kW. Yearly 234 MWh was consumed, far above the estimated 150 MWh. 300 users were connected, another 100 would like to be connected, but could not because of the lack of capacity. Due to the high load of the turbine, power failures occurred regularly.

In first instance the solution for the shortage of power was sought is expanding the plant, but the river flow did not allow distracting more water. The second solution



proposed was to replace light bulbs by fluorescent tubes and thus save energy. Energética was asked to examine this option.

In 1994 (till 1996) Energética started a project aimed to reduce and spread the electricity consumption. A second aim was to generate knowledge about micro-hydro plants. The NGO wanted to generate knowledge about operation and maintenance and organizational aspects of micro-hydro plants, in order to use it for future plants in Pojo, Kewiñapampa, Tables Monte and Independencia. Energética studied the energy use of consumers. 46% of the lamps used were light bulbs, 44% fluorescents, and 8% halogen (1% not known). Replacing the light bulbs would save 30 kW during peak hours. However, at some places in the grid, fluorescents were not an option, because the voltage was too low (185 V). This was caused by an unbalanced distribution of the demand over the three phases. This could be solved by adjusting the transformers. A simulation showed that additional fluorescents would not influence the inductive power in the net too much, so that capacitor banks would not be necessary. Another factor that was causing losses were distribution lines without function. These lines were removed. Furthermore, the canal was repaired. Water was leaking at several places, leading to a reduced maximum output of the plant. This was solved quite easily.

Moreover, Energética started a campaign to reduce and distribute the use of electricity. This campaign comprehended a leaflet distributed among the households, posters encouraging to reduce energy consumption and a short video with instructions.

Energética's package of measures turned out to be very effective. The demand during peak hours dropped from 84 kW to 40 kW. The behavioral change did not turn out to be sustainable though. In 2008, it had increased again to 70 kW, although the plant had less users.

The employees of the Cooperative received a training to increase technical and administrative capabilities. Lastly, a study was started to investigate other additional sources of electricity. However, the other measures turned out to be such a success that this was not necessary anymore.

### Expansion of- and competition with ELFEC

In 1997, the national grid was extended to Epizana and Totorá. The Cooperative considered selling electricity to the central grid, but the electricity company (ELFEC) was not interested. The second thought was to sell the plant and use the money for the development of the region. However, after the introduction of the grid, it turned out that the Cooperative could financially compete with the ELFEC quite easily. The tariff of the grid was 0.90 Bs/kWh, 0.40 Bs above the tariff of the Cooperative. The minimum charged amount of power of the Cooperative (25 kWh/month) was higher than the minimum charge of ELFEC (12 kWh/month), so that people using more

than 14 kWh/month were financially better off with the Cooperative. Most people used around 20 kWh/month. Despite the lower tariff of the Cooperative, many people moved to ELFEC, because they thought that the grid would have less power failures. After some months however the majority had returned because ELFEC turned out to be much more expensive and power failures occurred regularly as well. In the end, only 40 users left the Cooperative, several were using both.

The tariffs of the Cooperative and ELFEC for residential users converged somewhat over time, to 0.50 and 0.80 Bs/kWh respectively. For industrial users, the tariffs were respectively 0.70 and 1.00 Bs/kWh. In 2006 however, the Tarifa Dignidad was introduced, meaning a 25% reduction for residential users of the central grid consuming less than 70 kWh/month. Therefore, the price dropped to 0.60 Bs/kWh. This altered the Cooperative's competitiveness considerably. Because the minimum charged remained the same, the breakeven point shifted to 23 kWh/month. Only if users used more than this, the Cooperative was cheaper. Through these changes, another 42 users left the Cooperative.

Almost all users of the Cooperative do also have a connection with ELFEC. One chooses to have two connections to be surer of having electricity, because both networks face many power failures. A small questionnaire among the population (n=20) shows that the general opinion is that ELFEC has less power failures, while the Cooperative is cheaper (although no one knows the exact difference in terms of money). Price however is not the most important determinant for the choice between both. Eleven of the twenty interviewees do only have a connection of ELFEC (no one has only a connection of the Cooperative). Nine out of eleven says that they have chosen for ELFEC because ELFEC has less power failures. Only one thinks that ELFEC is cheaper than the Cooperative. Some people do think that ELFEC is a better company than the Cooperative, because they have bigger plants and more technology.

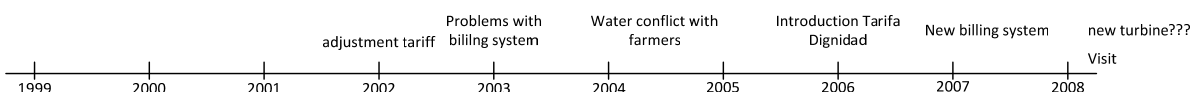
### Beneficiaries

The table shows that the number of users has fluctuated significantly over the years, influenced by the factors discussed above.

Industrial and commercial users have always been significant,

Year	# Users
1992	300
1997 (before grid)	400
1997 (after grid)	320
2005	322
2008	280

not in numbers, but in electricity used. In 1996, they consumed 7.000 kWh/month (32%). Industrial and commercial users are still very important for the Cooperative. Commercial users like restaurants are connected because they use more than 70 kWh/month, and cannot benefit fully from the Tarifa Dignidad. The three existing wheat mill have to use the plant as well,



because they can only operate by using three-phase voltage, which ELFEC does not offer. Together they consume on average 2,400 kWh/month, good for approximately 33% of the Cooperative's income.

Plans exist to build more mills in the vicinity, which should be connected to the plant as well. Moreover, new neighborhoods are being built which are probably not getting a connection of ELFEC, but do get one of the Cooperative.

The questionnaire shows that the electricity is mainly used for lighting (100%), television (90%), radio and electric showers (80%), refrigerators (75%) and for ironing (30%).

**Finance**

The investment of the plant was relatively high. The initial investment was 393,250 US\$. A consortium of INER/COFER (197,000 US\$), INEDER-Cooperación Internacional (76,000 US\$), the Alcaldía of Totorá (120,000 US\$), and locals (19,250 US\$, mainly labor provided) invested in the plant. The costs per kW are 3,745 US\$.

The financial situation was good in the first years, with annual profits of 30,000 Bs. However, the tariff did not keep pace with inflation and the plant started making losses. In 1996 Energética calculated that including all cost (depreciation included) the basic tariff should be 0.47 Bs/kWh. However, the Cooperative decided to raise the residential and industrial tariff from respectively 0.25 and 0.38 Bs/kWh to 0.30 and 0.50 Bs/kWh. In 2002, after three years of increasing losses, the tariff was adjusted again to 0.50 and 0.70 Bs/kWh. Today (2008), it is still the same. The minimum payment for residential users is 13 Bs for 25 kWh.

It is difficult for the Cooperative to raise the tariff. The stakeholders (users) have to give permission, and often blocked it. Nowadays, the Cooperative has to compete with ELFEC, which makes it even harder.

A financial overview of the last five years (in Bs) is given in the table below. It can be seen that since the introduction of the Tarifa Dignidad in 2006 the income dropped significantly. Costs for the Cooperative were low as well, because no large repairs had to be done, so that the revenue was still significant. Costs consist largely of wages (3,000 Bs/month). It is however possible that losses are going to take place in the near future, considering the high costs in previous years.

Year	2003	2004	2005	2006	2007
<b>Income</b>	90.481	83.311	81.745	63.075	65.903
<b>Costs</b>	78.607	81.711	78.462	36.294	48.597
<b>Revenue</b>	11.874	1.600	3.283	26.781	17.306
<b>Balance</b>	21.167	22.767	26.050	52.831	70.137

Energética has purchased a computer-controlled billing system for the Cooperative in 1996. However, when the tariffs were changed in 2002, the Cooperative was not able to adjust the system. They finally managed to

change it somewhere between 2005 and 2008. The billing system is out-of-date and does currently not function properly anymore. Therefore, a new billing system has been bought for 700 US\$. This should lead to a more efficient conclusion of the invoicing and a cost reduction.

**Future Plans**

To solve the shortage of water problem, a study is being conducted to the purchase of a more efficient turbine, using less water. 50% of the necessary funds are already available; there are some contacts with GTZ that possibly wants to donate the remaining 50%.

**Lessons Learned**

**MARKET**

Subsidies for electricity generated on large-scale will affect the competitiveness of stand-alone systems using a renewable source of energy. A major lesson that can be learned from this project is that micro-hydro plants are able to compete with the central grid, but that subsidies will make it more difficult.

**FINANCIAL / ECONOMIC**

Good financial control is a prerequisite for a healthy financial situation. An important lesson that can be learned is that tariffs are very often not adjusted to the inflation rate. This will cause losses that can be avoided easily.

The replacement costs of a micro-hydro plant are often not taken into account in the financial administration. As a consequence, it is not possible to build a new plant in case of a complete break down or in case more capacity is needed.

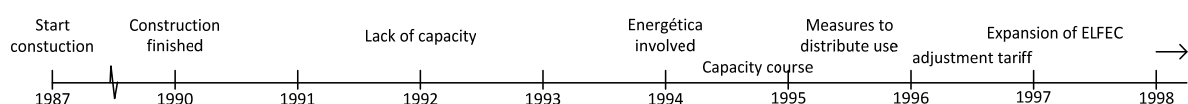
If a computer-controlled billing system is used, one should have the capacity to adjust it, e.g. in case of new tariffs. Otherwise, it is useless, or worse, it can hinder the introduction of adjusted tariffs.

Considering that normally it is assumed that costs per kW are around 3,000 US\$/kW, and that this plant is quite a large one (which usually reduces costs), there should be ways to reduce the initial investment. One of these ways is the use of more simple techniques, e.g. a simpler inlet system in comparison with the small artificial lake built here. Another possibility is the use of local materials.

**TECHNICAL**

Three-phase systems can enable agricultural development, but do also require more technical capabilities of the operators, because all phases have to be loaded equally. If not, the efficiency of the system will decrease. One should ensure that the person in charge is able to do this.

Three-phase systems are more vulnerable for power failures due to wind. These systems therefore require more maintenance efforts.



The operator of a plant should have enough capabilities to run the plant effectively.

Involvement of the local population, especially through the supply of labor, can reduce the construction time. If this is not possible, other (cheap) labor supply options should be considered, although this might be hard to arrange. The project shows that it is possible with volunteers as well.

#### INSTITUTIONAL

Participation of the users has many advantages, but also some disadvantages. Users will possibly only see short-term disadvantages of the adjustment of the tariff for inflation, not the long-term necessity, and therefore block the adjustment.

The direction of the plant should check the executive board tightly, especially in financial matters.

#### SOCIAL, CULTURAL AND BEHAVIORAL

Electricity use can be distributed more evenly along the day, increasing usage during daytime and decreasing usage during peak hours by starting campaigns to create awareness among the users. However, this campaigns should not be quitted if the goals are met, but should continue to sustain the desired behavior.

Some people are prejudiced against the small size of the Cooperative. They believe that a big company like ELFEC will always perform better, because they have bigger plants and more technology. This is probably a prejudice that small organizations have to fight often.

People in rural areas do not only base their choice on price, but also on quality. If a stand-alone system wants

to be competitive, one should also invest in the quality of the system.

## Communication

Energética tried to set up a collaboration between the Cooperative of Epizana and the Alcaldía of Pojo, who was in charge of the micro-hydro plant there. However, the Alcalde of Pojo refused to cooperate. He saw Pojo, capital of the first sección of the province Carrasco, as an independent section, not dependent on the capital of the second sección (Totora) of the province. Why he exactly refused is unclear.

The micro-hydro plant in Pojo was the only other plant in the vicinity. The Cooperative does not have any contact with other plants. In the past, there were contacts with Energética, but this ended after Energética stopped its micro-hydro activities.

## Sources

Interview Presidente Cooperative (12-09-2008)

Interview Gerente Cooperative (11-09-2008)

Interview Operator Cooperative (18-08-2008)

Interview Miguel Fernández F., director of Energética (05-08-2008)

Energética (1994)

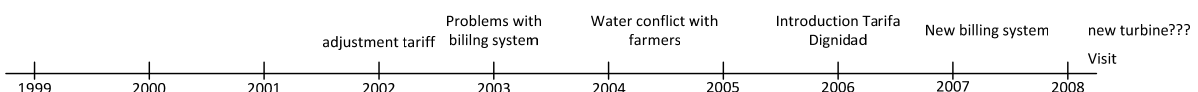
Energética (1996)

Instituto Nacional de Estadística (2008)

Koper, M. (2005)

Kublank (1992)

Questionnaire among population (n=20) (12-09-2008)







## Chapisirca

17°08'10.06"S, 66°08'43.47"W

<b>Capacity:</b>	40 kW
<b>Costs:</b>	116,320.- US\$
<b>Users:</b>	55
<b>Turbine:</b>	Pelton
<b>(Re)Start Date:</b>	1991 & 1996
<b>Organization:</b>	Energética

## Background

Chapisirca is a village of about 200 households in the sección Tiquipaya, in the mountains north of the city of Cochabamba. It can be reached from Tiquipaya (1/2 hour from Cochabamba) in about four to five hours. The villages lie at an elevation of 3,728 meters. The main source of income is potatoes. Furthermore, some onions and carrots are grown, but mainly for own use.

A small river splits the village in two parts. The centre of the village lies south of the river. Here is a primary and secondary school, a hospital and the market. A relatively small part of the village is north of the river. The houses here are more scattered.

## Project Description

### Implementation

In 1991, a micro-hydro 'expert' told the population of Chapisirca that it was possible to build a 25 kW plant for only 7,000 US\$. Energética heard about the plan and tried to convince the community that it was impossible. They were already deaf though through the magic phrase '7,000 US\$ para la luz' (light for 7,000 US\$). As could be expected, the project failed a couple of years and 40,000 US\$ later.

Energética and PROPER tried to convince the population after the project failed that it was possible to build a plant, but the inhabitants were totally disillusioned.

Finally, in 1996, the community decided to try it again, after consultation with the Alcaldía of Tiquipaya. Energética was asked to redesign the plant, and the Royal Dutch Embassy and the Alcaldía of Tiquipaya provided the necessary financial funds. The construction did not progress well because of the disillusioned populations, but things became better when a group of Italian volunteers became interested in the project and decided to help with the construction.

The plant was completely redesigned and worked well after its completion. In total, 180 man had spent 75 days in six years for the construction.

### Extension of the central grid

In 2007, ELFEC expanded the grid to Chapisirca. Not the entire village was connected, only the southern part of the village, where the majority of the population lives, the biggest users are situated and the houses are more densely located. The part of the village at the north bank of the river is still being served by the micro-hydro plant.

It was agreed that ELFEC took over the existing infrastructure of the micro-plant at the southern part of the village. The head of the Municipalidad had to agree that this was better for the local population, because the plant had to cope with a lot of power failures. Indeed, ELFEC turned out to have less failures and the population in the southern part is quite happy with the new situation, although the electricity of ELFEC is somewhat more expensive.

### Expectations

In first instance, the expectations of the local populations were tremendously high. Everyone was convinced that the project was going to be a great success and an example for other villages in Bolivia. Energética and the Alcaldía de Tiquipaya on the other hand expected a disaster, which became true. After the reconstruction, expectations of the local population were moderate. There were still some doubts about the technology after the previous illusions. After some time however, these doubts disappeared, because the plant functioned well. Energética was confident as well.

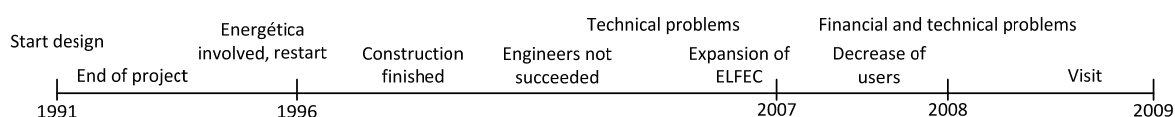
Nowadays, since the arrival of ELFEC, expectations are less positive. The income of the plant has decreased sharply, a lot of technical problems exist, and it is doubtful if the plants can keep functioning in the future.

### Technology

The plant uses a 40 kW, two jet Pelton turbine and a 80 kW three-phase generator. Frequency and voltage are controlled by regulating the water flow. Net head of the plant is 43.9 m, the flow-rate is 200 l/s. The concrete canal is 900 m long and covered at some places. The power house is situated approximately 3.4 km from the village. Power is distributed by a 3 kV high-voltage three-phase network and a 1,900 meter low-voltage network.

A shortage of water exists in July and August, and often in June and September as well. The canal is leaking at several places, as well as a water outlet. Nothing has been done to repair this, despite of the water shortage. There are also problems in times of rain. There is quite some vegetation in the surrounding areas that flows into the canal due to the rain and cause obstructions from time to time.

The turbine is leaking oil and the control mechanism of one phase is broken. Spare parts have to come from Italy, what takes a lot of time. Furthermore, an engineer has to come from Cochabamba, because there is no technical knowledge left in the village.





Two high-voltage post were destroyed during a storm two years ago, leading to high costs (800 Bs each).

**Organization**

The Cooperativa Hidroelectrica Chapisirca is managed by a president and treasurer whom are chosen every two years. The head of the Municipalidad, the Dirigente (chosen every two years as well) is the operator of the plant. The current Dirigente has been engaged for three years now. He visits the plant every two or three days and cleans up the canal every week.

In the past, two electricians worked for the plant as well. They have left the village however, and were not succeeded.

Users are socios. Once or twice a year there is a meeting. They come with new ideas regularly, like the implementation of an irrigation system to use an excess of water. This system was built in 2007.

Socios used to spend a lot of time for the plant. The economic situation however is bad in the valley since 2005. Since then, socios do not want to spend too much time for repair works, because they preferred to work on their fields to earn a living.

**Beneficiaries**

Currently there are 55 users. There used to be 130 users, but more than half the village was disconnected since the arrival of ELFEC in 2007.

**Finance**

The tariff of the plant is 0.70 Bs per kWh, with a minimum of 5 Bs. This has not changed for years now. Approximately 25% of the users use the minimum. More than 50% do not use more than 10 kWh/month. No one is using more than 30 kWh/month.

Average income of the Cooperative is 500 Bs/month. The Cooperative is making losses. How much is unknown, the treasurer was not present during the visit. The Municipalidad makes up the deficit.

**Lessons Learned**

**MARKET**

The rural electrification program in Bolivia financially encourages distribution companies to expand their grid to remote rural areas. This can create unfair competition with stand-alone systems, as can be seen in Chapisirca.

**ECONOMICAL/FINANCIAL**

A certain number of users are necessary to be able to generate sufficient income. It is often hard to adjust the financial policy when the number of users suddenly sharply drops. One of the reasons is that socios do not want to raise the tariff.

Without the adjustment of the tariff by inflation, it is not possible to manage a plant sustainable in the long run. Financial knowledge and awareness is necessary to cope with this problem.

**TECHNICAL**

A lot of engineers in Bolivia claim to be experts in the designing and construction of micro-hydro plants. They assume that the technology is quite simple, and that a somewhat technically skilled person should be able to manage the design and construction process. This is obviously not the case. Micro-hydro technology is difficult to design and implement. To do it properly, a lot of knowledge and experience is required.

A very important lesson that can be learned is that the local presence of technical engineers is of vital importance for the functioning of a micro-hydro project. In Chapisirca, an electrical and a mechanical engineer were trained to maintain the plant. Almost all technical problems could be solved locally. However, these local capabilities have disappeared, because both engineers have not been succeeded. The community has to call in external expertise now, which is costly and which is causing delays.

**INSTITUTIONAL**

If the person in charge of the plant is not chosen specifically for that function, but get the operation and maintenance as appendage of his/her main function, this will not foster the way the plant is managed. The management of a plant requires different skills than being in charge of a village. An unskilled board will probably not see which adaptations are required for a plant, and how to carry these out.

Chapisirca learns us that a system is necessary to be able to guarantee the quality and experience of persons or organizations that are implementing micro-hydro projects. As long as this is not the case, inexperienced people will keep posing as experts.

**SOCIAL, CULTURAL AND BEHAVIORAL**

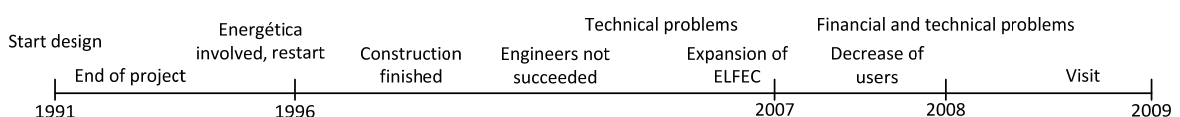
The desire for electrification is enormously in many rural areas. People will get excited by the opportunity to get connected to a (mini-)grid. Through this excitement, many communities will stop thinking rationally, and put their money in the hands of unskilled 'experts'.

**Communication**

There are no other plants in the region. The plant does not have contacts with other systems. In the past, Energética used to come by regularly. This has not happened anymore since Energética stopped its micro-hydro power activities.

**Sources**

- Interview Alcalde Chapisirca (03-10-2008)
- Interview Presidente (03-10-2008)
- Fernández F., M. (1997) Optimización en Epizana, Errores y Reconstrucción en Chapisirca.



## Pojo

17°45'32.31"S, 64°51'36.51"W



<b>Capacity:</b>	<b>100 kW</b>
<b>Costs:</b>	<b>254,285.- US\$</b>
<b>Users:</b>	<b>200</b>
<b>Turbine:</b>	<b>Michell Banki</b>
<b>Start &amp; End Date:</b>	<b>2001 – July 2007</b>
<b>Organization:</b>	<b>Energética</b>

## Background

Pojo, a small village at an elevation of 1,984 meter, is situated on the main road between Cochabamba and Santa Cruz. It is lying in a fertile valley, transected by the Río Pojo. Pojo is the capital of the second sección of the province Carrasco in the Departamento de Cochabamba and the village is therefore a meeting point for the population of the neighboring villages. Besides the administrative function, Pojo serves an educational function as well. The big primary and secondary school provides education for many children in the vicinity. The inhabitants live of the cultivation of fruits and vegetables, which are sold in the big cities.

## Project Description

### Implementation

In 1997 de Prefectura de Cochabamba and the Alcaldía de Pojo decided to build a micro-hydro plant in Pojo. The project was going to serve as an irrigation system as well. Energética and the Universidad Mayor de San Simon in Cochabamba were asked to design the electro-mechanical part of the project, the PRI (Program for Integrated Irrigation) would design the civil works. The canal was going to be 3 km, and passed many agrarian fields. These fields should be irrigated using the canal of the plant.

The cooperation between the different organizations was not without problems. The construction started in Jun 1999. Energética however did not agree with the design of the civil works. The water contained too many sediments during and just after rainfall and the inlet would become obstructed. Furthermore, the geographical characteristics of the area through which the canal passed did not favor an open concrete canal and demanded more settling basins. The Prefectura, who was in charge, agreed, but said that the additional basins would be added later on, as well as the concrete wall before the inlet of the settling basin that Energética proposed to reduce the chance of obstruction. Afterwards, the Prefectura decided against these adaptations.

The Minicentral Hidroeléctrica Pojo started functioning in 2001, when construction works were finished.

### Expectations

Expectations of the Prefectura and the Alcaldía were high. The irrigation function of the project would

increase yields, and the electricity supplied would boost the economic activities in the village. Furthermore, Pojo would get a more prominent function as capital of the sección. Energética was less enthusiastic. They expected a lot of obstruction-problems, and problems with the gravelly surroundings.

### Technology

The plant used a 100 kW Michel Banki WK-V turbine and a three-phase generator. Net head of the plant was 50.2 m, the penstock was 143.8 m and the flow rate 250 l/s. Power was distributed by a 24.9/14.4 kV three-phase high-voltage network.

The canal was used for irrigation purposes as well. Many fields were connected to the system by small outlets.

### Organization

No strong organizational structure existed. The Alcalde was head of the Minicentral Hidroeléctrica Pojo and the Alcaldía administered financial matters. Furthermore an operator and an electrician were engaged.

### Beneficiaries

Approximately 200 households were connected. Furthermore a couple of small shops, two hostels, a primary and secondary school and the sectional government building used electricity.

### Finance

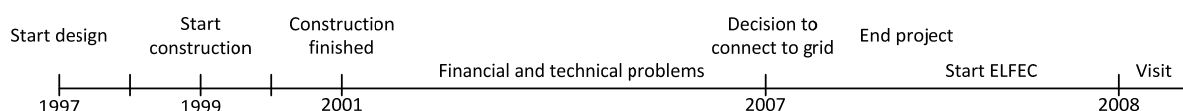
The initial investment was 254,285 US\$<sup>1</sup>. This was donated by the Prefectura de Cochabamba and the Royal Dutch Embassy.

The tariff for electricity was 20 Bs for unlimited use. Annual income of the plant was between 15,000 and 18,000 Bs, costs were 40,000 Bs. The Municipalidad made up the difference.

### End of project

The project faced many technical and financial problems. During periods of rain, the inlet was completely obstructed by mud. This caused long-lasting power failures, especially in the rainy season (up to 2 weeks continuously). Moreover, parts of the canal were destroyed due to landslides several times. Lastly small stones sometimes were able to enter the penstock and destroyed the blades of the turbine (see picture on top). Reparations were costly, and the Municipalidad was not

<sup>1</sup> Exchange rate: 5.98 Bs/ US\$



able anymore to pay them, besides the structural annual losses. Moreover, reparations took a very long time, because experts had to come from Cochabamba, which took at least 15 days.

In 2007, the Alcalde decided to join the 3<sup>rd</sup> phase of the Rural Electrification Program in Cochabamba. ELFEC would install a one-phase distribution line to Pojo and have the disposal of the local network of the plant. The plant was dismantled in July 2007. Besides the cost-saving advantages, the Alcalde hoped that ELFEC would have less power failures.

ELFEC started in September 2007. The hydro-plant is still there. The Alcalde has started a study to replace the system to two small villages, 6 to 7 hours from Pojo. Costs would be ± 20,000 US\$.

Villagers are unhappy with the new situation. Their costs have increased significantly, many spoke of a three to four time increase. Power failures still occur on a daily basis. Furthermore, the Alcalde wants to develop the agrarian sector. However, this is almost impossible without a three-phase distribution network, because machines above ± 7 hp (5.4 kW) can only operate using three-phase voltage.

## Lessons Learned

### TECHNICAL

One of the major lessons learned in this project is that it is very important that an experienced organization/person designs and constructs a plant. If the plant is used for multiple purposes, this should be coordinated well and should not be an obstacle for the functioning of the plant. Many organizations/people think that it is not that hard to construct (parts of) a plant. This project has proven again that this is not the case.

Furthermore, it is hard to design plants in areas with a lot of sediments in the water. This can cause long-during power failures. Special attention to this should be paid during the designing and construction phase.

Another major lesson is that tubes, although more expensive, can better be used than concrete canals in gravelly areas. If concrete canals are used, one should pay close attention to the design of the forebay tank.

Furthermore, it is important to have sufficient technical knowledge in the organization. The calling in of experts from big cities can cause delays and is expensive.

Lastly, a three-phase distribution network is a requirement for agricultural development. This is one of

the big advantages of micro-hydro systems over the central grid.

### INSTITUTIONAL

A strong organization is necessary to manage the plant. The manager should preferably be engaged fulltime.

### ECONOMICAL / FINANCIAL

A plant as social project will make the users quite satisfied, but will not improve the financial situation of a plant, and can eventually lead to the dismantling of the scheme. The tariff should be a representation of the actual costs, and should be adjusted to inflation.

Furthermore, it can be learned that electricity for a central grid may be superior in terms of technical performance, one should keep in mind however that in remote rural areas the tariff is very often much higher than a stand-alone system. This should be taken into account as well in the decision process.

## Communication

Energética tried to start a cooperation between the organizations of the micro-hydro plants in Epizana and Pojo. The organization in Epizana already had acquired valuable experience with operation and maintenance and financial management. Energética and Epizana agreed that the latter would give courses to the management of the Minicentral Hidroeléctrica Pojo and exchange information in the future. The Alcalde of Pojo refused however. He saw Pojo as an independent sección that did not need any help from another sección (Titora, which also get electricity of the plant in Epizana, is the capital of the second sección). Furthermore, he expected that Epizana would give false information, trying to destroy the plant.

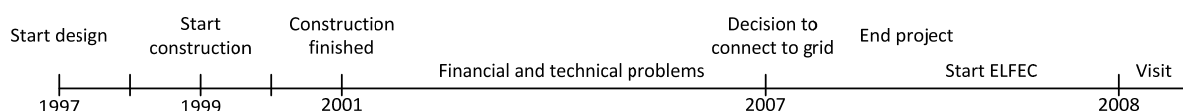
During its operation, Pojo functioned independently. They did not contact the plant of Epizana, nor Energética. Technical problems were solved with local expertise, or by calling in experts from Cochabamba.

## Sources

Interview with administrator of the Municipalidad Pojo (19-09-2008)

Interview with person in charge of electricity matters of Municipalidad Pojo (19-09-2008)

Interview Miguel Fernandez Fuente, director of Energética (07-11-2008)



## Flor de Mayo

16°04'00.00"S, 67°09'51.40"W



Capacity:	15 kW
Costs:	24,590.- US\$
Users:	54
Turbine:	Pelton
Start Date:	April 2001
Organization:	IHH

### Background

Flor de Mayo is a small village in the sección La Asunta. It was established by immigrants from the Altiplano, twenty years ago, who moved because their land was tired after intensive use. They went to the Sur Yungas because of the money that can be earned with the cultivation of coca.

The village lies at an elevation of 784 meter in tropical surroundings. Coca is the main source of income, together with the cultivation of some fruits. The village has grown rapidly since the building of a bridge that connects the community to the main road. The number of inhabitants doubled since 2001.

### Project Description

#### Implementation

Since the establishment of the village, the community would like to have electricity, because they were used to have it at their previous location on the Altiplano. A public call for the submission of projects from the UNDP/SGP was the opportunity to construct a micro-hydro plant. The village asked IHH to design a system. IHH agreed, because topographical conditions were very good; the flow rate of the river is continuous and more than sufficient throughout the year and the site is in the near proximity of the village, favoring a low cost plant and easy operation.

IHH started in 1999 with the design. Construction started in August 2000, and the plant was finished April 20<sup>th</sup>, 2001.

The construction was carried out by the auto-construction method of IHH. Villagers have to construct the plant; IHH monitors the process and visits the plant once every one or two months to correct mistakes.

Furthermore, IHH gave the inhabitants a course about administration, maintenance and operation of the plant and they helped with the administration of the project during the start-up phase.

#### Expectations

Expectations were that the plant would be able to generate enough electricity for at least the next 20 years, assuming a 1.5% growth rate of the demand.

#### Technology

The plant uses a 15 kW, four jet Pelton turbine, and a three-phase, 20 KVA generator. Frequency and voltage

are controlled by a dump-load. Net head of the plant is 60.6 m; the penstock has a length of 170 m. The canal is 650 m long, and the power house is situated 300 meters from the village. Power is distributed by a 320 m low-voltage single-phase network.

#### Organization

The plant is managed by the Asociación Micro Central Hidroeléctricas Flor de Mayo. The board of the association consists of a president, vice-president, treasurer, secretary, and a communicator. The board is elected democratically every two years by the socios.

The socios, the people who have built the plant, own the system. New inhabitants who are using electricity are usuarios. They can become socio by paying 400 US\$, which is an equivalent of the amount of work delivered. The Association meets four or five times a year to discuss problems or to inform the socios.

One operator is engaged. He receives a salary of 300 Bs/month and is in charge of the daily operation of the plant.

#### Beneficiaries

The plant is build by 42 socios. 40 still live in Flor de Mayo. As said before, the village has grown rapidly. There are fourteen usuarios, 30 to 40 households would like to have a connection, but it is only possible to add an additional ten houses. Some households have bought a refrigerator.

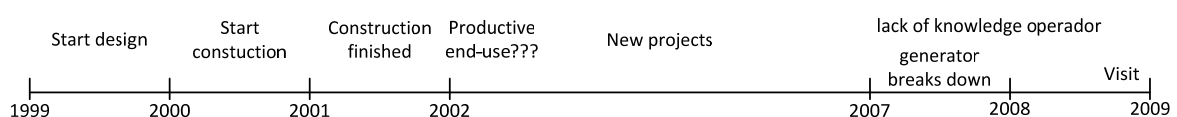
Furthermore, the electricity is used for street lighting and for the primary school, which uses five computers and a video projector.

#### Finance

The project is financed by the UNDP/SGP. The Alcaldía has paid for the distribution network and street lighting. The village bought construction materials and delivered manpower.

Socios and usuarios have different tariffs. Socios pay a minimum of 15 Bs for 15 kWh/month, and 0.80 Bs for every additional kWh. Usuarios pay 30 Bs for the 15 kWh minimum and 1 Bs for every additional kWh. The tariffs have not been adjusted since the beginning of the project.

Income has to cover operation- and maintenance costs, repairs, salary of the operator and savings for future big replacements. The saving-target is 1,000 US\$ a year. Income fees of new socios will be added to the savings.





The salary of the operator has increased in recent years. In 2006 it was 200 Bs/month, in 2007 250 and in 2008 300.

The average income is ± 1200 Bs per month. Costs are ± 600 Bs, excluding the salary of the operator. Total revenue in 2008 was 2,800 Bs, in 2007 2,200 Bs.

In 2007, the Asociación had to replace the generator, costing between 3,000 and 3,500 US\$.

## Lessons Learned

### FINANCIAL/ECONOMIC

The Association aimed at saving 1,000 US\$ each year for big replacements. This does not happen anymore. The main reason is that the tariff is not being adjusted to rising costs (e.g. the salary of the operator). This should be done to avoid losses in the (near) future.

It is hard to raise enough income when the number of users is relatively small.

Financial knowledge and awareness of the current financial situation is limited as well, because of the regularly changing of the treasurer. More should be done to ensure a proper information transfer.

### TECHNICAL

There is a lack of technical knowledge of the operator. The first operator has had a course from IHH. However, the person in charge has changed several times, through which the knowledge necessary was lost. The current operator does not have sufficient knowledge, which led to the break-down of the generator, leading to high costs.

A major lesson that IHH has learned is that the design of the construction should be as simple as possible to ensure a proper functioning. This will simplify the understanding of the conceptual design on the part of those responsible for the construction. The same holds for the system to control the plant.

Not all new villagers can be connected to the grid, because the village has grown too fast thanks to the profitable coca cultivation and the increased accessibility of the village due to the bridge and road, connecting the village with the main road. The additional problem is that users cannot increase their consumption too much. The lesson that should be learned is that villages tend to grow very fast in areas with a lot of economic activities. The 1.5% growth rate of demand is probably too low.

### INSTITUTIONAL

The project has led to improvements in educational services. The school is now using computers and a video projector.

Some villagers have bought a refrigerator and sell ice creams. Furthermore, the socios noted that it is possible to do something with the access of electricity during day time. This has led to the idea of IHH and the UNDP to start productive end-uses in the next project. The inhabitants of Flor de Mayo want to start a metal workshop and a workshop for carpentry.

### SOCIAL, CULTURAL AND BEHAVIORAL

The project has led to proud feelings and a high self-esteem within the community. The community members have seen that it is possible to accomplish a lot when they work together. After the construction of the plant, they have started two new ambitious projects: the building of a bridge over the Río Bopi and a road to the village, through which the community is better accessible and has grown fast, and a drink water installation. Both are completed successfully.

The auto-construction method has led to differences between socios and usuarios. Socios see the usuarios as somewhat inferior.

IHH has learned that local communities are able to organize, manage, solve problems, and effectively use the auto-construction model. This led to major cost-reductions of the construction.

## Communication

Although the village is just half an hour walk from the village of Charía, communication does not take place, neither with Charía nor with other villages in the vicinity. The villagers and board are aware of problems and successes in other villages, but do not consult with each other. (Technical) Problems are discussed with IHH. IHH is called, or the board is going to La Paz.

## Sources

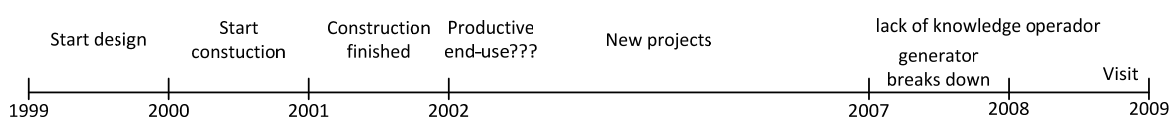
InformeFinal Microcentral Hidroeléctrica Flor de Mayo, August 2001, IHH, La Paz

Interview Presidente Plant (12-10-2008)

Interview Tesorero (treasurer) Plant (12-10-2008)

Conversations with population (10-10-2008)

Website UNDP/SGP: [http://sgp.undp.org/web/projects/3630/microcentral\\_hidroelectrica\\_comunidad\\_flor\\_de\\_mayo.html](http://sgp.undp.org/web/projects/3630/microcentral_hidroelectrica_comunidad_flor_de_mayo.html) (09-02-2009)



## Charía

16°03'40.92"S, 67°10'15.14"W



<b>Capacity:</b>	<i>20 kW</i>
<b>Costs:</b>	<i>392,423.- Bs</i>
<b>Users:</b>	<i>92</i>
<b>Turbine:</b>	<i>Pelton</i>
<b>Start Date:</b>	<i>June 2004</i>
<b>Organization:</b>	<i>IHH</i>

### Background

Charía is a small village in the sección La Asunta. The community lies between the busy road from Asunta to San José and the Río Bopi at an elevation of 818 meter. The climate is tropical; the main source of income is the cultivation of coca. Furthermore, the population grows some rice, citrus fruits, bananas, corn and yucca. Children from surrounding villages come to Charía to visit the secondary school. On-going passengers stop in the village to buy ice creams.

### Project Description

#### Implementation

In 2002, the population of Charía asked IHH to build a plant after the example of Flor de Mayo. The inhabitants of Charía could see the electric light bulbs of their neighbors every evening and did not want to lag behind. IHH visited the village and was positive about the topographical situation. Moreover, experiences in Flor de Mayo were very good and IHH and the UNDP/SGP decided to use these experiences and start a productive end-use facility as well.

By mutual agreement it was decided to establish a microempresa (=small company) to process bananas and coffee. Bananas are abundant in the region, but the value is low and transport expensive and difficult. Therefore, one tried to dehydrate, process and pack them, in order to add value and to create a new market. The coffee was not abundant in the region, but IHH and the UNDP/SGP hoped that the community would start growing them. Both organizations had gained experience with the processing of coffee in the project in Camata, which was the first attempt to start a microempresa. Charía was the second.

The construction started in 2003, using the auto-construction method developed by IHH. During the construction, some problems were encountered. Firstly, in October 2003, the road to Sud Yungas was blocked twenty days by farmers, delaying the supply of building materials. Later on, in November, an extraordinary flood destroyed parts of the settling basin that was being build and part of the tube that formed the canal. Furthermore, the road to the Sud Yungas was inaccessible in December and January 2004 due to heavy rainfall.

Despite these problems the project was finished in June 2004.

#### Expectations

IHH, the UNDP/SGP and the villagers hoped to increase the quality of life through the supply of electricity and to increase and diversify sources of income through the establishment of the small enterprise. One expected that diversification was important, because chances were that coca, the main source of income, would be forbidden by the then ruling government.

The plant would be able to generate enough electricity for at least the next twenty years, assuming a 1.5% growth rate.

#### Technology

The plant uses a 26 kW, four jet Pelton turbine, a three-phase, 40 KVA generator and a 20 kW electrical control system. Frequency and voltage are controlled by a dump-load. Net head of the plant is 59.2 m, the penstock has a length of 156 m and the flow-rate is 53 l/s. The canal is 925 m long and consists of a tube. The power house is situated 300 meters from the village. Power is distributed by a low-voltage single-phase network of 2000 meter.

#### Organization

The plant is managed by the Microempresa Charía. The board consists of a president, vice-president, treasurer, secretary, and a communicator. The board is elected democratically every year by the socios.

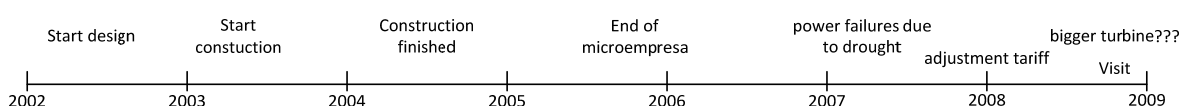
A special committee was established to manage the small enterprise and to explore the market for opportunities the sell the products processed.

The socios, the people who have build the plant, own the system. New inhabitants who use electricity are usuarios. The socios and the board meet every three months to discuss problems or to inform the socios. These are interactive meetings, the socios come with many new ideas, e.g. to buy a bigger turbine to enlarge the plant and to install a three-phase distribution network in order to be able to establish metal and wood workshops.

One operator is engaged. He receives a salary of 350 Bs/month and is in charge of the daily operation of the plant. He inspects the plant twice a day and cleans it every three days.

#### Beneficiaries

The plant was built by 74 socios. In 2008, there were 76 socios (two had paid a fee to become socio) and 16



usuarios. A lot of users have bought a television or refrigerator. Someone is selling ice creams, which is quite a big business. He sells a couple of hundred ice creams a day.

Another big user is the secondary school that is quite large.

## Finance

The total investment of the project was 392,423 Bs. The UNDP/SGP paid 262,588 Bs, the Alcaldía of Asunta 35,000 Bs and the population 94,835 Bs.

The organization wants to save 1,000 US\$ a year. This is not a problem in recent years. In 2006, total revenue was 27,224.60 Bs (income was 43,754 Bs, costs 16,529.40 Bs) and in 2007 it was 21,950.60 Bs (income 35,666 Bs, costs 13,715.40 Bs). At the end of 2007, the micro-empresa had 60,416.60 Bs of liquid assets.

It was decided to adjust the tariffs in 2008, because a down-ward trend was discovered in the total revenues. In 2007, socios and usuarios paid a minimum of 15 Bs for 25 kWh/month, and 0.60 Bs for each additional kWh. This was raised to a minimum of 16 Bs for 25 kWh/month and 0.70 Bs for each additional kWh.

These figures show a very healthy and reactive financial organization.

## Lessons Learned

### MARKET

The microempresa in this project was not successful. The socios decided to quit the experiment after a year. There were several problems. The most important one was that the socios were not interested enough in the cultivation of bananas and coffee. The income gained by coca cannot be replaced easily by other products and the future of coca is not in danger anymore since the election of Evo Morales as president of Bolivia. The lesson that can be learned is that the establishment of a productive end-use should be closely related to the main source of income of the population.

Second, not enough knowledge existed about marketing methods, distribution channels, etc. More attention should be paid to these aspects when a productive end-use facility is created. It cannot become successful without paying attention to the creation of new knowledge, organizational structure, etc.

### FINANCIAL/ECONOMIC

The microempresa did not have enough money to buy bananas from the socios. Starting capital was lacking. This aspect should be taken into account as well, besides the recommendations mentioned above. Starting a productive end-use facility is not only about providing the machines.

The Association shows us that it is possible to save 1,000 US\$ each year, so that the plant can run sustainable. To do this, the board should have sufficient financial knowledge and be able to react to financial data and trends. Furthermore, it is possible in this case, because the number of users is significant.

### INSTITUTIONAL

On the other hand, the project also shows that it is possible to create some new income sources. The shopkeeper who is selling ice creams shows us this. He earns a nice additional income.

### TECHNICAL

The project shows that a three-phase distribution network is necessary to start productive end-uses like metal and wood workshops. Some villagers would like to start those, but it is not possible due to the single-phase network.

Power failures occurred during the winter of 2007. This was caused through a period of excessive drought. The lesson learned is that it is possible to design a plant in one year, but the disadvantage is that measurements of the river flow do also span just one year. Even with a careful estimation of the flow rate, it is still possible that a lack of water occurs in years with extreme conditions. Maybe new methods can be developed to estimate flow-rates more precisely.

### SOCIAL, CULTURAL AND BEHAVIORAL

Observability and success are important drivers for diffusion. The main reason why Charía went to IHH was that they had seen the success of the plant in Flor de Mayo.

## Communication

Although there are many micro-hydro plants in the vicinity, communication does not take place. The villagers and board are aware of problems and successes in other villages, but do not consult with each other. (Technical) problems are discussed with IHH. IHH is called, or the board is going to La Paz.

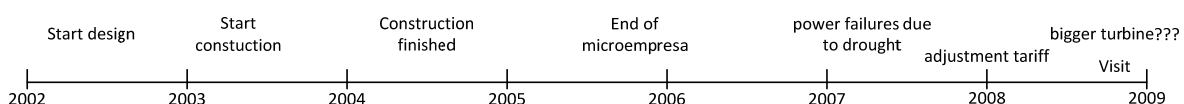
## Sources

Interview Presidente (10-10-2008)

Interview Tesorero (treasurer) (10-10-2008)

Presentación Microcentral Hidroeléctrica y Planta Deshidratadora de Platano y Procesadora de Café Charía, July 2004, IHH, La Paz

InformeFinal Charía, October 2004, IHH, La Paz



## Agua Blanca

14°49'19.06"S, 69°06'30.46"W



<b>Capacity:</b>	<i>30 kW</i>
<b>Costs:</b>	<i>342,400.- Bs</i>
<b>Users:</b>	<i>92</i>
<b>Turbine:</b>	<i>Pelton</i>
<b>Start Date:</b>	<i>June 2005</i>
<b>Organization:</b>	<i>IHH</i>

### Background

Agua Blanca is a small community in the National Park Apolobama, close to the border with Peru, in the north-west of Bolivia. It is called after the swirling water of the Río Soratera that passes the village. It lies at an altitude of 3,960 meter, and is surrounded by snow-capped mountain peaks.

The main source of income is the cultivation of potatoes. Besides these, many people have a small herd of llamas and alpacas, serving for meat and wool. An emerging source of income is tourists, trekking from Curva along the more and more popular trek to Pelechuco, a village 3 km downstream. Many of those backpackers stay in the Albergue (hostel) in Agua Blanca, because hostels in Pelechuco are far less attractive options to stay.

### Project Description

#### Implementation

The construction of the system started in 2004, after a year of measuring the flow rate and designing the plant by IHH. This plant was constructed according to the auto-construction method developed by IHH. This means that the community builds the plant, while the process is monitored by IHH who visited the village regularly to correct things when necessary. Furthermore, IHH gave the inhabitants a course about administration, maintenance and operation of the plant and they helped with the administration of the project during the start-up phase.

Besides the construction of the plant, an already existing weaving mill was equipped with electric machines, in order to increase the quantity and quality of the output, consisting of cloths and artifacts made of llama and alpaca wool. One chooses not to establish a new productive end-use, because those enterprises often fail, but to follow on an existing structure, the Asociación Artesanal Nueva Esperanza.

The plant was finished in June 2005 without much difficulties. The only real problem that occurred was that an argument arose between members and non-members of the weaving association. The latter thought that the first benefitted more from the plant, while everyone contributed an equal amount of labor. Rivalry between members and non-members exists since the creation of the association. During the construction, it was hushed up by the leaders of the community.

#### Expectations

IHH, the UNDP/SGP (who financed the plant) and the villagers hoped to increase the quality of life through the supply of electricity and through the expansion of the weaving association. Furthermore, one hoped that more tourists would visit the Albergue.

The plant would be able to generate enough electricity for at least the next 20 years, assuming to supply 108 families with electricity (1.5% growth rate).

#### Technology

The plant uses a 50 kW Pelton turbine with two injectors and a three-phase 30 kW generator. Frequency and voltage are controlled by a dump-load. Net head of the plant is 175.2 m, the penstock has a length of 395 m and the flow-rate is 30 l/s. Because the river is steep and fast-running, no canal is necessary. The power house is situated 100 meters from the village. Power is distributed by a low-voltage single-phase network.

Technical problems were encountered the first two years. The platform of the turbine and generator was not resistant to the vibrations caused by the couple, through which both broke loose. IHH had to reinstall the whole system. All problems were solved after two years.

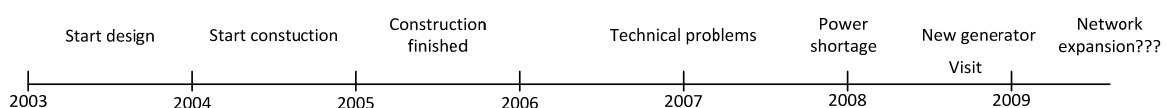
Another problem that occurred was the shortage of power. Many villagers bought an electric shower (5,400 W). This caused power failures during peak hours in the morning. During a meeting one decided to limit and spread the use of the showers. Problems were solved, but the socios decided to buy a bigger 90 kW generator. Lastly, the forebay tank is occasionally frozen over in June and July. This is solved easily by the operator, but can cause short power failures.

#### Organization

The plant is managed by the Asociación Hidroeléctrica Agua Blanca. The board consists of a president, (financial) administrator and a secretary. The board is elected democratically every year by the socios.

The socios, the people who have built the plant, own the system. New inhabitants who use electricity and have not helped with the construction are usuarios. They can become socio by paying 375 US\$. Originally, this was 1,000 US\$. This however was reduced after protests of two usuarios who would like to become socios.

A meeting is organized once a year. Sometimes additional meetings are organized. Socios come with many new ideas during these meetings, like the purchase of a





bigger generator and the extension of the grid to other villages. This last plan is still taken into consideration. One operator is engaged. He receives a salary of 150 Bs/month and is in charge of the daily operation of the plant. He inspects the plant every couple of days.

**Beneficiaries**

The plant was built by 88 socios. Now there are 90 socios (two new users paid the fee) and two usuarios. Many users have bought an electric shower and some have a television. Other notable users are the weavers association and the hostel.

**Finance**

The total investment of the project was 342,400 Bs. The UNDP/SGP contributed 274,900 Bs, the Alcaldía of Pelechuco 35,000 Bs and the population 32,500 Bs. The Association made losses the first two years due to necessary repairs of the plant. This was solved the third year, and the Association made a profit last year. The tariff consists of a basic rate of 10 Bs/ month and an additional 0.40 Bs/kWh. Socios and usuarios pay the same. The tariff will be changed when the new generator is installed.

**Central Grid Expansion**

The distribution company Emprelepaz extended the central grid to Pelechuco in July 2008. The grid passed Agua Blanca, and a distribution network and street lighting were installed. However, the population did not want to have a connection to their houses when they were asked so. They believe that it is better for the local economy when they pay their money to their own Association. Proud feelings played an important role in this decision. They had built the plant themselves, and they wanted it to be successful. Furthermore, the tariff would be 22 Bs/month plus 0.50 Bs/kWh, which is much more expensive than that of the Association. Through the extension of the grid socios realized that they can do the same. Now there are plans to expand the Association's mini grid to other villages as well. It is investigated, together with IHH, if this is feasible.

**Lessons Learned**

**MARKET**

Competition with the central grid is possible. Despite of subsidies for electricity of the central grid, micro-hydro stand alone systems are still able to compete financially and technologically. To enter the market of alpaca- and llama-wool products one needs a warranty of quality and authenticity. These are hard to obtain, and the women have to increase their skills to increase the quality of their products. Furthermore, it is not known how to enter the market and how and where to sell the products.

**FINANCIAL / ECONOMIC**

A productive end-use facilities needs a certain amount of starting capital, in this case to buy wool.

**TECHNICAL**

In this project, IHH used a new method to calculate the water flow of the river during the year. A computer program used data of the rainfall of the last 14 years in combination with water flow measurements to calculate the minimum flow of water. This seems to turn out as a good method, but this should be proven the next years. A solid construction of the turbine-generator couple is necessary for a good functioning of the plant.

**INSTITUTIONAL**

It is possible to start productive end-use activities. One man started a small metal workshop. The provision of electrical equipment for the company does not result in an increase in sales. The employees cannot work during large parts of the year when they are needed on the potato field.

**SOCIAL, CULTURAL AND BEHAVIORAL**

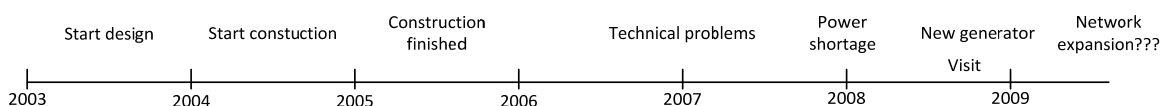
Social cohesion in a village should be good to carry out the auto-construction method without any problems. Problems will occur when social difficulties already exist. Power shortages may occur through an overload of the system. This may occur through a miscalculation of the expected demand. A lot depends on whether or not the local population adjusts its life pattern. If many electrical showers and televisions are bought, demand will increase sharply. To prevent this, one should incorporate the climatic conditions in the demand analysis. A shortage of demand can be solved through collaboration of the users. Collectively, one can reduce and spread the use of electricity. Users have the drive to continue the operation of the plant, even in case of competition with the central grid. The auto-construction method of IHH aroused proud feelings and increased the self-esteem in the community. This led to ambitious plans like the expansion of the mini-grid.

**Communication**

The plant in Agua Blanca is a bit isolated. There was another plant in the nearby village of Pelechuco, but this plant was replaced by the grid. Other plants are a couple of hours away. The Association does not communicate with those plants. When there are problems that cannot be solved locally, IHH is called. Furthermore, engineers of IHH visit the plant regularly.

**Sources**

Interview Presidente (31-10-2008)  
 InformeFinal Agua Blanca, August 2005, IHH, La Paz



**Yanamayo**  
 16°15'25.94"S, 67°14'49.39"W



<b>Capacity:</b>	<b>28 kW</b>
<b>Costs:</b>	<b>292,343.- Bs</b>
<b>Users:</b>	<b>109</b>
<b>Turbine:</b>	<b>Michell Banki</b>
<b>Start Date:</b>	<b>August 2007</b>
<b>Organization:</b>	<b>IHH</b>

**Background**

Yanamayo is a small, long-drawn out village in the sección La Asunta. The community lies alongside the road to Asunta and the Río Bopi at an elevation of 812 meter. The climate is tropical; the main source of income is the cultivation of coca. Furthermore, the population grows some rice, citrus fruits, bananas, corn and yucca. Children from surrounding villages come to Yanamayo to visit the secondary school. The village is possibly going to get a more important function thanks to the hospital that is being built.

**Project Description**

**Implementation**

In 2001, the community of Yanamayo constructed a pico-hydro plant of approximately 2 kW in the Río Yanamayo. A German engineer living in Chamaca, a village at walking distance, had already built a similar plant for his hospital, and several other plants in nearby communities. The German did not have any background in hydro-power, but managed to build small, inefficient plants at suitable locations with locally manufactured materials for a relatively low price. His design spread quickly through the region. The villages of Chamaca (1 plant), Charobamba (2) and Palmar (4) do nowadays have one or more systems.

The system in Yanamayo however did not supply enough electricity to meet the existing demand. Villagers were only able to use two 12 V light bulbs each. Moreover, the village was growing quite fast, leading to more problems.

In 2006, the village asked IHH to design and build a 70 kW plant for Yanamayo and the earlier mentioned surrounding villages. The new plant would replace all the small schemes that became rapidly incapable to meet the growing demand. Voltage would be distributed using medium voltage lines of maximum 10 km. There were however not enough funds available. The UNDP/SGP would only spend 35,000 US\$.

Therefore IHH decided to build a smaller plant in Yanamayo, because the lack of supply was worst there. The plant was built by the auto-construction method, using as much of the existing civil works as possible. IHH gave the inhabitants a course about administration, maintenance and operation of the plant and they helped with the administration of the project during the start-up phase.

Furthermore, the UNDP required that a means of productive end-use would be incorporated in the project. It was decided that a woodcraft workshop was to be establish, in order to make furniture and to learn the students of the secondary school a handicraft.

The construction faced some problems. It was delayed because a road-construction project was carried out simultaneously, which drew heavily of the population's energy and motivation. Furthermore, a period of intense rainfall at the end of 2006 made it impossible to work any further. Lastly, uneven contribution of labor among the beneficiaries led to frictions between them, which led to the stoppage of the project for a while until there was an agreement between the parties and leveling of labor.

The project was finished in August 2007. This was however not the end of the construction works. In January 2008, the penstock was destroyed partially through a landslide caused by excessive rainfall. It took the community three months to repair the damage done. It took such a long time because materials had to come from the city of La Paz, and the roads were inaccessible due to the rain. Currently, the plant is running without any problems.

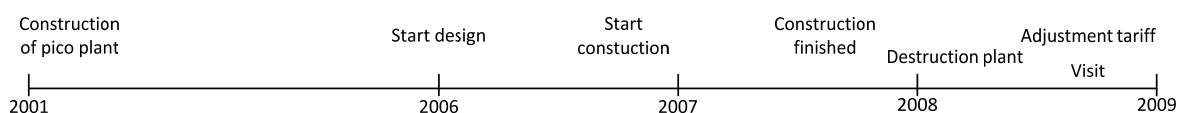
**Expectations**

Expectations were that the plant and the workshop would increase the quality of life in the community. Furthermore, students would be able to learn a craft. Furthermore, this project was IHH's first experience with the use of three separate penstocks, each leading to a different injection of the turbine. Normally, in case of multiple jets, one penstock was used, and the water flow was divided just before the turbine. This option was chosen in order to be able to use already existing penstocks. IHH expects that this technology would work well.

Lastly, the plant should provide enough electricity for 20 years, until 2027, assuming an annual grow in demand of 1.5%.

**Technology**

The plant, fed by the Río Yanamayo, uses a 30 kW Michell Banki turbine, a three-phase, 40 kW generator and a 28 kW electrical control system. Frequency and voltage are controlled by a dump-load. Net head of the plant is 13.7 m, the flow-rate is 423 l/s. Three penstocks are being used of a length of 227 m. The system does not make use of a canal. The power house is situated



230 meters from the village. Power is distributed by an 800 m low-voltage three-phase network.

**Organization**

The plant is managed by the Asociación de Servicios Eléctricos Yanamayo. The board of the Association consists of a president, vice-president, secretary (who is also in charge of finance), and a communicator. The board is elected democratically every year by the socios. The socios, the people who have build the plant, own the system. New inhabitants who use electricity are usuarios. The Association meets every three months to discuss problems or to inform the socios. These meetings have an interactive character. The socios come up with new plans, like to purchase of a satellite to receive television signal.

One operator is engaged. He receives a salary of 400 Bs/month and is in charge of the daily operation of the plant.

**Beneficiaries**

During the design of the plant 94 households lived in the village. IHH calculated that in 20 years this would be 120. The village has grown fast however. Currently there are 74 socios and 35 usuarios.

A big user is the secondary school that is in the village. Furthermore, the construction of a hospital was started in 2007. The hospital is probably going to be a big user as well.

Many people have bought a refrigerator, which increased consumption considerably.

**Finance**

The total investment of the project was 292,343 Bs. The UNDP/SGP paid 268,300 Bs. The Alcaldía de La Asunta had promised to pay the costs for the distribution network, but did not keep it. Therefore, the community decided to pay 24,043 Bs themselves.

Tariffs were set to a basis of 5 Bs and an additional 1 Bs/kWh for socios and 10 Bs and 1 Bs/kWh for usuarios, but adjusted later on to 10 Bs and 2 Bs/kWh for usuarios, because the socios did not agree that usuarios could get electricity for almost the same price, without having contributed labor for the construction of the plant.

**Lessons Learned**

**FINANCIAL/ECONOMIC**

It is often impossible to find enough financial resources to build large plants. Financial resources are available for

projects of IHH, but limited to a maximum of ± 35,000 US\$.

**INSTITUTIONAL**

IHH's auto-construction method is less successful if it is carried out simultaneously with other projects, because it draws heavily on the community.

The wood-workshop was still not fully into operation, because the man in charge did not have sufficient time to start up the workshop. He has to do it besides his normal occupation as farmer and does not get paid by the Association. If a productive end-use will be set up, one should realize that it costs a certain amount of resources, among others time and money.

**TECHNOLOGICAL**

Small, inefficient local build plants can work fine, but cannot supply sufficient electricity for relatively large villages. It is possible to build multiple small plants, like in Palmar, but this increases maintenance and management efforts. Furthermore, local knowledge is limited, through which it is impossible to build an automatic voltage control system. The flow rate has to be controlled manually, which is time-demanding.

The hydraulic design of the plant with multi-pressure pipes to a single hydraulic turbine has been good. Using this method, it is easier to expand an existing plant.

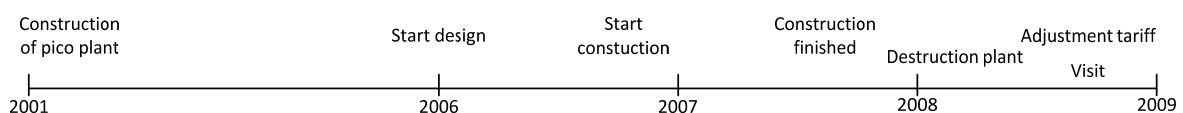
Geographical and climatic conditions can require more robust methods for the construction of the penstock. The penstock is often built on a steep slope that is very sensitive for land-slides. A more robust construction-method should be developed.

**Communication**

There are many pico- and micro-hydro plants in the surrounding areas and several similar systems build by IHH (Charía – 1.5 hours, Flor de Mayo – 2, Quinuni – 2.5). Communication however does not take place. The villagers and board are aware of problems and successes in other villagers, but do not consult with each other. (Technical) problems are discussed with IHH. IHH is called, or the board is going to La Paz.

**Sources**

Interview Presidente (14-10-2008)  
 InformeFinal Yanamayo, October 2007, IHH, La Paz



## Quinuni

16°14'44.56"S, 67°07'45.04"W



<b>Capacity:</b>	34 kW
<b>Costs:</b>	45,500.- US\$
<b>Users:</b>	120 (expected)
<b>Turbine:</b>	Pelton
<b>Start Date:</b>	April 2009 (expected)
<b>Organization:</b>	IHH

## Background

Quinuni is a small village in the sección La Asunta in the Departamento de La Paz. It is situated on the banks of a small river at the elevation of 820 meter. The cultivation of coca is the main source of income, while bananas and corn are grown as well. Approximately 60 families live in Quinuni itself. An equal amount lives in the surrounding areas. The secondary school is located in the village and provides education for the region.

## Project Description

### Implementation

In 2003, the inhabitants of Quinuni decided to construct a micro-hydro plant to electrify the village and houses in the vicinity. Many other villages in the sección La Asunta already had electricity generated by a plant. A Bolivian expert was asked to make a design and construct the plant. Costs were 21,000 US\$, the villagers would pay 125 US\$ each and help with the construction. The Alcaldía de La Asunta would pay the remaining part.

After more than a year, the construction of the plant was completed, and the distribution network installed. However, the plant did not function properly. Two streetlights on the main square were giving light; there was not enough power though to use more lamps.

It turned out that the 'expert' did not have any experience at all. It was his first project, and he had made enormous mistakes in the design. The settling basis was too small and too low to take enough water. The capacity of the canal was too low as well. The forebay tank was not incorporated in the design at all, so that the water directly runs over from the canal to the penstock, resulting in an irregular water supply. Lastly, the place of the penstock was chosen wrongly, the slope was not steep enough.

The 'expert' tried to re-design the plant for more than a year without any result. Another engineer was asked to help, again without improvements.

In 2007, IHH became involved in the project. A new design was made, and funds were sought. The PNCC and the UNDP both pay one-third of the 45,500 US\$ investment. IHH contributes 7,100 US\$ and the beneficiaries 8,350\$ for building materials. The villagers construct the plant; engineers from IHH monitor the construction.

New problems were encountered in October and November 2008. The PNCC and the ViceMinisterio,

which administer the funds of the UNDP, did not agree about the conditions of the payment. Furthermore, the board of the PNCC was changed, encompassing new regulations and conditions, which could not be met directly by IHH and the villagers. The ViceMinisterio decided to part with the project after threats to go on hunger strike. The PNCC has the power to decide now; the villagers have to wait to buy the turbine and generator.

### Expectations

Expectations in Quinuni were high when the plant was constructed in 2003. The community had seen many villages where micro-hydro was introduced successfully. After the project failed, disillusionment prevailed, but the community never gave up entirely. Expectations were a bit less high when the project was restarted. Now (October 2008) everyone is very enthusiastic again and one expects that the project is completed soon.

### Technology

The plant is of 34 kW capacity and is going to use a Pelton turbine and a three-phase generator. The high-voltage distribution lines are approximately 2 km in length. The settling basin, the canal and the distribution network are adapted from the previous design, all other parts are rebuilt.

### Organization

When the plant is finished, the villagers will start a Cooperativa that runs the plant. This Cooperative will consist of a board with at least three members, which will be chosen by the socios every year. An operator will be appointed, who will earn a small income for the services delivered. The villagers who constructed the plants become socios, and own the plant. New future users will become usuarios.

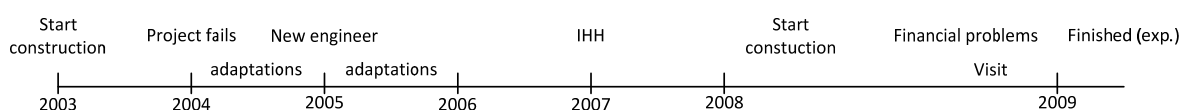
### Beneficiaries

Expectations are that 120 households will be connected, as well as the secondary school that takes care of the education of all children in the surrounding area. There are no workshops or lumberyards.

## Lessons Learned

### TECHNICAL

The most important lesson learned in this project is that there probably are a lot of unskilled engineers, who claim to be expert in micro-hydro. Quinuni is not the first



## Quinuni

16°14'44.56"S, 67°07'45.04"W

project that is damaged by the lack of knowledge of the technology. It is often thought that micro-hydro is an easy technology, and can be build be anyone. This is clearly not the case. Knowledge and experience are key elements in the successful implementation of new projects and are both very rare in Bolivia.

IHH has learned in previous projects that a three-phase distribution network is desired by the local population and possibly enables the generation of productive end-uses and new sources of income. This lesson is applied in Quinuni.

### INSTITUTIONAL

The community and IHH have learned that bureaucracy can hinder the implementation of micro-hydro projects significantly. Bolivian government agencies are slow and passive, and are usually not very fond of working together. Besides this, the frequent changing of authorities will lead to frequently changing rules, hindering transparency and efficiency.

### SOCIAL, CULTURAL AND BEHAVIORAL

Although people have very negative experiences with a technology, they will continue / start over again with it when an implementing organization is able to regain the confidence of the community. In first instance, they will be somewhat reserved, but this will disappear when the project progresses.

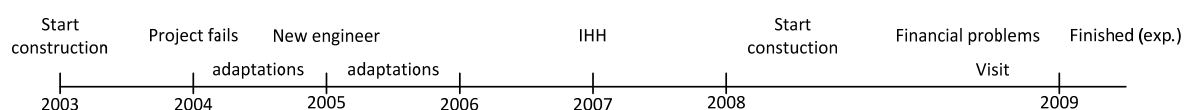
### Communication

Problems have been communicated to IHH, the ViceMinisterio and the PNCC. Communication with other projects has not been taken place. The population of Quinuni is aware of problems and successes of other micro-hydro projects in the region, but not in detail.

### Sources

Interview Dirigente Quinuni (13-10-2008)

Interview José Luis Monroy (IHH) and Dirigente Quinuni (06-10-2008)



### **Appendix III      Interviewed persons and institutions**

Energética	Miguel Fernández Fuente Director
IHH	Emiliano Montaña Gonzáles Researcher
IHH	José Luis Monroy Cuellar Researcher
VMEEA	Virginia Portugal  Two other persons
Watermotor	Ron Davis





## Appendix IV Static barriers to the diffusion of micro-hydro power

### Market barriers

Disturbed competitiveness due to subsidies	Landscape
Non-consideration of externalities	Regime
Misallocation of financial resources	Niche

### Financial/Economic barriers

Micro-hydro plants for very small communities are not financially sustainable	Niche
Micro-hydro plants in poor areas need $\pm$ 150 users to be financially sustainable	Niche
Micro-hydro plants cannot be financed with a commercial loan	Niche
Lack of starting capital	Niche
High initial investment of micro-hydro plants	Niche
Neglect to use local materials	Niche
Inflation is not passed on to the users	Niche
Not all costs are passed on to the users	Niche
Project seen as social venture	Niche

### Technological barriers

Limited possibilities to increase capacity of micro-hydro plants	Niche
Erosion of mountain slopes destroy the canal and/or penstock	Niche
Lack of local technical knowledge	Niche
It is difficult to expand a micro-hydro plant	Niche
Lack of data of flow rate small rivers	Niche
Lack of methods to accurately measure flow rate in short period of time	Niche
Low sustainability of concrete canals	Niche
Obstruction of open canals	Niche
High costs of tubes to be used as canal	Niche
Lack of appropriate technology	Niche
Lack of trainings facility operators	Niche
Lack of micro-hydro experts in rural areas	Niche
Lack of technical capabilities to maintain three-phase system	Niche
Power failures due to shortage of water	Niche
Weak technological performance of micro-hydro plants	Niche
Lack of technical capabilities	Niche
Lack of knowledge transfer	Niche
Labor-intensive billing system	Niche
Lack of knowledge of software system	Niche



## Institutional barriers

Liberal reforms hinder collaboration between niche and regime	Landscape
Lack of transparency of grid-expansion policies	Regime
Bias towards regime-technology of government	Regime
Neglect of advantages micro-hydro technology	Regime
Lack of intention of regime-actor to cooperate with niche-actors	Regime
Lack of coordinating institution	Regime/Niche
Discontinuous learning cycles through frequently changing management	Niche
Unsuitable people with responsibility	Niche
Lack of visible successful examples	Niche
Lack of awareness of opportunities of technology	Niche
Lack of awareness of opportunities	Niche
Ineffective communication between global niche and project level	Niche
Lack of entrepreneurial skills to establish productive end-use facility	Niche
Lack of knowledge about business processes	Niche
Absence of three-phase network as barrier for economic development	Niche
Badly thought-out approach to implement MHP in local communities	Niche
Presence of incapable engineers	Niche
Conflicting purposes of the available water	Niche
Poor participation of beneficiaries	Niche
Involvement users prevent adjustment of tariffs	Niche
Lack of trainings facility operators	Niche
Local inability to contact micro-hydro experts	Niche
Lack of certification system / rating system	Niche
Low-tech appearance of technology	Niche

## Social, cultural and behavioral barriers

Bias towards regime-technology of users	<b>Regime</b>
Dependence from development programs	<b>Niche</b>
Lack of ownership-feelings	Niche
Creation of social differences through the self-assembly method	Niche

## Appendix V Cost-Benefit Analysis (CBA)

### Assumptions CBA

#### Socios

#	76,00
Tariff - Minimum (25 kWh)	16,00 Bs
Tariff - Additional (/kWh)	0,70 Bs
Minimum Use	25,00 kWh/month
Average Use	44,00 kWh/month
Growth Consumption	1,0150

#### Additional

Bs/\$	7,25
i	7,00%
Inflation	5,80%
Fluctuation inflation	5,00%

#### Usuarios

#	16,00
Tariff - Minimum (25 kWh)	16,00 Bs
Tariff - Additional (/kWh)	0,70 Bs
Minimum Use	25,00 kWh/month
Average Use	44,00 kWh/month
Growth Consumption	1,0150

#### Fees

entrance fee	100,00 US\$
# families paid	2,00

#### Operation and Maintenance

Maintenance	1.000,00 US\$/year
Wage operator	350,00 Bs
Number of operators	1,00
Additional costs	7.000,00 Bs

#### Growth

Growth of families	1,0150 /year
Maximum # families	120,00

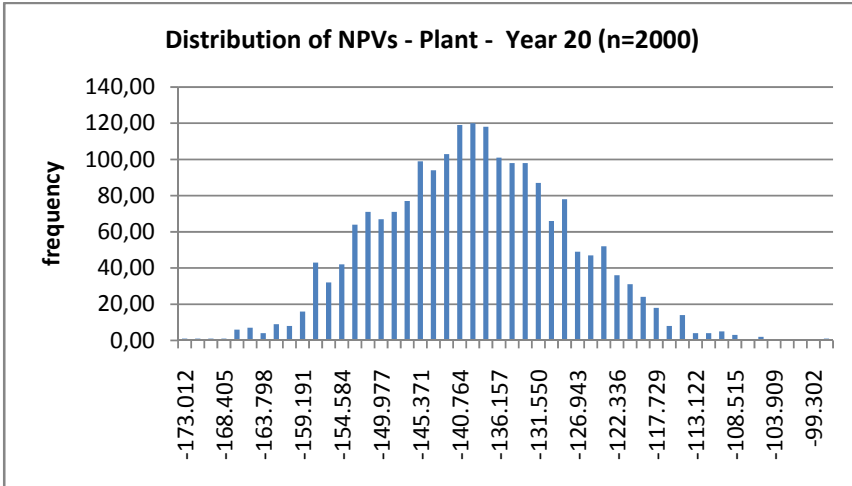
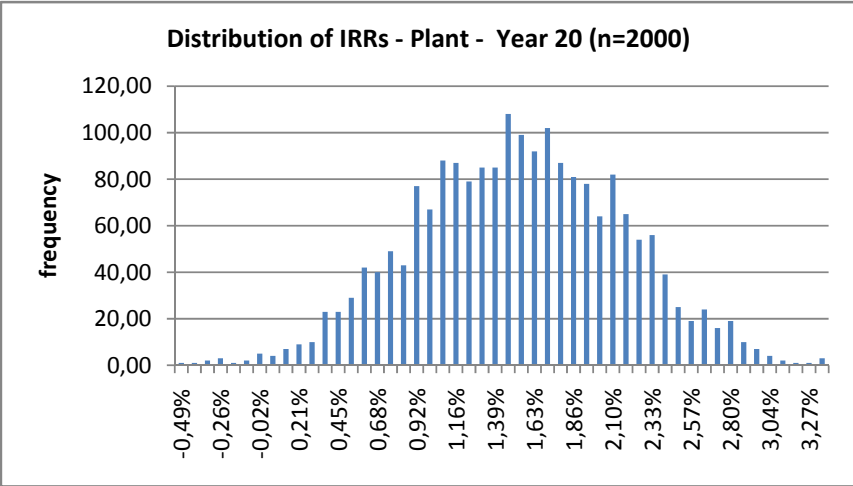
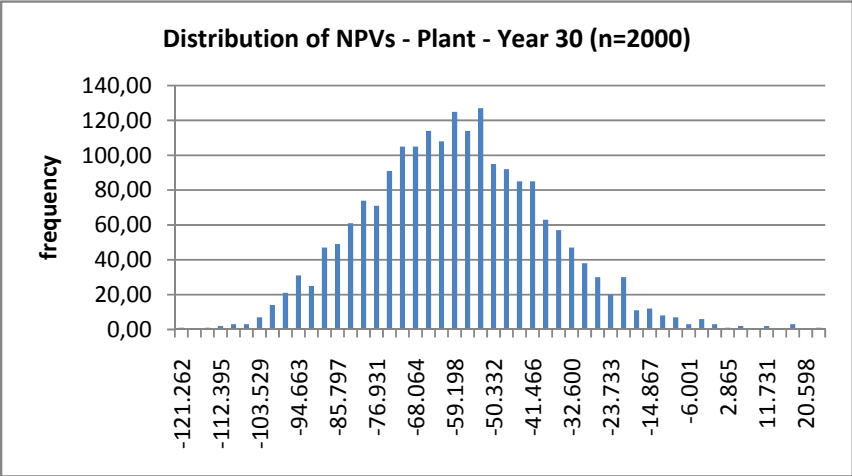
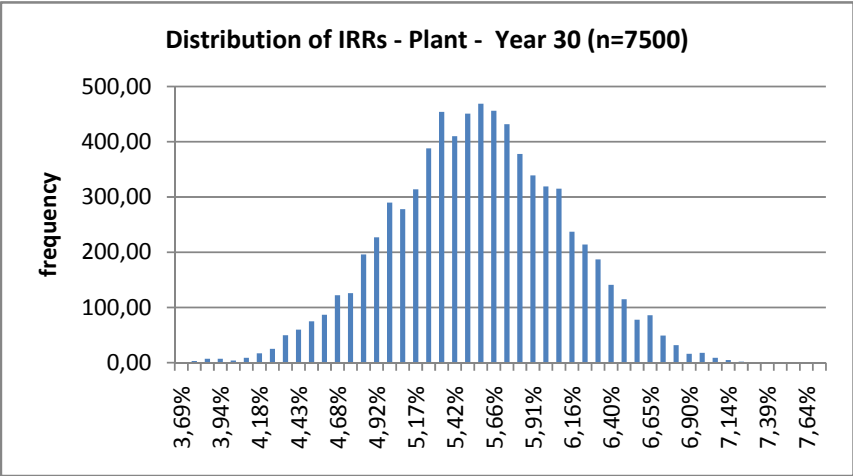
## Data CBA

Year		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
		0	1	2	3	4	5	6	7	8	9
inflation	Inflation static		5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%
	Inflation variable		7,60%	6,83%	6,90%	10,02%	6,71%	4,28%	4,74%	7,54%	1,60%
	Inflation variable		1,0760	1,0683	1,0690	1,1002	1,0671	1,0428	1,0474	1,0754	1,0160
plant - plant	<b>Plant - Costs</b>										
	Investment:										
	UNDP	195.060,00									
	Municipality La Asunta	35.000,00									
	Local	94.835,00									
	Maintenance				7.253,00	7.253,00	7.253,00	7.739,81	8.071,41	8.453,69	9.091,43
	Salario operators				350,00	350,00	350,00	373,49	389,49	407,94	438,71
	Additional				8.926,40	6.112,40	7.000,00	7.469,83	7.789,87	8.158,80	8.774,30
	<b>Total costs:</b>	324.895,00			16.529,40	13.715,40	18.453,00	19.691,55	20.535,20	21.507,78	23.130,30
	<b>Plant - Income</b>										
	Number of socios				76	76	76	76	76	76	76
	Tariff - Minimum				16,00	16,00	16,00	16,00	16,76	18,02	18,31
	Tariff - Additional				0,70	0,70	0,70	0,70	0,73	0,79	0,80
	Income socios:				26.903,54	26.903,54	26.903,54	26.903,54	28.177,73	30.303,43	30.789,53
	# Users				8,00	12,00	16,00	16,24	16,48	16,73	16,98
	# Users - Round off				8	12	16	16	16	17	17
	Tariff - Minimum				16,00	16,00	16,00	16,00	16,76	18,02	18,31
	Tariff - Additional				0,70	0,70	0,70	0,70	0,73	0,79	0,80
	Income users:				2.812,80	4.219,20	5.625,60	5.625,60	5.892,04	6.732,56	6.840,56
	Additional income		1.450,60								
<b>Total income:</b>		1.450,60		43.754,00	35.666,00	32.529,14	32.529,14	34.069,77	37.035,99	37.630,09	
Liqued Assets				11.241,40	38.466,00	60.416,60	74.492,74	87.330,34	100.864,91	116.393,13	130.892,92
<b>Total (income - costs):</b>	<b>-324.895,00</b>	5.620,70	5.620,70	27.224,60	21.950,60	14.076,14	12.837,60	13.534,57	15.528,22	14.499,79	
<b>Plant - NPV</b>	<b>-324.895,00</b>	<b>-319.642,01</b>	<b>-314.732,67</b>	<b>-292.509,29</b>	<b>-275.763,28</b>	<b>-265.727,19</b>	<b>-257.172,95</b>	<b>-248.744,30</b>	<b>-239.706,74</b>	<b>-231.819,81</b>	

	Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
	10	11	12	13	14	15	16	17	18	19	20	
inflation	Inflation static	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%
	Inflation variable	2,42%	8,97%	4,19%	2,98%	5,38%	2,66%	10,01%	10,16%	1,62%	7,08%	9,15%
	Inflation variable	1,0242	1,0897	1,0419	1,0298	1,0538	1,0266	1,1001	1,1016	1,0162	1,0708	1,0915
plant - plant	<b>Plant - Costs</b>											
	Investment:											
	UNDP											
	Municipality La Asunta											
	Local											
	Maintenance	9.237,26	9.460,46	10.308,86	10.740,30	11.060,72	11.655,36	11.964,88	13.162,63	14.500,39	14.735,25	15.778,41
	Salario operators	445,75	456,52	497,46	518,28	533,74	562,44	577,38	635,17	699,73	711,06	761,40
	Additional	8.915,05	9.130,46	9.949,27	10.365,66	10.674,90	11.248,80	11.547,52	12.703,49	13.994,59	14.221,26	15.228,03
	<b>Total costs:</b>	<b>23.501,33</b>	<b>24.069,19</b>	<b>26.227,69</b>	<b>27.325,36</b>	<b>28.140,56</b>	<b>29.653,44</b>	<b>30.440,90</b>	<b>33.488,21</b>	<b>36.891,73</b>	<b>37.489,27</b>	<b>40.143,25</b>
	<b>Plant - Income</b>											
	Number of socios	76	76	76	76	76	76	76	76	76	76	76
	Tariff - Minimum	18,75	20,44	21,29	21,93	23,10	23,72	26,09	28,74	29,21	31,28	34,14
	Tariff - Additional	0,82	0,89	0,93	0,96	1,01	1,04	1,14	1,26	1,28	1,37	1,49
	Income socios:	31.533,48	34.361,38	35.799,45	36.867,46	38.849,52	39.881,19	43.873,52	48.332,54	49.115,38	52.592,41	57.402,21
	# Users	17,24	17,50	17,76	18,02	18,29	18,57	18,85	19,13	19,42	19,71	20,00
	# Users - Round off	17	17	18	18	18	19	19	19	19	20	20
	Tariff - Minimum	18,75	20,44	21,29	21,93	23,10	23,72	26,09	28,74	29,21	31,28	34,14
	Tariff - Additional	0,82	0,89	0,93	0,96	1,01	1,04	1,14	1,26	1,28	1,37	1,49
	Income users:	7.005,84	7.634,12	8.421,48	8.672,72	9.138,98	9.902,87	10.894,20	12.001,42	12.195,81	13.746,51	15.003,69
	Additional income											
	<b>Total income:</b>	<b>38.539,33</b>	<b>41.995,50</b>	<b>44.220,93</b>	<b>45.540,18</b>	<b>47.988,50</b>	<b>49.784,06</b>	<b>54.767,72</b>	<b>60.333,96</b>	<b>61.311,19</b>	<b>66.338,92</b>	<b>72.405,90</b>
	Liqued Assets	145.930,91	163.857,22	181.850,46	200.065,29	219.913,23	240.043,85	264.370,67	291.216,42	315.635,88	344.485,53	376.748,18
	<b>Total (income - costs):</b>	<b>15.037,99</b>	<b>17.926,31</b>	<b>17.993,24</b>	<b>18.214,82</b>	<b>19.847,95</b>	<b>20.130,62</b>	<b>24.326,82</b>	<b>26.845,76</b>	<b>24.419,45</b>	<b>28.849,66</b>	<b>32.262,65</b>
<b>Plant - NPV</b>	<b>-224.175,26</b>	<b>-215.658,60</b>	<b>-207.669,38</b>	<b>-200.110,88</b>	<b>-192.413,51</b>	<b>-185.117,24</b>	<b>-176.876,91</b>	<b>-168.378,23</b>	<b>-161.153,39</b>	<b>-153.176,22</b>	<b>-144.838,94</b>	

Year		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
		21	22	23	24	25	26	27	28	29	30
inflation	Inflation static	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%	5,80%
	Inflation variable	1,51%	3,28%	2,99%	9,79%	9,78%	6,69%	7,18%	8,07%	6,92%	3,11%
	Inflation variable	1,0151	1,0328	1,0299	1,0979	1,0978	1,0669	1,0718	1,0807	1,0692	1,0311
plant	<b>Plant - Costs</b>										
	Investment:										
	UNDP										
	Municipality La Asunta										
	Local										
	Maintenance	17.221,41	17.481,93	18.054,94	18.594,63	20.414,69	22.411,88	23.910,45	25.626,51	27.695,84	29.613,05
	Salario operators	831,03	843,61	871,26	897,30	985,13	1.081,51	1.153,82	1.236,63	1.336,49	1.429,00
	Additional	16.620,69	16.872,12	17.425,15	17.946,01	19.702,58	21.630,11	23.076,40	24.732,60	26.729,75	28.580,08
	<b>Total costs:</b>	<b>43.814,52</b>	<b>44.477,32</b>	<b>45.935,18</b>	<b>47.308,24</b>	<b>51.938,81</b>	<b>57.020,06</b>	<b>60.832,69</b>	<b>65.198,67</b>	<b>70.463,43</b>	<b>75.341,18</b>
	<b>Plant - Income</b>										
	Number of socios	76	76	76	76	76	76	76	76	76	76
	Tariff - Minimum	34,65	35,79	36,86	40,47	44,43	47,40	50,80	54,90	58,70	60,53
	Tariff - Additional	1,52	1,57	1,61	1,77	1,94	2,07	2,22	2,40	2,57	2,65
	Income socios:	58.270,55	60.180,53	61.979,40	68.046,00	74.703,04	79.698,03	85.417,98	92.315,44	98.705,87	101.772,60
	# Users	20,30	20,61	20,92	21,23	21,55	21,87	22,20	22,53	22,87	23,22
	# Users - Round off	20	21	21	21	22	22	22	23	23	23
	Tariff - Minimum	34,65	35,79	36,86	40,47	44,43	47,40	50,80	54,90	58,70	60,53
	Tariff - Additional	1,52	1,57	1,61	1,77	1,94	2,07	2,22	2,40	2,57	2,65
	Income users:	15.230,65	16.516,37	17.010,07	18.675,03	21.478,32	22.914,46	24.559,04	27.748,63	29.669,50	30.591,31
	Additional income										
	<b>Total income:</b>	<b>73.501,21</b>	<b>76.696,91</b>	<b>78.989,46</b>	<b>86.721,02</b>	<b>96.181,36</b>	<b>102.612,49</b>	<b>109.977,02</b>	<b>120.064,08</b>	<b>128.375,37</b>	<b>132.363,90</b>
	Liqued Assets	406.434,87	438.654,46	471.708,74	511.121,53	555.364,07	600.956,50	650.100,83	704.966,24	762.878,18	819.900,90
	<b>Total (income - costs):</b>	<b>29.686,69</b>	<b>32.219,59</b>	<b>33.054,28</b>	<b>39.412,79</b>	<b>44.242,55</b>	<b>45.592,42</b>	<b>49.144,34</b>	<b>54.865,41</b>	<b>57.911,94</b>	<b>57.022,73</b>
<b>Plant - NPV</b>	<b>-137.669,22</b>	<b>-130.396,83</b>	<b>-123.424,14</b>	<b>-115.654,04</b>	<b>-107.502,39</b>	<b>-99.651,58</b>	<b>-91.742,76</b>	<b>-83.490,88</b>	<b>-75.350,62</b>	<b>-67.859,70</b>	

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