ESMAP TECHNICAL PAPER
090

Stimulating the Picohydropower Market for Low-Income Households in Ecuador

December 2005

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

PURPOSE

The Energy Sector Management Assistance Program (ESMAP) is a global technical assistance partnership administered by the World Bank and sponsored by bi-lateral official donors, since 1983. ESMAP's mission is to promote the role of energy in poverty reduction and economic growth in an environmentally responsible manner. Its work applies to low-income, emerging, and transition economies and contributes to the achievement of internationally agreed development goals. ESMAP interventions are knowledge products including free technical assistance, specific studies, advisory services, pilot projects, knowledge generation and dissemination, trainings, workshops and seminars, conferences and roundtables, and publications. ESMAP work is focused on four key thematic programs: energy security, renewable energy, energy-poverty and market efficiency and governance.

GOVERNANCE AND OPERATIONS

ESMAP is governed by a Consultative Group (the ESMAP CG) composed of representatives of the World Bank, other donors, and development experts from regions which benefit from ESMAP's assistance. The ESMAP CG is chaired by a World Bank Vice President, and advised by a Technical Advisory Group (TAG) of independent energy experts that reviews the Programme's strategic agenda, its work plan, and its achievements. ESMAP relies on a cadre of engineers, energy planners, and economists from the World Bank, and from the energy and development community at large, to conduct its activities.

FUNDING

ESMAP is a knowledge partnership supported by the World Bank and official donors from Belgium, Canada, Denmark, Finland, France, Germany, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom. ESMAP has also enjoyed the support of private donors as well as in-kind support from a number of partners in the energy and development community.

FURTHER INFORMATION

For further information on a copy of the ESMAP Annual Report or copies of project reports, please visit the ESMAP website: **www.esmap.org**. ESMAP can also be reached by email at **esmap@worldbank.org** or by mail at:

ESMAP
c/o Energy and Water Department
The World Bank Group
1818 H Street, NW
Washington, D.C. 20433, U.S.A.
Tel.: 202.458.2321
Fax: 202.522.3018

Stimulating the Picohydropower Market for Low-Income Households in Ecuador

December 2005

John Green

Manuel Fuentes

Kavita Rai

Simon Taylor

Energy Sector Management Assistance Program
(ESMAP)

First printing December 2005

Table of Contents

List of Tables

List of Figures

List of Photos

Preface

Providing modern energy services in remote rural areas is often costly and difficult to achieve. However, the availability of reliable energy supplies in rural areas is one of the key components required to help countries meet many of the Millennium Development Goals. Rural communities around the world deserve the opportunity to benefit from their abundant natural resources and to have access to modern energy supplies.

Picohydro (very small hydropower units suitable for a single household or a small group of households) is a comparatively cheap option and can be used by millions of people who now live in unelectrified areas of developing countries in which a hydropower resource exists. It is becoming a mature technology that should now be considered as part of the menu of alternatives to grid extension, diesel generators, solar photovoltaic (PV) systems, and other systems now being used in rural areas.

In comparison with solar PV, grid extension, and diesel generators, picohydro can be installed at a lower cost for the same energy output, and in the markets in which it has become established, subsidies have not been required. However, there is a need for programs to support the emergence of picohydro markets in developing countries.

This project has undertaken the groundwork to establish the road map for that development in Ecuador, by initiating a market assessment for picohydro in the Andean region, developing technical capacity to install and maintain picohydro systems at demonstration sites, and helping a small group of businesses see the commercial opportunities arising from the sale of picohydro systems in the country. A sales and commercial infrastructure for picohydro may emerge in Ecuador as a result of these activities. However, further training courses on installation and maintenance for potential picohydro dealers in other regions and an awareness-raising promotion campaign in conjunction with the main actors would help that to be achieved. In addition, the establishment of a system of monitoring, quality assurance, and certification for picohydro equipment will help to ensure that the benefits of using reliable, good-quality equipment are made evident to purchasers. If these activities are supported, picohydro will be able to play a significant role in helping to improve the lives of those people who would otherwise not have access to electricity and the educational, economic, and social benefits it can bring if properly developed.

If the main outcome of this project is that it raises awareness in the international community about the role that picohydro systems can play in providing rural people around the world with a source of electricity to give them access to lighting, communications, and low-power productive uses, then it would have been worthwhile. The fact that it has also provided these benefits to a small number of communities in Ecuador and set the foundation for the creation of a market for picohydro in the country will also be seen as a significant achievement.

Acknowledgments

This report was prepared by IT Power, United Kingdom, under the direction of Mr. Philippe Durand (World Bank), lead energy specialist and task manager for ESMAP activity P079802. The main authors of the report are Simon Taylor, Manuel Fuentes, and Kavita Rai, from IT Power. John Green reviewed, edited and approved the final document.

Acknowledgment should be given to the Department for International Development (United Kingdom) for support via a Knowledge and Research project on picohydro and the clean development mechanism that complemented this Energy Sector Management Assistance Program initiative. The results of the research done on picohydro in Vietnam and the Philippines would not have been possible without the support of Prof. Nguyen duc Loc of the Vietnam Support Program for Sustainable Energy Development in Hanoi and Vicente Roaring and Olegario Serafica of the Renewable Energy Association of the Philippines, all of whom are committed to the sustainable development of picohydro technology for the benefit of the remote rural areas of their countries.

The success of the project has been a result of the committed and skilled work of Ecuadoran partners, particularly Milton Balseca, the local hydro expert; and staff of TecnoTramaAmbiental (TTA) in both Spain and Ecuador; Xavier Vallve; Oriol Gavalda; Emma Ramirez; Juan Gallarza; Carlos Navas; Patrik Lopez; and Elio Ramirez.

The success of the pilot projects in Ecuador was made possible by the belief of the local communities in Ozogoche, Zapallo, Alto Tena, and Las Caucheras; thanks go to the communities there, the local leaders, and picohydro dealers who helped install the equipment. The help of Piedad Andi as translator and mediator in the communities of Alto Tena and Zapallo was invaluable. Recognition should also go to José Antonio Bejarano, leader of Ozogoche, who tragically died last year in an accident. He had the vision that this technology could truly help his people.

Thanks also to David Seymour and Glenn Whalan of Asian Phoenix, who supplied the picohydro units and were always available to provide advice and support during the installation and commissioning of the units.

Acknowledgment is given to the staff of the Department of Renewable Energy and Energy Efficiency at the Ecuadoran Ministry of Energy and Mines, who assisted in the site selection and training seminar before installation of the pilots, especially to Jorge Alava, former director of DREEE, and Xavier Gomez; Robet Pinzon and Marcelo Neira from CONELEC, who have supported the introduction of picohydro technologies and helped with the logistics for the training seminar; and Jose Dulce of CONAM, who strongly supported this project in all its activities. Special thanks to Nidhi Sachdeva for desktopping the final report and to Marjorie Araya for coordinating the publications process, both from ESMAP.

Abbreviations and Acronyms

AIS	Andean Integration System
ANIAD	Antique Development Foundation (the Philippines)
CONAM	National Council of Modernization
CONELEC	National Council of Electricity
CDM	clean development mechanism
DEREE	Dirección de Energías Renovables y Eficiencia Energética (MIEM)
DFID	Department for International Development (UK)
ELC	electronic load controller
ESMAP	Energy Sector Management Assistance Program
EVN	Electricité de Vietnam
FERUM	Rural and Marginal-urban Electrification Fund
hh	Household
HH	high-head
HPC	Hydro Power Centre
IMS	Institute of Materials Science
INE	Instituto Nacional de Energía
INECEL	Instituto Ecuatoriano de Electrificación
IN-SHP	International Network on Small Hydro Power
KaR	Knowledge and Research (DFID R&D Program)
kW	Kilowatt
LH	low-head
MEM	Ministerio de Energía y Minas
NGO	nongovernmental organization
NHE	Nepal Hydro and Electric Pvt. Ltd.
O&M	operation and maintenance
PH	Picohydro
PV	Photovoltaic
REAP	Renewable Energy Association of the Philippines
RERC	Renewable Energy Research Centre (Vietnam)

RESCO	rural energy service company
RRA	rapid rural appraisal
SHS	solar home systems
SIISE	Integrated System of Social Indicators of Ecuador
SIN	Sistema Interconectado Nacional
TTA	TramaTecnoAmbiental
VSED	Vietnam Support Program for Sustainable Energy Development
Wp	watts peak

All monetary amounts are in U.S. Dollars unless otherwise indicated

Executive Summary

1. The main aim of this World Bank–ESMAP project has been to pave the way for picohydro to become accessible to low-income households in Ecuador, with the view to replicating the process in the Andean region and other developing countries. This has been done through five main activities: (1) assessing the main experiences in picohydro technology and market developments, looking particularly at Vietnam and the Philippines[1]; (2) reviewing the existing use of microhydro in five Andean countries[2] and assessing their potential picohydro market; (3) establishing 31 pilot picohydro projects in two provinces of Ecuador with full participation of the end users in local communities; (4) encouraging a sustainable local infrastructure for supporting picohydro technology in Ecuador through training local technicians and bringing local dealers forward to consider picohydro as a business venture; and (5) conducting a rapid rural appraisal in the communities before and after the installation of the picohydro pilots to consider the technological and social impacts in the Ecuadoran situation.

Main Outputs

2. There are five main outputs of this project. First, the project builds on the findings from an associated U.K. Department for International Development (DFID) project,[3] which evaluated the successes and lessons to be learned from the Vietnamese picohydro experience and assessed the factors that have led to the emergence of a picohydro market in the Philippines following the import of equipment from Vietnam. As part of this process, an investigation was done of the options for technology transfer of picohydro to Ecuador and how improvements in equipment quality can help to improve the sustainability of the market.

3. Second, a rapid review of the extent of existing use of microhydro and picohydro in the Andean countries (Ecuador, Peru, Bolivia, Colombia, and Venezuela) was made, including assessing the type of market, installed capacity, and costs of the technology. An assessment of the potential market and the institutional barriers to the diffusion of picohydro in these Andean countries was also made. Based on rural electrification and income data as well as estimation of hydrological resources in the various regions of the five Andean countries, the estimates that resulted from this assessment are summarized in Table 1.

---

[1] This part of the project was cofinanced by UK Department for International Development (DFID), under its Knowledge and Research (KaR) program.
[2] Ecuador, Peru, Bolivia, Colombia, and Venezuela.
[3] "CDM pilot project to stimulate the market for family-hydro for low-income households," DFID KaR Project R8150 (2002–2004).

Table1: Market Size for Picohydro in the Andean Region

Country	Nonelectrified rural households	Technical achievable no. of households that could use picohydro	Range of genuine household market based on capacity and willingness to pay
Bolivia	515,815	355,000	55,000–109,000
Peru	1,462,783	671,000	98,000–197,000
Ecuador	249,199	137,000	16,000–32,000
Colombia	127,343	39,000	7,000–14,000
Venezuela	72,170	28,000	4,500–9,000
Total	**2,427,310**	**1,230,000**	**180,500–361,000**

4. Third, 31 picohydro pilot projects were established in five villages of two provinces with varied topography and natural environment. Ten pilots were installed in Chimborazo in the Andes Mountains and 21 in Napo, in the lowland Amazonian rain forest. These projects have provided lighting and reliable AC power for a total of 193 people; and in the monitored first six months of operation, although there were two instances of generators burning out (these were replaced under warranty), the units are all operating and continue to be used even in the village that has subsequently had a grid connection.

5. Fourth, to build the foundation for a sustainable local commercial infrastructure for picohydro technology in Ecuador, a training course was given for installation and maintenance aimed at engineers and technicians. In addition, discussions about business opportunities for picohydro were conducted with potential importers and companies that have the rural-based commercial structure in place to eventually act as dealers. This resulted in high levels of interest from most in the private sector, with the view that even without any marketing about 20 picohydro systems could immediately be sold in one year by each dealership for a very small initial investment. However, there was a requisite that more technical information be forthcoming and support for importation be put in place, because it was recognized that if the units were made in Ecuador, the price would be higher than if they were imported from Vietnam. Also, one of the larger electrification companies thought that despite picohydro being an economic service for isolated households, the company could not make it into a profitable business.

6. Fifth, an activity on rapid rural appraisal (RRA) of the pilot projects ran throughout the project, which established a baseline for the communities chosen, monitored the picohydro equipment for more than six months of operation, and conducted a social impact assessment at the end of the project.

Experience with Picohydro Technology

7. Typically, picohydro systems have a capacity of between 200 and 1,000 watts of electrical power, but the term "picohydro" can include systems up to 5 kilowatts, with a range of turbines for varying heads ("low-head" propellers, "medium-head" turgo or cross-flow runners, and "high-head" pelton wheels). Generally, they are used for domestic electricity applications such as lighting, television and radio, and battery

charging. The units are small and cheap and typically are owned, installed, and used by a single family, hence, their commonly used name of “family-hydro” (see Photo 1).

Photo 1: Picohydro Installed in Ecuador for Family Use

8. In Vietnam, China, and Nepal picohydro technology has become widely available at an affordable cost to rural households, with turbine prices in the range of $25 for 200 watts to $1,000 for 3 kilowatt community pelton systems. The technology that has fueled this market development has been mainly a mix of locally made low- and medium-head units, although the experience has been that units from China are inefficient, unreliable, and sometimes unsafe and have a life of less than two years. Generally, the market mechanism has been a “cash and carry” model in which technical information is spread by word of mouth.

9. There are some other countries that have experienced picohydro market development, primarily in SE Asia (e.g., the Philippines), India, and South America. There has been only minor uptake of the low-head technology in Africa to date, but there remains a massive unexploited potential throughout the developing world and in niche markets in North America and Europe.

10. Vietnam has seen the purchase of most picohydro schemes outside China, and it is estimated that approximately 120,000 units have been installed since the late 1980s, most in the northwest corner near the border with China. The Philippines has recently experienced a small, but growing activity in the development of low-head picohydro turbines for 220 volts through the import of equipment from Vietnam. The distance of the Philippines from mainland China has meant that the poorer-quality equipment that has flooded the Vietnamese market has not been able to penetrate the

Philippines, so there has been a more controlled development of family hydro in the country.

11. On the basis of a project undertaken for DFID between 2002 and 2004 in Vietnam and the Philippines, called the "CDM pilot project to stimulate the market for family-hydro for low-income households," a study of the two different market mechanisms that have taken place in these countries has been gained for this ESMAP project.

12. The following are the main concluding points and lessons learned from this project that are important in the Ecuador situation:

- Compared with other small-scale renewable and conventional energy options for rural areas of developing countries, picohydro is one of the most immediately affordable sources of electricity (even for the "poor").
- Vietnam has seen the most development of picohydro for small amounts of power for family use, with about 120,000 units deployed, but not all of this development has been sustainable because of poor-quality products being employed by rural people with annual incomes typically of only $300.
- Nevertheless, the Vietnam market for picohydro remains strong, and even considering pressures that tend to reduce the market (grid extension efforts and promises made), it is still expected to be in a range of 20,000 to 25,000 units per year.
- The Philippines had virtually no low-head picohydro development until units began to be exported from Vietnam in the late 1990s. Most of these units are of higher quality and have been installed with competent engineering support and the use of proper civil works, using funding support from local (and national) government and nongovernmental organizations (NGOs). Also, to maximize the units' potential, the larger picohydro units have often been chosen to supply electricity into microgrids for clusters of households or small villages.
- The Philippine market for off-grid electrification remains large (2.7 million households), and picohydro has an immediate potential market of more than 24,000 units and a total market as large as 120,000 units.
- The Vietnamese and Philippine picohydro experience having been researched, an approach to analyzing market characteristics and estimating market potentials has been developed and applied directly to the Andean region.
- Vietnamese picohydro technology in association with local dealers in Ecuador (also through support from the Ecuadoran government to further stimulate the local market) having been successfully demonstrated, work can now be focused on scaling up the deployment of many thousands of picohydro units in the country.

Economic Analysis of Picohydro

13. Picohydro technologies are part of a menu of options for bringing modern energy services to households in unelectrified areas of developing countries where the hydro resource exists. A comparison of capital and operating costs for calculating the life-cycle costs of various renewable energy and diesel genset systems was conducted. It was found that individual picohydro is one of the most affordable sources of electricity, especially for community-based projects, with life-cycle costs for each household between $74 and $150 per year, compared with the life-cycle costs of solar, hybrid, wind, or fossil fuel–based options, which start at $140 per household per year. In addition, a picohydro unit can provide power at 220 volts AC instead of 12 volts (from photovoltaic–solar home systems [PV-SHS]), which then requires expensive inverters to upgrade to AC power.

14. The economic analysis (on a life-cycle cost basis) for good-quality picohydro units shows that the technology compares favorably with other small-scale (renewable or diesel-based) options for bringing modern energy services to households in unelectrified areas of developing countries. As far as being affordable, picohydro can in many circumstances be within the reach of the poor (using the definition that the "poor" live on less than $2 a day) and is valuable because AC power that can be linked to income-generation activities is produced.

Opportunities for Picohydro in the Andean Region

15. Analysis has shown that Ecuador has a good potential for exploiting picohydropower resources and a history of micro- and minihydro on which to base the new development of picohydro. The potential actual household market for picohydro is estimated to be a minimum of 16,000 in Ecuador out of a technically achievable total of 137,000 unelectrified residences that are off grid and near the required hydraulic resources.

16. The neighboring Andean countries show even more potential, especially Peru and Bolivia, with a minimum of 98,000 and 55,000 households, respectively, estimated to be the market in those countries. From the DFID study that cofinanced this Energy Sector Management Assistance Program (ESMAP) project[4] and analyzed the global market demand for picohydro systems, the genuine household market potential for low-head picohydro was found to be 285,000 in the five countries of the Andean community, which is similar to the range of 180,000 to 360,000 estimated in this project, which could represent between 7 percent and 15 percent of the households yet to be electrified in these countries. This compares with a global potential of about 4 million units and 740,000 estimated for all of Latin America (Brazil has the highest potential because of its relatively larger population).

17. Experience in the picohydro sector in Asia, in which hundreds of thousands of systems have been sold in the past 15 years on a cash-and-carry basis, has shown that

[4] "CDM pilot project to stimulate the market for family-hydro for low-income households," DFID KaR Project R8150 (2002–2004).

it is also realistic to deploy that many picohydro units in Ecuador and the Andean region. However, a major lesson learned is that because of the poor quality and limited life span of cheap equipment, less than half of the 120,000 units installed in rural areas of Vietnam are actually still operating.

18. Recent developments in the Philippines and now through this project in Ecuador have shown that there may be a model for the sustainable deployment of picohydro, but that it requires higher-quality equipment and engineering support.

19. With completion of the pilot demonstrations, the costs associated with deployment (which the project supported) were $475 per unit (including equipment, civil works, and electrical cabling costs), with estimated operational and maintenance costs of $5 per year. Given a conservative equipment life of only five years, an end user would need to save $40 per year to purchase another picohydro system worth $200. Given these costs, the opportunity clearly now exists for further expansion of the market for good-quality picohydro products in Ecuador and the neighboring Andean region countries and other parts of Latin America.

Impact of the Project

20. By successfully demonstrating good-quality picohydro technology through the pilot projects (with training and awareness-building activities for all stakeholders involved) and showing that a dealer-based, private sector–led approach to picohydro projects can be financially viable, a deeper understanding about how to build the local infrastructure for the commercialization of picohydro in Ecuador has been gained. To stimulate a sustainable market for picohydro, it is important that these elements be in place.

21. The impact of the pilots on end user beneficiaries has been carefully considered in the project. Benefits include an increase in the quality of life because of better lighting systems enabling community activities during the evenings. Beneficiaries have pointed out that there were fuel savings and an increase in the productive output as well as increased opportunities for educational and social activities.

22. Through the RRA undertaken and the training of users, along with the actual implementation of the pilots, the end users overcame their initial apprehension about the technology and now have confidence in maintaining the picohydro systems and have also acquired additional skills.

23. It is clear that for reliable and long-lasting installation, operation, and maintenance of the picohydro systems, proper site assessment (e.g., river flows during different seasons), training of both owner and operator, and provision of safety and best-practice guidelines are essential.

24. It has been found that the demonstration of picohydro technology has created a market development effect in which requests for more systems have been made in the target villages and by neighboring communities. The private sector, government, and international donors can all play a part in supporting the scale-up of picohydro

deployment in Ecuador, providing an example to other Andean countries and other developing countries alike.

Recommendations for Future Actions

25. It has been shown that picohydro can provide services to low-income families in rural areas in Ecuador. There is a segment of the rural population for which picohydro is certainly affordable, but much more awareness is required of the potential benefits of the technology over other forms of off-grid electrification (e.g., diesel gensets). However, financing support may still be required to make it possible for the poorest customers to afford a picohydro system, particularly if good-quality technology is to be used and installed properly.

26. It is clear from the experience gained in this project that a dealer-based energy service model, with postsales maintenance support fed by currently available good-quality equipment, can deliver the sustainable deployment of picohydro systems for real benefits to rural households.

27. Some obstacles do remain before potential dealers will entertain picohydro commercially in Ecuador, but they can be overcome. For example, a more thorough understanding of the latest technology through input from manufacturers and suppliers from Asia will give local dealers confidence, and it will be important for the conditions surrounding the importation of large numbers of picohydro units to be clarified.

28. Many more potential dealers would come forward if a proper evaluation was done of the actual market locations and how picohydro can add value to products and give possibilities for productive uses in these locations. At the same time, to motivate participation in projects this study should be complemented by training and information dissemination about picohydro to potential beneficiaries.

29. In addition to these aspects being in place, to make this model commercially viable and to scale up the use of picohydro in developing countries, what is now required is concentration on establishing standards and certification/licensing for the products and providing technical support for feasibility studies and site-level installation, operation, maintenance, and warranty. Close community liaison is crucial in determining how picohydro technology is best organized at the end user level. For example, beneficiaries may need to provide their labor and local materials to reduce initial capital costs, pay for and carry out proper operation and maintenance, and understand the importance of using the technology within its capability.

30. Subsidy for the capital costs of picohydro technology is not a priority area except perhaps for the poorest of the poor, whereby some of the capital costs for good-quality systems ($475 per 200 W unit in this project) would be provided by national renewable energy programs and households would be expected to meet the operation and maintenance costs and to save $45 per year for the next new turbine.

31. Support is required, however, for quality assurance/licensing of the equipment from national energy ministries together with universities that have appropriate testing facilities, support is needed to stimulate the establishment of easier

importation of technology and new sales infrastructure through regional bodies and the appropriate government departments, and seed money is needed to help institutions set up engineering support services from multi- and bilateral agencies. That can also be done in conjunction with the private sector (dealers, rural energy service companies [RESCOs], rural banks, entrepreneurs, etc.) as well as NGOs.

1

Introduction

1.1 The main aim of this World Bank–ESMAP project in Ecuador has been to pave the way for picohydro to become accessible to low-income households in the country, with the view to replicating the process in the Andean region and other developing countries. Ecuador offers an ideal place to assess and stimulate a new energy market because a large proportion of the 250,000 unelectrified low-income families live within 300 meters of small streams in which a picohydro system could be installed for an individual household or group of households.

1.2 The Ecuadoran Ministry of Energy and Mines (MEM) is looking to stimulate the small-scale electrification market in the country because there is an emerging potential for energy services and a sufficient capacity and willingness to pay for electricity in a large portion of unelectrified rural households.

1.3 Picohydro technology is becoming mature with the widespread deployment of equipment in Asian countries such as Vietnam, China, and Nepal. However, few international donors or national governments are aware of the potential for picohydro to be used in rural development programs. The technology can provide a much-needed, low-cost solution for supplying electricity for lighting and low-wattage appliances to millions of off-grid isolated households.

1.4 There is a large potential market for picohydro in Andean countries and throughout the developing world. However, the poor quality and unreliability of the systems (coming mainly from China) that have to date dominated the market have created a poor image for picohydro technology. Good-quality systems are now becoming more available, and although they are significantly more costly than the cheapest versions, they are still substantially cheaper and more cost-effective than other options for electricity generation in many cases, as shown in the economic analysis performed as part of the project.

Scope and Organization

1.5 The ESMAP project is a small and low-cost initiative approved in May 2002 undertaken by IT Power Ltd. of the United Kingdom, as the international and lead consultant, and by TramaTecnoAmbiental (TTA)–Ecuador, as the local consultant, with specialist input from Ing. Milton Balseca, a local hydro expert. The project commenced in March 2003, and the final activity took place at the end of 2004. There were five main activities as shown in Table 1.1.

Table 1.1: ESMAP Picohydro Project Activities, Timetable, and Outputs

Activity	Dates	Outputs
1. Assessment of existing markets for picohydro	Aug 2003	Analysis carried out in Vietnam and the Philippines to help assess potential in Ecuador and the Andean region
2. Picohydro (PH) pilot projects	June–Dec 2003	31 PH systems established in 2 provinces
3. Training seminar	Sept 2003	44 participants attended in-country technical seminar
4. Impact assessment	Oct 2003–Oct 2004	Carried out through rapid rural appraisal in three parts: • Baseline—Oct 03 • Monitoring—Dec 03–Jun 04 • Impact Assessment—Nov 04
5. Dissemination (local business opportunities)	Nov 2004	8 potential dealers/developers for picohydro interviewed

1.6 The Ministry of Energy and Mines (MEM) was closely associated with the project and had particular responsibilities in activities 2, 3, and 5 (for example, they were the leaders of the training seminar). This project has enabled MEM to present one further hydro-based option in its current rural electrification program, at the same time helping to build a sustainable market for an emerging picohydro sector for Ecuador.

1.7 The international and local consultants had to engage all relevant stakeholders to achieve the outputs for the project. This included the installers of systems, the end users themselves, the potential future dealers for picohydro technology, other governmental bodies interested in integrating picohydro into their electrification plans, state electricity utilities, NGOs, and rural development operatives. At the same time, because of the international nature of the project, contact was maintained with suppliers of picohydro technology from Vietnam and groups in other Andean countries and nations in Latin America interested in developing markets for picohydro.

2

Existing Markets for Picohydro

2.1 To better understand the opportunities in Ecuador and the wider Andean region an assessment was undertaken of existing markets for picohydro (PH) globally, drawing from experience in Vietnam, China, and the Philippines. Before assessing these opportunities, this chapter gives an overview of picohydro technology and experience in Asia.

Background of Picohydro

2.2 Typically, a picohydro unit has a capacity of between 200 and 1,000 watts of electrical power, but the term "picohydro" can include systems up to 5 kilowatts. A low-head propeller or medium-head turgo-type turbine (see Photo 2.1 and 2.2) is used for domestic electricity applications such as lighting, television and radio, and battery charging. The units are small and cheap (in the range of $25 for 200 W to $580 for 1,000 W) and typically are owned, installed, and used by a single family, hence the commonly used name of "family-hydro."

Photo 2.1: Vietnamese 200 watt, low-head picohydro "propeller" unit in the Philippines

Photo 2.2: Vietnamese 200 watt, medium-head picohydro "turgo" unit in Ecuador

2.3 The different types of technologies used for picohydro power throughout the world cover a range of turbine types, applicable to different heads. Annex 1 gives more details on the technologies available:

- Tiny pelton wheels ("Peltric" sets) are being promoted in Nepal for sites with 20 to 50 meter heads—only a hosepipe is required for a penstock. Many hundreds have been installed, and there are dozens of manufacturers (see Photo 2.3).

- In the Philippines there is a trial being conducted of tiny cross-flow turbines ("fireflies") at 5 to 20 meter heads, and there is similar development in Colombia (see Photo 2.4).

- In the United States, Canada, and Australia a few companies offer a variation on the turgo turbine for medium- and high-head sites, principally to serve remote off-grid dwellings (see Photo 2.5). Also, some mountainous countries in Europe have developed small pelton turbines for powering remote Alpine lodges.

- China and Vietnam have had the greatest dissemination of low-head propeller turbines, suitable for only 1 to 2 meter head (sometimes called "standing" turbines) (see Photo 2.6), and tiny turgo turbines for 5 to 11 meter head (or "sitting" turbines).

Photo 2.3: High-head pelton wheel "Peltric set" (c/o KMI, Nepal)

Photo 2.4: Medium-head cross-flow turbine (c/o PRRM, Philippines)

Photo 2.5: Medium-head turgo turbine (c/o Platypus, Australia)

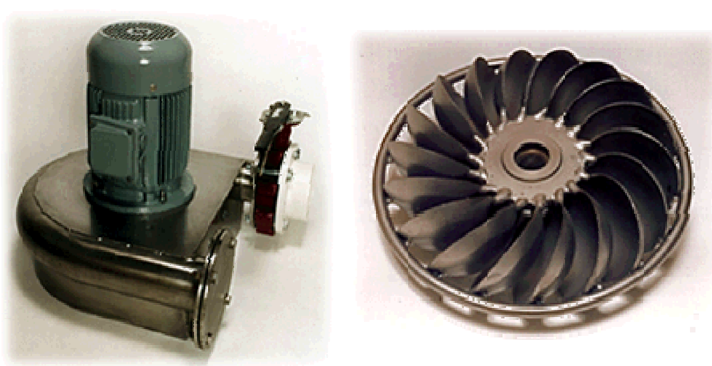


Photo 2.6: Low-head propeller turbine (Vietnam)

2.4 Globally, low- to medium-head sites (1.3 to about 10 m) are by far the most widespread, available from irrigation canals as well as streams, and in both hilly and plains areas. These sites often avoid the political difficulties of crossing land outside the ownership of the family seeking to develop a scheme, because low-head picohydro schemes do not require a long supply pipe to bring water from farther up the hill, and they simply employ a compact flume (for conveying the water into the unit) and a short draft tube (for creating the head by drawing water through) as an integral part of the turbine. Higher-head sites have been developed in areas where the topography lends itself to this type of development, such as in countries of the Himalayas.

2.5 In Vietnam, China, and Nepal picohydro (or family-hydro) technology has become widely available at an affordable cost, as shown in Table 2.1.

Table 2.1: Cost Structure for Installation of Various Forms of Picohydro

Cost	**Low-head PH (China)**	**Low-head PH (Vietnam)**	**High-head Peltric (Nepal)**
Capacity	300 W (actually 100 W)	200 W	1,000–3,000 W
Turbine	$15–20	$50–$150	$1,000–$3,000
Civil works	$20 (but often very minimal)	$100–$200	Site variable
Transmission line	$20–100	$20–$100	Site variable
Household electrical system	$10–50	$10–$50	$10–50
Engineering support	-NA-	$200	Site variable
TOTAL	**$65–$190**	**$380–$700**	**$2,000–$6,000**
Cost/kW	**$650–$1,900**	**$1,900–$3,500**	**$2,000**

2.6 The technology that has fueled this market development has been a mix of locally made low- and medium-head units, despite the fact that these units are inefficient and short lived. Other countries that have experienced market development are primarily in South and Southeast Asia and in South America, and there are about 10 countries with picohydro manufacturing capability.

2.7 Picohydro units have also been sold in North America, Europe, Australia, and the Pacific Islands. There has been only minor uptake of the low-head technology in Africa to date,[5] but there remains a massive unexploited potential throughout Southeast Asia, South America, the Indian subcontinent, and Africa.

Picohydro Experience in Vietnam

2.8 Vietnam has seen many picohydro schemes being installed; the technology naturally finds its market in areas where other hydro development or grid extension work is not taking place, because of either remoteness or low local affordability. It is estimated that approximately 120,000 units have been installed in Vietnam since the late 1980s,[6] most in the northwest corner, near the border with China.

2.9 The number of households in Vietnam without grid power was 4.8 million in 2000, and that number could be as high as 3 million by 2010.[7] Approximately 50 percent (2.4 million) live in rural areas where houses are close to a stream or irrigation canal, and it is estimated that 65 percent of these households (1.56 million) have direct access to a water course. Because only a low percentage of these households are likely to be in a location suitable (sufficient water flow and adequate head and distance to the residence) for the installation of a low-head picohydro unit, the market is estimated to consist of 200,000 households.

Vietnam Market Characteristics

2.10 In Vietnam millions of rural households will continue to lack access to electricity from a grid connection in the foreseeable future. Many households in the country have chosen off-grid solutions to obtain electricity, and because of the favorable hydro resources and the presence of cheap picohydro turbines, the country has the highest use of picohydro in the world. Even some conventional electricity consumers (grid connected) choose picohydro as a backup because the grid is unreliable.

2.11 The number of units sold indicates that picohydro is likely to have provided electricity to approximately 130,000 households. However, only about 40 percent, or less than 50,000, of these systems are likely to still be operational.[8] The main reasons

[5] Glenn Whalan, Asian Phoenix, 2003.
[6] Hydropower Department, Institute of Energy in Vietnam, statistics, 1996.
[7] Options for Renewable Energy in Vietnam, ASTAE, World Bank, 2000.
[8] Hydropower Department, Institute of Energy in Vietnam, statistics, 1996.

for the high failure rates are the low quality and durability of the turbines that are sold.

2.12 A proper inventory of each province's picohydro development has never been conducted, but it is estimated that the two provinces that have the largest number of systems are Hoa Binh (7,000) and Son La (15,000) in northwest Vietnam.

2.13 Annexes 1 and 2 provide details on the suppliers of this large number of picohydro units. In summary, the market is being supplied by the following:

1. Low-quality, cheap picohydro equipment imported from China with a rated capacity of 300 watts (but actual power of 100 W) are sold through open markets in the larger cities and towns to private dealers and shops at provincial and district levels. These units dominate the market with 90 percent coverage, mainly because of their low price of approximately $20.

2. Private Vietnamese workshops have copied the Chinese equipment and sell it through the same outlets as the Chinese originals. The units do not have a nameplate or a brand name, and the quality is even lower than that of the Chinese original.

3. The MTD series of the Renewable Energy Research Centre (RERC)[9] in Hanoi has been sold in limited quantities (several hundred units), most often at noncommercial prices for demonstration and pilot installations. The effort of RERC is to lower the price of these better-quality units down to $45 to $50.

4. RERC's closest competitor is the "Hydrotec," a product of the Institute of Materials Science (IMS) from Ho Chi Minh City, which is similar in price.

5. The PowerPal picohydro unit is an improved copy of the MTD series equipped with a basic voltage regulator and an improved bearing and generator arrangement. The price of a PowerPal depends on the market, as some are sold overseas, but in Vietnam the price is about $85.

6. Secondhand picohydro turbines are also on the market coming from communes in which grid electricity has become available and through the theft of whole picohydro units, which are sold at prices lower than $15 per unit.

2.14 Generally, the market characteristics for picohydro systems is that they are sold for cash in the markets in Hanoi and other towns and cities, mainly in the northern provinces, by shops that deal with electrical equipment, pumps, generators, or agromachinery. Although some very small subsidies have reportedly been available in certain provinces, for example, from the national electricity distribution company,

[9] Renewable Energy Research Centre at Hanoi University of Technology.

Electricité de Vietnam (EVN), the market is basically "cash and carry."[10] In general, the government of Vietnam is not providing funding for promoting picohydro or for renewable energy in general, and all the promotion has been done mostly by word of mouth.[11]

2.15 Rural people install these systems on their own land (irrigation fields or channels) or even on public land (a river or creek). Usually concentrations are found where several families have built a small dam in the river to create a head difference and installed a number of systems. Wires to the houses (often without insulation) are supported by bamboo and cover distances up to 300 meters, although if the transmission line is as long as that, there are issues of poor systems performance owing to a large voltage drop as well as a higher risk of theft because the unit is not near the end user's house. The load is normally fixed, running a few lights continuously (to keep the generating voltage steady) and a radio cassette, black-and-white television, or electric desk fan as required. There are often no sluice gates to stop water flowing to the machines nor any electronic controllers to govern their electrical output. When not in use, the units are simply removed from the small dams and left by the riverside or, more often, taken home to prevent theft, which has been a major problem.

Vietnam Lessons Learned

2.16 The reputation of Vietnam in mass development of picohydro is at risk of becoming tarnished by various negative experiences; approximately half of the units originally installed are now out of service because of the uncontrolled supply of cheap, low-quality equipment from China. Surveys carried out in Vietnam as part of the DFID-supported component of this project showed that out of 29 farmers interviewed in Mai Chau and Da Bac districts in the northwest, 16 (55%) had replaced their Chinese picohydro system at least once (and in one case four times) over a range of system lifetimes (1 to 12 years), with an average replacement of 1.8 times during a 6-year period. Total picohydro unit replacement costs were surveyed to be from $13 to $20 for Chinese equipment, and typical repair costs were found to be $1 for a new bearing and $2 for rewiring the permanent magnet generator. Coupled with the lack of useful information about the technology, that gives decision makers a difficult task in selecting picohydro units over other more mature, similar-size renewable energy systems, such as PV or wind chargers, even though picohydro costs are significantly lower (see later section on the economic analysis of picohydro). Further research is therefore required on the technical details of the latest developments in picohydro in countries such as Vietnam (for example, in using rare earth magnets in the generator) to satisfactorily address their perceived weaknesses and to provide clear information about their technical performance to those designing rural electrification programs in other potential countries such as Ecuador.

[10] W. Rijsenbeek, 2000, ISES RESuM Project. http://resum.ises.org/cgi-bin/resum/resum.py?showproject&PHVietnam.
[11] Interview with Nguyen Duc Loc, RERC, 2003.

2.17 Despite the poor record of the picohydro market in Vietnam, higher-quality equipment (as deployed through this pilot project in Ecuador) is available in the country and can still offer cheap and sustainable electrification to millions of low-income families in developing countries, especially those living in low-lying areas in which traditional hydro schemes (requiring either high head or high flow) cannot be used. The issues to be addressed to guarantee sustainability are being taken seriously by institutions in Vietnam and neighboring countries such as the Philippines, where lessons are being learned from the Vietnam experience.

Picohydro Experience in the Philippines

2.18 The Philippines has recently seen a small but growing activity in the development of picohydro and microhydro schemes for communities.[12] There are home-grown technologies used in the Philippines, such as small cross-flow runners ("Fireflies") for battery charging at medium-head sites, but the application of low-head turbines for 220 volt supply has been possible only through the importation of equipment from Vietnam. The greater distance of the Philippines from mainland China has meant that the poorer-quality equipment that has flooded the Vietnamese market has not been able to penetrate the Philippines, so there has been a more controlled development of family-hydro in the country.

2.19 The Renewable Energy Association of the Philippines (REAP) is just one of the suppliers of family-hydro in the Philippines. It supplies the Hydrotec product from Vietnam and has helped communities install 65 units to date (200 W to 1,000 W units), with a total of 31 kilowatts installed. PowerPal of Vietnam, which has a local dealer in Iloilo City, has sold approximately 30 units (mostly 200 to 500 W).[13] There are thought to be some private developments, and as of early 2003, 100 to 150 family-hydro systems have been installed countrywide, mainly in the central Visayas; on the island of Panay; and in the central Cordilleras on the main island, Luzon. That is indeed only a very small number, given the very large potential in the Philippines.

Philippine Market Characteristics

2.20 Because of the favorable rain pattern and topography across the islands of the Philippine archipelago and the 30.5 percent[14] of households that remain without a grid connection, there is room for the development of micro- and picohydro. There is a large potential market of 2.72 million households that could be beneficiaries of renewable energy systems such as picohydro. As part of the DFID-funded research

[12] As of 2001, there were thought to be a minimum of 180 kilowatts of microhydro installed in the country (17 schemes), but a significant number have been installed since then.
13 See examples of these installations at www.solarelectric.com.ph/water.htm#Negros and www.powerpal.com/1inuse.html.
14 www.nea.gov.ph/accomplishments_of_re.html.

project,[15] a market assessment was undertaken in the Philippines; 37 provinces were chosen for the picohydro development based on the following key indicators:

- Electrification level
- Topography and water resources
- Affordability and willingness to pay

2.21 This methodology was subsequently used as a basis for the market assessment undertaken in Andean countries (see chapter 2).

2.22 Annex 2 provides more details about the full picohydro potential and experience in the Philippines, but initial conservative calculations of the immediate potential market in the selected provinces was estimated to be more than 24,000 units. That would supply more than 100,000 households (because many units would be shared by houses in clusters), which is 7.5 percent of the total potential off-grid households in the priority provinces. Further detailed analysis concluded that the total market could be as large as 120,000 units during a 10-year period.

Economic Analysis of Picohydro

2.23 Picohydro technologies are part of a menu of options for bringing modern energy services to households in unelectrified areas of developing countries where the hydro resource exists. Others include PV-SHS, small PV power plants often combined with diesel and wind, small wind turbines, small-scale biomass gasification, as well as the most commonly found small diesel or petrol gensets. Table 2.2 presents the comparative capital and operating costs for these various systems, using the higher-quality picohydro units as the basis, the cost of which varies from country to country.

2.24 Picohydro can be seen as one of the most affordable sources of electricity for rural areas of developing countries, with life-cycle costs for each household ranging from $74 to $150 a year. If larger picohydro units are installed at the community level, the costs are shared between households and life-cycle costs for each household drop to about $30 to $40 per year. That compares with the life-cycle costs of solar-, hybrid-, wind-, or fossil fuel–based options, which start at $140 per household per year. In addition, a picohydro unit can provide power at 220 volts AC instead of 12 volts (from PV-SHS), which then requires expensive inverters to upgrade to AC power.

15 “CDM pilot project to stimulate the market for family-hydro for low-income households,” DFID KaR Project R8150 (2002–2004).

Table 2.2: Comparative Costs of Small-Scale Energy Options for Rural Households in Developing Countries

Technology	Capacity (no. hh)	Voltage	Indicated lifetime	Equipment cost over lifetime ($)	Install-ation cost ($)	Operating & maintenance cost per year (est.) ($)	Life-cycle cost ($/year per hh)
Family picohydro	200 W (1 hh)	220/110 V AC	5 years	80–200	40–300	50	74–150
Community picohydro	3,000 W (15 hh)	220/110 V AC	15 years	3,000	Varies: 1,000–3,000	200	~31–40
PV-solar home system	100 Wp (1 hh)	12 V DC	20 years	600–800	200–600	100	140–170
PV hybrid plant	2,000 Wp (10 hh)	12/48 V DC	20 years	20,000–25,000 (excl. genset)	2,000–2,500	500 (excl. diesel or petrol)	160–188
Small wind (China)	300 W (1 hh)	12 V DC	15 years	800	300	80	153
Small diesel/ petrol gensets	1–3 kW (1–3 hh)	220/110 V AC	10 years	1,000–5,000	100–350	40–400 (depends on hours of use)	150–311

2.25 Affordability varies widely across developing countries, and the ability of picohydro to address the energy needs of the poor depends on what the definition of "poor" is. To make some sensible global analysis, it is assumed that the poor live on less than $2 a day, or $730 a year.

2.26 Assuming that 6 percent to 9 percent of poor rural householders' income is currently spent on forms of electrical energy,[16] then modern energy services must come at a price of $44 to $66 a year or less to be affordable to the poor. This cost does not cover the value of time to collect kerosene/diesel or car batteries from towns, the traditional forms of energy used by households for lighting. It also does not consider that energy from modern equipment (i.e., electricity) may be more useful than that provided by traditional fuels and is thus more "valuable" to some people. Given this $44 to $66 cost basis, it can be seen that quality picohydro systems can be affordable to the poor only though community-based schemes in which the costs are shared by a number of users. However, if financing mechanisms can be encouraged for payments for family-hydro equipment to be made over a number of years to dealers or service providers (with picohydro units therefore requiring a life span that exceeds this payback period), then the opportunities for the technology can be explored in new rural markets. Electricity utilities in rural areas are more likely to have the finances and energy services delivery modes in place, but the likelihood of their entering this market is low.

[16] A survey of unenergized households shows that the 80 percent of households below the poverty level spend about 6 percent to 9 percent of their income on energy for lighting and other "electricity consuming" devices, with the poorest spending 9 percent—World Bank, 2001.

2.27 Despite this inexact analysis, the rural poor will often try to exploit any reasonably affordable options for electricity open to them, and the kilowatt-level picohydro technology can promote many end uses (using AC power) and generate income to help the poor, and in some cases the very poor, in regard to employment. Through the provision of brighter lighting, the technology can be a useful tool for craftspeople, for example, helping them to produce better painting or weaving. Also, the technology is beneficial to women and children in the reduction of drudgery (e.g., mechanical power for milling) and for health, by encouraging smokeless kitchens when it is used for electric cooking and lighting.

Summary

2.28 Typically, picohydro systems have capacities of between 200 and 1,000 watts of electrical power and generally are used for domestic electricity applications such as lighting, television and radio, and battery charging. The units are small and cheap and are typically owned, installed, and used by a single family, hence, their commonly used name of family-hydro.

2.29 In Vietnam, China, and Nepal low-head picohydro technology has become widely available at an affordable cost to rural households, with turbine prices ranging from $25 for 200 watts to $580 for a 1 kilowatt system. The technology that has fueled this market development has been mainly a mix of locally made units, although the experience is that units from China are inefficient and dangerous and have a life of less than two years. Generally, the market mechanism has been a cash-and-carry model in which technical information is spread by word of mouth.

2.30 There are some other countries that have experienced picohydro market development, primarily in South and Southeast Asia and South America. There has been only minor uptake of the low-head technology in Africa to date, but there remains a massive unexploited potential throughout the developing world.

2.31 The economic analysis (on a life-cycle cost basis) for quality picohydro units shows that the technology compares favorably with other small-scale (renewable or diesel-based) options for bringing modern energy services to households in unelectrified areas of developing countries, especially for community-based projects. As for affordability, picohydro can in many circumstances be within the reach of the poor (assuming that the poor live on less than $2 a day) and is valuable because AC power is generated, which can be linked to income-producing activities.

2.32 The following serves as a summary of the research work completed as part of the DFID Knowledge and Research (KaR) project, which looked closely at the picohydro experiences in Vietnam and the Philippines and the opportunities for further expansion of the market for good-quality picohydro in countries such as Ecuador:

- The Vietnamese have the most experience worldwide for the development of small amounts of power (hundreds of watts) for family use using picohydro, but not all of this development has been sustainable because of poor-quality products being used by rural people with annual incomes of only $300.

- In Vietnam there have been an estimated 120,000 units deployed during a period of about 15 years, benefiting 130,000 people (mostly in the northwest), but it is thought that only about 50,000 of these units are still operating owing to sustainability issues.

- Nevertheless the Vietnam market for picohydro remains strong, driven by the fact that there are 4.8 million households still off the grid in Vietnam, and during the near term the market could be 150,000 units, although 40,000 to 50,000 of these would be units for rehabilitation.

- Even considering pressures to make this market shrink (grid extension efforts by the Vietnamese government, EVN promising communes that they will be connected to the grid soon, and the tendency for picohydro to be considered as being for the poor), the market is still about 20,000 to 25,000 per year.

- Analysis done to consider whether Vietnam would benefit from clean development mechanism (CDM) financing for a “bundle” of many thousands of picohydro systems shows that the viability of a CDM project is low.

- That result is due, first, to the picohydro market delivery mechanism already in place making it very difficult to monitor and verify the systems installed and, second, to the low emission reduction potential calculated (this analysis was based on RRA done in the field). An extra concern for Vietnam was that any project that may be proposed would not have additionality, in other words, because of the continual availability of very cheap units from China, it is likely that more picohydro projects would be done even without CDM funds.

- In the Philippines, despite its relative closeness to South China and Vietnam, there was virtually no picohydro development, especially of the low-head type, until good-quality units began to be available by export from Vietnam in the late 1990s.

- To date there are thought to be about 150 units in operation led by only a few entrepreneurial private developers. Most of these units are the higher-quality ones and have been installed with competent engineering support and the use of proper civil works, raising support funding from local (and national) government and NGOs. Also, to maximize the units’ potential, the larger systems have often been chosen to supply electricity into microgrids for clusters of households or for small villages.

- The Philippine market for off-grid electrification remains large (2.7 million households) despite the rural electrification gains by DoE, partly because the counting method of off-grid dwellings is poor and partly because the population growth rate remains high.

- Picohydro has a considerable potential in the Philippines; a detailed market analysis shows that the immediate potential market is more than 24,000 units and the total market is as large as 120,000 units, or 12,000 per year (half the Vietnamese market expansion).

- However, because of the limited dissemination of technology to date, the distance of the source of the technology, and the subsequent lack of knowledge of picohydro potential, market stimulation is required in the Philippines.

- Analysis has shown that the CDM could form an important part of that market stimulation in the Philippines and that a bundle of projects would be viable. The reason is that the unelectrified rural population is richer than its Vietnamese counterpart and uses more CO_2-emitting fuel for its power needs and the development would not likely happen without the CDM financing because of the nascent nature of the picohydro market.

- A bonus of the CDM financing is that it can “buy down” the cost of the high-quality picohydro products from Vietnam in the early stages of the bundled project, thereby inducing more sustainability for end users and inducing local manufacturing to also be of high quality in the future.

3

Opportunities for Picohydro in Ecuador and the Andean Region

3.1 The potential market and the institutional barriers to the diffusion of picohydro in Ecuador and the other Andean countries are summarized in this chapter and in annex 3. A review of the extent of the existing use of microhydro and picohydro in Ecuador and the four other nations in the Andean Community (Venezuela, Colombia, Peru, and Bolivia), including the sources and costs of the equipment, has been reported separately to ESMAP.

Existing Situation with Small Hydro in Ecuador

3.2 Ecuador (see Figure 3.1) is characterized by great geographical, biological, and ethnic diversity. Its population is projected to grow from 12.4 million in 1999 to 15.2 million in 2010, with 40 percent of the population living in rural areas.

3.3 Approximately 77 percent of the rural population of 1.1 million households is now electrified, and by 2009 Consejo Nacional de Electricidad (CONELEC) plans to electrify an additional 150,000 households through grid extension. Considering population growth, that will still leave about 160,000 rural households (or 12 percent of the rural population) with no access to the grid by 2009/10.

3.4 There are hundreds of villages scattered around Ecuador that presently do not have a source of electricity, but do have a local hydro resource that could be tapped. Rural and dispersed households use low-quality and, in some cases, relatively expensive alternatives to electricity for lighting. In addition to wood and crop residues (often used for cooking), households use diesel (or kerosene, although the sale and use of kerosene in the country is banned for environmental reasons) in simple wick lamps, flashlight batteries, and candles for lighting.

Figure 3.1: Map of Ecuador

Ecuador Market Conditions

3.5 The country is divided into four regions: the coast (costa), mountains (sierra), Amazonia (oriente), and an island territory comprising the Columbus Archipelago (Galapagos Islands), which has no hydroelectric potential.

Coastal Region

3.6 The relatively flat coastal region has comparatively little hydropower resource. However, in the border zone with Colombia, there is a very strong hydroelectric potential as well as an energy deficit. Rural electrification is developed, but the national grid or Sistema Interconectado Nacional (SIN) is far away from many communities.

3.7 Households without a grid supply spend on average $8 per month on meeting their electricity needs through alternatives, with a range of $7 to $10.[17]

[17] Consejo Nacional de Modernizacion del Estado (CONAM), 2001

Sierra Region

3.8 The sierra region, comprising approximately 25 percent of the country's territory and approximately 50 percent of the country's rural population, has the best potential small-scale hydropower resource.

3.9 The households in the sierra spend $4 to $8 per month on their electricity needs for lighting and entertainment.

3.10 On the basis of a market survey done by IT Power as part of a 2001 World Bank-GEF project,[18] "Technical Assistance for Rural Electrification Project for the Dispersed Rural Populations of Ecuador," it was found that provision of high-quality electricity in the sierra region has a high potential of promoting income-generating activities beyond daylight hours. That in turn will increase the purchasing power of the inhabitants and can result in a higher energization ratio as off-grid energy services become more affordable.

Amazon Region

3.11 The oriente region of Ecuador, which comprises approximately half of the country's landmass, is characterized by lowlands draining approximately 73 percent of the waters of the country. With rainfall of 4,000 millimeters per year, the region has significant low-head hydropower potential.

3.12 The border zone with Peru is a less densely populated area that has a very high hydroelectric potential. The border zone with Colombia has an energy deficit although there is very strong hydroelectric potential. Rural electrification is quite developed, but the grid (SIN) is very often far away from communities.

3.13 This region has a very low household income, and expenditures for lighting/electricity vary from $4 to $6 per month. However, there is a definite need for the provision of electricity for community services such as medical clinics/dispensaries, schools, and community centers.

Installed Small Hydro Systems and Further Potential

3.14 Ecuador has an exceptional hydropower potential. The high mountains of the Andes enjoy heavy precipitation, river flows are large, and the water availability through the year is high. The theoretical hydropower potential in Ecuador is estimated to be approximately 74,000 megawatts; more than 30,000 megawatts is considered to be technically feasible and 21,520 megawatts is considered to be economically feasible. Indeed, hydropower (mainly large scale) accounted for almost 70 percent of the country's electricity supply in 1997.

[18] "Power and Communications Sectors Modernization and Rural Services Project" (PROMEC).

3.15 The first electricity service in Ecuador was provided by the two 12 kilowatt microhydro turbines installed at Loja in 1887. By the 1960s approximately 1,200 hydropower schemes had been installed, having a capacity of approximately 120 megawatts. During the 1970s there were approximately 2,000 small-scale hydropower schemes operating in the country.

3.16 With the rapid expansion of the use of thermal power plants and large-scale hydropower since then, most of the smaller hydropower projects have fallen into disuse. Only about 10 percent of the equipment is still operating; much of it has been pulled out completely from the old sites. Many of the schemes have been made redundant because of the extension of the grid. Some of these schemes could be renovated and integrated into the grid, but the regional electricity companies responsible for operating and maintaining the systems generally do not consider them to be of priority because the plants are not likely to be profitable for them.

3.17 The Instituto Ecuatoriano de Electrificacion (INECEL) produced a report in 1997[19] providing details of 101 potential hydropower sites in Ecuador having a capacity below 5 megawatts. The schemes have a potential capacity of approximately 78 megawatts. The Instituto Nacional de Energía (National Energy Institute; INE) also analyzed the status of private minihydro plants in 1999.[20] A further 90 sites, having capacities ranging from 5 megawatts to 50 megawatts and an approximate total capacity of 1,800 megawatts, have also been studied. However, a thorough study of small-scale hydropower resources (less than 5 MW) has not yet been undertaken for the whole of Ecuador, partly because the smaller projects are much less site specific, and so the economic feasibility of the smaller end of hydropower in the country remains unknown.

Local Experience with Small Hydro Technology

3.18 There has been some local experience in the design and production of small-size Pelton and Mitchell Banki turbines in Ecuador. There are at least 14 Pelton turbines that have been manufactured in Ecuador. These turbines appear to be working satisfactorily. However, the local design of these turbines has not yet been standardized, and each turbine is made according to the requirements of the client for a given project. There does not appear to have been any coordination among the different agencies involved in these projects, which would have helped to reduce costs.

3.19 The total number of Mitchell Banki turbines installed is not known. INE has been the institution leading the design and implementation of these turbines. In 1986 INE prepared a detailed design guide for Mitchell Banki turbines. Currently, there are eight models available for head ranges from 10 to 70 meters and power from 10 to 150 kilowatts.

---

19 "Small Hydroelectric Power Plants Catalog (IC < 5 MW)," Instituto Ecuatoriano de Electrificacion (INECEL), 1997.

20 "Study of the Development of Private Hydroelectric Mini Power Plants," UNDP-ESMAP, 1999.

3.20 It appears that there is little opportunity for cost reduction through the scaling up in the number of manufactured mini- and microhydro turbines, because there is not sufficient demand for any kind of mass or systematic production. Each turbine produced was the result of a unique effort and was designed to the user's specification.

3.21 There is no experience with manufacturing picohydro turbines in Ecuador. However, the large potential market for picohydro systems and the relative ease of manufacture compared with that of larger units may lead to the establishment of local manufacturing capabilities for these types of systems.

Potential Market for Low-Head Picohydro in Ecuador and the Andean Region

3.22 Located in South America, the five Andean countries together have 120 million inhabitants living in an area of 4,700,000 square kilometers.

3.23 The Andean subregion is an area with immense natural wealth, accounting for roughly 25 percent of the world's biological diversity. Sustained use of this rich biodiversity poses a challenge to these countries, particularly considering that irreversible loss of valuable biological and genetic resources has been speeding up in recent decades.

Figure 3.2: Map of Pacto Andino

3.24 The heads of state of the Andean community have called attention to the need to coordinate community policies and strategies on sustainable development and environmental management that will help to deepen and improve the Andean integration process. With that objective in mind, this report considers the region as a unit in regard to developing a market for the use of the picohydro technology to provide electricity to the unelectrified rural populations (see summary in Table 3.1).

Table 3.1: Summary of Andean Region Basic Statistics

Country	Total Pop.	Rural Pop.	% rural	Rural hh	% rural electrification	Rural hh not electrified	% earning more than $2/day
Bolivia	8,328,700	3,109,095	37.3	885,921	41.8	515,815	61.4
Peru	25,661,690	9,315,193	36.3	2,053,845	28.8	1,462,783	58.6
Ecuador	12,082,020	4,629,840	38.3	1,086,161	77.1	249,199	47.7
Colombia	4,128,045	2,288,010	55.4	457,602	72.2	127,343	71.3
Venezuela	3,791,644	821,380	21.7	205,345	64.9	72,170	63.6
TOTAL	**53,992,099**	**20,163,519**	**37.3**	**4,688,874**	**48.2**	**2,427,310**	

3.25 An assessment of the market demand for picohydro systems globally was carried out in 2004 for the main countries thought to be appropriate for such development.[21] In this study the genuine household market potential for low-head picohydro was found to be 285,000 in the five countries of the Andean community. That compares with a global potential of about 4 million units and 740,000 estimated for all of Latin America (Brazil has the highest potential owing to its relative higher population).

3.26 This ESMAP study has reassessed the market demand for low- and medium-head picohydro in the Andean region. To do the reassessment it was necessary to determine the conditions under which demand is expected to occur. Those conditions can be defined as follows:

1. The rural population is not already electrified or likely to attain grid connection in the next 5 years (in general it is only in limited cases that households will supplement grid connection with other renewable energy systems).

2. There are sufficient hydro resources in the location (that is difficult to assess, and some estimates have had to be made based on a methodology generated in the Philippines that considers rainfall and topography [see Table 3.3, resulting in a percentage of rural areas of the country applicable for tapping low-head hydro resources).

[21] "Guide to the CDM and Family-Hydro Power," Mariyappan et al., 2004.

3. There is an ability and willingness to pay for the systems. Good-quality picohydro technology costs from $50 to $60 a year to purchase (presumed through a dealer or developer), install, and maintain. Assuming that households typically spend 8 percent to 9 percent of their income on energy, it is estimated that households with an annual income of $730 ($2/day) will be able to purchase, install, operate, and maintain a picohydro system.

3.27 It is assumed that a household will have demand for a picohydro system only when all of these three conditions coexist, that is, a household will need to be in a rural location that is not already electrified but that has sufficient hydro resources and also will have enough income to purchase the system.

3.28 However, to estimate the genuine picohydro market, a range is used in all cases to consider those that are willing to pay for a system (between 25% and 50%). The percentage of the population that meets only conditions 1 and 2 is taken as the technical picohydro market.

3.29 The resultant percentage of the population in the countries that meet conditions 1 and 2, or all three conditions is an approximation, because it has not been possible to determine to what extent the data sets for rural electrification, hydro resources, and income relate to each other. For example, it is not known whether all hydro resources are located in electrified areas, thereby negating any market demand (although that is not likely), or whether any persons who are able to pay are located in areas that have hydro resources.

3.30 Table 3.2 shows the method by which these percentages have been used to obtain the number of households that may have demand for a picohydro system and the number of systems that could be sold in each market.

Table 3.2: Methodology Used to Estimate the Potential Size of the Market for Picohydro

	Inputs				Result
Step 1	Population	% rural population	People/ household	% rural electrified	Rural households without electricity
Step 2	Location of rural population without electricity according to natural regions	Hydro resources according to natural regions	% of unelectrified rural population with access to suitable hydro resources	Technology selection (microgrid—100 W PH, 500 W PH) according to hydro resources	The technical possible number of households without electricity and with hydro resources (possible number of units to be installed) = *technically achievable picohydro market*
Step 3	Average GNP/capita		% with income of $730 or more per year	Between 25% and 50% are genuinely willing to pay	Total rural population with hydro resources, capacity, and willingness to pay for picohydro = *range of genuine picohydro market potential*

3.31 To undertake a common methodology and a common estimation among the five targeted countries, three different morphological areas have been defined according to rainfall, topography, and the way rivers are spread across these areas. These reference areas for Ecuador, as presented in the section on Ecuador's market conditions, are the coast (costa), lowland (Amazonia), and upland (sierra). Each natural region analyzed in the country concerned is categorized into these three reference areas, and by using the analysis undertaken in the Philippines,[22] the potential for low- and medium-head picohydro in each of the reference areas is presumed, as shown in Table 3.3.

Table 3.3: Percentage Area of the Country Suitable for Picohydro (low head and medium head) for Upland, Lowland, and Coastal Areas, Based on Experience in the Philippines

Region	Hydro potential for low-head picohydro (1–2 m)	Hydro potential for medium-head picohydro (5–11 m)
Upland	30%	15%
Lowland	15%	5%
Coastal	3%	0%

3.32 This hydro potential can be met either by picohydro feeding into microgrids or by picohydro stand-alone systems. The assumption is that each microgrid would power five clustered households with a 500 watt unit and each stand-alone system would power a single household with a 200 watt unit, as the example in Table 3.4 shows.

[22] DFID KaR project R8150. http://www.dfid-kar-energy.org.uk/html/r8150.htm.

Table 3.4: Example Power Demands Supplied by Various Capacities of Picohydro Equipment in Typical Rural Households

End use	Power (W)	200 W PH unit (for 1 hh)	500 W PH unit (for 5 hh)
Domestic uses			
Lights			
Incandescent lightbulbs	40		2
	60	1	
Fluorescent lightbulbs	20		5
	40		
Compact fluorescent lamps	7	2	3
	11		2
	15	2	4
Television and radio			
Small black-and-white TV	20		1
Large black-and-white TV	40		1
Small color TV	60	1	1
Large color TV	100		
Radio	10		3
Radio cassette	30	1	2
Other uses			
VHF communication radio	40		
Food processor			
Water pump			
Refrigerator			1 (when no demand from other end uses, e.g., in the day)
Total power demand (W)		**194**	**493**

3.33 It is also assumed that the households that are able and want to access a microgrid for the 500 watt units are a nominal 15 percent across all topographies. The rest are powered by stand-alone picohydro systems (200 watt systems).

3.34 These assumptions have been used to estimate the total potential number of picohydro units across the Andes, first, in Ecuador, then the same for the other four nations.

Potential Picohydro Market in Ecuador

3.35 Ecuador has been divided into three natural regions: sierra, Amazonia, and coastal. Recent analysis of the unelectrified population in Ecuador shows that the majority of unelectrified households as a whole would be in rural areas, whereas previous analysis presumed that these unelectrified households would be separated according to the urban/rural percentage divide. This new analysis has almost doubled the identified potential household market.

Step 1

3.36 The 2001 national census[23] and basic infrastructure and household analysis undertaken by the SIISE[24] were used as a reference to estimate the total rural

[23] Instituto Nacional de Estadística y Censos (INEC), 2001.

population without electricity in each natural region. Information from CONELEC on provincial indexes of electrification[25] has also been used. Results are shown in table A3.1 in annex 3.

Step 2

3.37 The categorization of Ecuador's natural regions into the reference areas is shown in Table 3.5. On the basis of this assumption and by using the results of step 1, the total number of potential households that could benefit from picohydro technology is determined, as shown in Table 3.6(second column from the right). It also shows the total number of picohydro units, by size and configuration that could be used to meet the demand.

Step 3

3.38 According to World Bank data[26], 47.7 percent of Ecuador's rural population earns more than $2 per day (or $730 per year). It is assumed that this percentage of the population could afford to buy a picohydro unit but also that between 25 percent and 50 percent would be willing to pay. This genuine picohydro market range (measured in numbers of households), which is shown in the right-hand side column of Table 3.6, is calculated considering that the 500 watt picohydro supplies a microgrid of five households and the 200 watt picohydro supplies a single household (family-hydro).

Table 3.5: Categorization of Ecuador's Natural Regions into Reference Areas

Region	% upland	% lowland	% coastal
Coastal	40	40	20
Amazonia	40	60	0
Sierra	100	0	0

Table 3.6: Market Size for Picohydro Units and Number of Households Benefiting in Ecuador

Region	Technical market (no. of PH units)	Composed of				Technically achievable (no. of hh)	Range of genuine household market based on capacity and willingness to pay
		Low-head 500 W PH	Med.-head 500 W PH	Low-head 200 W PH	Med.-head 200 W PH		
Coastal	29,791	3,125	1,344	17,706	7,616	47,665	5,684–11,368
Amazonia	12,421	1,304	559	7,391	3,167	19,874	2,370–,740
Sierra	43,110	4,311	2,156	24,429	12,215	68,977	8,225–16,451
Total	**85,322**					**136,515**	**16,279–32,559**

24 La Vivienda y la Infaestructura Basica en el Ecuador 1990–2001, Secretaria Tecnica del Frente Social, SIISE.
25 Estadistica del Sector Electrico Ecuatoriano, 2002, CONELEC.
26 World Development Indicators—World Bank, 2001.

Potential Picohydro Market in the Andes

3.39 Using the same method of analysis for the rest of the Andean region reveals that the region has a substantial current total technical potential of more than 0.75 million picohydro units, which would benefit more than 1.2 million households (or 50% of the unelectrified population); 670,000 of these households are in Peru. Details of this analysis are in annex 3.

3.40 By considering the populations' ability and willingness to pay, the total actual market can be determined. Between 180,500 and 360,000 picohydro units can be sold in the near term (i.e., in the next 5 years). See Table 3.7 for a summary by country.

Table 3.7: Summary of Market Size for Picohydro and Number of Households Benefiting in the Andean Region

Country	**Technical market (no. of PH units)**	**Composed of**				**Technically achievable (no. of hh)**	**Range of genuine household market based on capacity and willingness to pay**
		Low-head 500 W PH	Med.-head 500 W PH	Low-head 200 W PH	Med.-head 200 W PH		
Bolivia	222,171	22,317	11,009	126,461	62,385	355,475	54,565–109,131
Peru	419,461	43,506	19,413	246,532	110,009	671,137	98,322–196,643
Ecuador	85,332	8,740	4,058	49,526	22,998	136,515	16,279–32,559
Colombia	24,282	2,614	1,028	14,815	5,825	38,852	6,925–13,851
Venezuela	17,589	1,905	733	10,794	4,156	28,143	4,475–9,064
Total	**768,825**	4.8%	1.8%	63.8%	29.6%	**1,230,122**	**180,567–361,247**

3.41 The minimum household market for picohydro in the five Andean countries is therefore estimated as follows:

- Bolivia—55,000, or 10.6 percent of unelectrified households
- Peru—98,000, or 6.7 percent of unelectrified households
- Ecuador—16,000, or 6.4 percent of unelectrified households
- Colombia—7,000, or 5.5 percent of unelectrified households
- Venezuela—4,500, or 6.2 percent of unelectrified households

TOTAL—180,500, or 7.4 percent of unelectrified households

3.42 These results show that the picohydro market in Ecuador is more limited than in other countries of the region, even if it has the second highest rural population. As can be seen in Table 3.1, that is due to the highest level of reported electrification (77%), and yet the lowest affordability (it is the only country with more than 50 percent of the population earning less than $2 per day).

Summary

3.43 Analysis in Ecuador shows that the country has an exceptional hydropower potential and has had a fair amount of small-hydro development in the past, but that the majority of the smaller hydropower projects have fallen into disuse. Despite Ecuador having more than three-quarters of its rural areas electrified, it is believed that there is a large market opportunity for picohydro in the country.

3.44 A methodology for estimating the genuine picohydro market in Ecuador and the four other nations of the Andean region was developed by looking at (1) rural electrification rates; (2) different morphological areas in each country defined according to rainfall, topography, and the way rivers are spread across the region; and (3) local capacity and willingness to pay factors.

3.45 This analysis has shown that there is an actual near-term picohydro market of a minimum of 16,000 households in Ecuador, but that this market is substantially smaller than some potential markets in other Andean nations, especially in Peru and Bolivia. The total actual picohydro market in this region is estimated to be a minimum of 180,500 households, representing about 7.4 percent of the total households yet to be electrified, which compares with an estimate of 740,000 in the Latin American region as a whole and 4 million globally.

4

Picohydro Pilots in Ecuador

4.1 The plan for establishing picohydro pilot projects in Ecuador originally called for 10 units in each of the three different regions of the country. The final choice of these regions was made through a resource and needs assessment by consulting with and seeking specific guidance from Dirección de Energías Renovables y Efficiencia Energética (DEREE)[27] in the Ministerio de Energia y Minas[28] (MEM) to determine which areas would be best suited for the pilot projects. This process was started in April 2003 by the international consultant, IT Power, and continued by the local consultant, TramaTecnoAmbiental (TTA), during May and June 2003. DEREE gave the final approval in July 2003.

4.2 This section details the methodology used to carry out the resource and needs assessment to determine which areas of the country would be best suited for the picohydro pilots and explains the site selection with a brief description of each site and location. Annex 4 presents each of the installations deployed in the pilot areas. Photo 4.1 through 4.4 give impressions of the four pilot communities eventually chosen.

Photo 4.1: Ozogoche Community

[27] Department for Renewable Energy and Energy Efficiency.
[28] Ministry of Energy and Mines.

Photo 4.2: Zapallo Community

Photo 4.3: Las Caucheras

Photo 4.4: Alto Tena Community

Methodology

4.3 The methodology used to identify the possible candidates for the installations was as follows:

- Define the geographical regions in which the picohydro systems could be installed

  Meetings with government organizations devoted to rural and social development of poor unelectrified communities were carried out to identify priority areas.

- Identify communities with potential capacity to install the picohydro systems

  Once the regions were identified, communities in these regions were analyzed. Based on this analysis, a set of communities was selected for visiting. These visits involved the following:

  - Making contact with a representative of the community
  - Analyzing the hydro potential of the location
  - Identifying the possible installation sites in collaboration with the community
  - Considering the accessibility of the locations

- Conduct detailed analysis of selected communities

  When a short list of communities was finalized, further analysis was done on each community to select the final 30 sites. The analysis involved the following:

  - A second inspection of each community was carried out.
  - The possible actual sites for the picohydro units, with flow and head measurements, were determined.
  - Basic socioeconomic surveys were done to identify the needs of the communities.

- Identify Dealers/Technicians

  - Dealers were identified to carry out the installation and postinstallation services. The candidates were required to participate in a training seminar planned to take place before the installation of picohydro pilots was started.

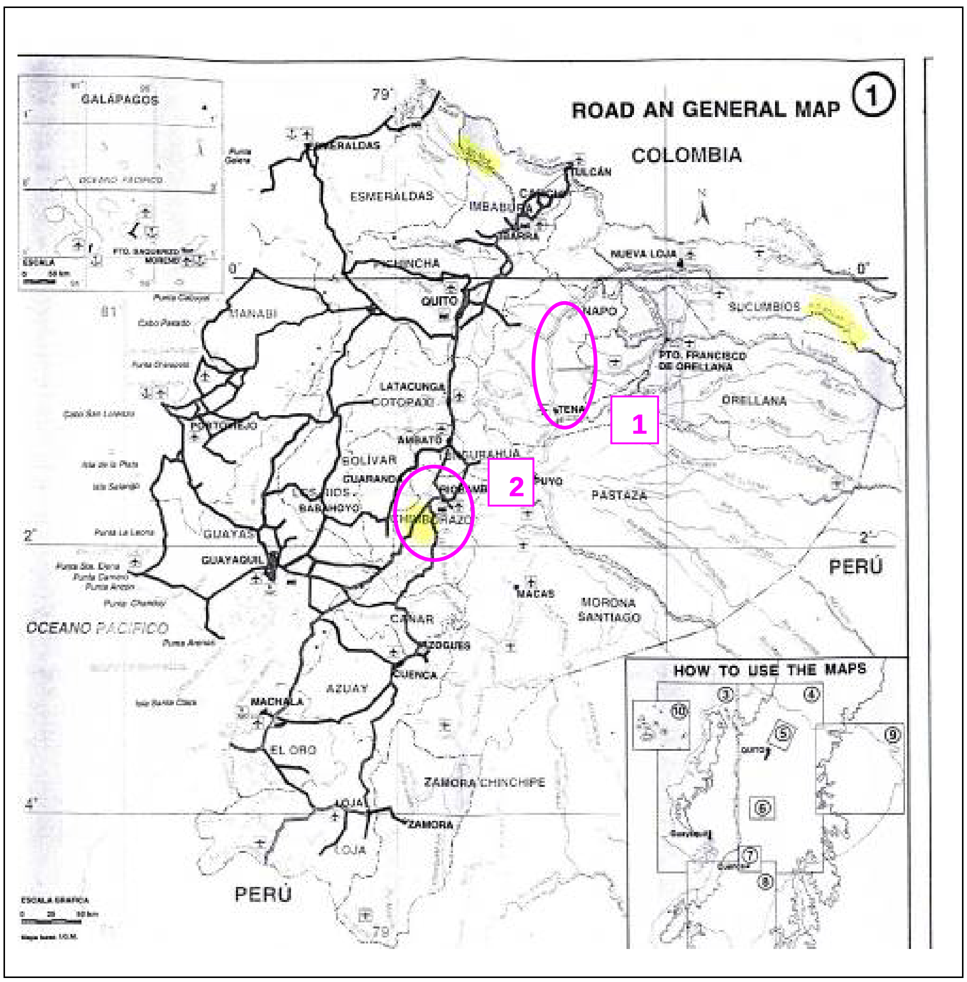
4.4 Decisions on where the 30 pilots would be sited in the two selected regions in the provinces of Chimborazo and Napo and who would be the beneficiaries were made during four separate field visits by the local and international consultants and a local hydro expert with the following schedules:

- Chimborazo field visit 1: June 11–14, 2003
- Napo field visit 1: June 15–18, 2003
- Napo field visit 2: August 30–31, 2003
- Chimborazo field visit 2: September 2–3, 2003

Site Selection

4.5 Two regions were selected in the Chimborazo and Napo provinces (see Figure 4.1).

Figure 4.1: Locations of Picohydro Pilots (1 = Napo, 2 = Chimborazo)



Chimborazo Region

4.6 The region in the Chimborazo **province** was selected because of the high percentage of indigenous peasants in the population, low electrification rates, and a high incidence of poverty. Chimborazo Province, with the capital city Riobamba, is located 161 kilometers directly south of Quito and can be reached from there in four hours by bus. Chimborazo lies along the backbone of the Andes and can be characterized as follows:

- High altitude (3,000–4,000 meters) and mountainous, with volcanoes and rolling hills
- Low tree coverage
- Sufficient water runoff for the pilot projects
- Population in clustered settlements
- Electrification level of 69.2 percent (lower than the average of 77%)[29]

4.7 The project team initially contacted the secretary of agriculture of Chimborazo, who was already working to provide energy services to rural communities in the region. In collaboration with the department's staff, an itinerary to conduct field visits to the target communities was prepared. The first field trip then took place with technicians from the department.

4.8 The communities of Chambo, Quimiag, and Llucud in the southeast of the province were visited. It was found that a high percentage of householders were already served by the conventional grid and that there were limited hydro resources. Visits to the communities of Galtelaime, Galtecachipata, San Vicente of Pitin, San Juan of Pitin, Gualiñag, Llatagpama, Chicatus, and Chapsi belonging to the municipality of Alausí, revealed that all these communities had a low electrification rate. However, the absence of sufficient hydro resources ruled them out of the project. Visits then took place to communities in the municipality of Guano to the northeast of the province—Llapo, the Providence, Chazo, Kahuají—but all of these locations were already electrified.

4.9 As a result of the field trips, the Guaslan Training Centre and the Alto Ozogoche community sites were finally selected.

The Guaslan Training Centre

4.10 This Guaslan Training Centre is located near Riobamba, the capital city of the province of Chimborazo (see photo 4.5). The center, which belongs to the Provincial Ministry of Agriculture, has 41 hectares for cattle and agricultural production. The center is used mainly to provide training to local communities as well as to hold

[29] CONELEC—PLAN NACIONAL DE ELECTRIFICACIÓN (2002–2011)—data from 1995.

conferences and events at a national level and has facilities to accommodate 50 persons. The site was chosen because the installed units could be used for demonstration purposes for end users as well as stakeholders at a national level who come to the center for training.

4.11 Another interesting characteristic of the site is that the source of water for the picohydro units is an irrigation channel. By installing in an irrigation channel, the project was able to demonstrate the minimum source of water needed to generate electricity with a picohydro system; the installation would be applicable to many sites in the sierra region, where there are irrigation channels derived from small streams.

Photo 4.5: The Guaslan Training Centre

The Community of Alto Ozogoche

4.12 The community of Alto Ozogoche, which has 40 families and about 180 inhabitants, is located in the northeast of Chimborazo Province, 38 kilometers from the highway Charicando-Ozogoche. The community lies next to the lagoons of Ozogoche, as can be seen in photo 4.6. It was not electrified, and at the time of the installations there was a distance of 12 kilometers to the grid. For current energy consumption candles are used for lighting, batteries for radios, and firewood for cooking.

4.13 Houses are made of concrete blocks, bricks, and mud. There is a strong sense of community and shared facilities, including a community center and a communal room for handicraft production.

4.14 Productive activities in the community include agriculture, agribusiness (there are three cheese factories), handicrafts, and national and international tourism.

Photo 4.6: The Community of Alto Ozogoche and the Lagoons

Napo Region

4.15 The province of Napo, with the capital city Tena, has a population of approximately 105,000, and is located in the large river Napo basin. It is one of the six Amazon provinces (Sucumbios, Orellana, Napo, Pastaza, Zamora Chinchipe, and Morona Santiago) and is composed of five municipalities (Tena, Archidona, Quijos, Chaco, and Arosemena Tola).

4.16 Napo is located 132 kilometers southeast of Quito and can be reached by bus in five hours by traveling west across the Andean ridge to Baeza then south to the lowlands of the Amazonian fringe. The region can be characterized as having the following:

- Low topography, rolling hills, and thick rain forest
- Rich hydro resources due to the runoff from the Andes into the many large rivers and its location in a higher rainfall region
- Dispersed, small settlements that lie along the many rivers draining into the Napo River basin
- A 41.3 percent electrification level (well below the average of 77%)[30]

4.17 The consultant team contacted the provincial prefect of Napo, which gave its support to the project and offered collaboration. The team also met the Unit for Social and Community Development of the Provincial Council and arranged a meeting with community leaders of the region. At this meeting, representatives from Pano, Misahualli, Chontapunta, Cosanga, San Pablo, Cotundo, Papallacta, Sardinas,

[30] ibid.

Limones, and Oyacachi were all present and collaborated in producing a list of potential communities.

4.18 After an initial screening of these communities in collaboration with the provincial council, visits were conducted to identify places and users that met the requirements for receiving picohydro installations.

4.19 Several communities of the municipalities of Puerto Napo, Misahualli, and Cosanga were visited. These areas all had dispersed housing and available hydro resources. Communities that were eventually selected were Las Caucheras, Cosanga, the Zapallo community, and the Alto Tena community.

Las Caucheras, Parroquia Cosanga

4.20 The Caucheras is a small farmers' cooperative, with each member assigned between 50 and 100 hectares of land. The members of the coop are not natives of the community. They live in other cities and use the land mainly for agriculture and cattle raising. There are about 30 families in the cooperative, with a total of 200 people (see photo 4.7). Most of the families use candles and kerosene for lighting, batteries for small radios, and firewood as cooking fuel. Productive activities in the community are oriented toward cattle raising, greenhouses for vegetables, trout breeding, and ecotourism.

Photo 4.7: Typical Household in Las Caucheras

Zapallo Community

4.21 The Zapallo community sits on the banks of the river Pano, surrounded by a tributary, the river Jatunyacu. The closest electrified community is the community of Santa Rosa, situated on the road Tena-Pano, 1,000 meters from Zapallo, and on the other side of the river Pano. The houses in this community are dispersed within a radius of 200 meters. Because of the width of the river Pano, it is unlikely that the grid will reach the community. Most of the houses are made of wood and guadúa cane with tin roofs (see photo 4.8). The main productive activity in the community is agriculture, mainly corn, cocoa, yucca, bananas, and coffee.

Photo 4.8: Gathering Area of the Community of Zapallo

Alto Tena Community

4.22 The community of Alto Tena has about 40 households, all located near the river Chico, a tributary of the river Tena, and can be reached through the Tena-Moyuna Road (see photo 4.9). The community has a school and a preschool. The main productive activities are poultry keeping and agriculture, cultivating bananas, yucca, coffee, and cocoa.

4.23 Candles and kerosene are currently used for lighting, and resident's power small radios with batteries. Firewood is used as fuel for cooking.

Photo 4.9: Typical Household in Alto Tena

Identification of Dealers

4.24 Several potential picohydro dealers[31] were contacted during the field visits. All those who expressed an interest in participating in the project were invited to a training seminar held in the Guaslan Training Centre, which belongs to the Provincial Ministry of Agriculture. During that time they were trained in the technical aspects of installing and operating picohydro systems and gained an understanding of the maintenance aspects. They were encouraged to convey this information to end users so that they would take on the responsibility and costs of maintaining the pilot systems in the long term. They were also asked to produce a report about their financial and technical capabilities, and after the seminar (which is described in chapter 5), they were interviewed and the final selection was done.

4.25 Fausto Moreno was selected as the dealer of the Chimborazo region. He has been committed to renewable energy for a long time. He installs and manufactures systems, such as small wind turbines, biodigesters, and solar driers for local communities, and therefore maintains continuous contact with local residents. He also has a mechanical workshop.

4.26 Marco Peña was recommended to be one of the dealers of the Napo region. He is a professor at the Technical Institute Juan XXIII dedicated to youth education in the area of mechanics and electrical installations. The institute has a fully equipped workshop. In particular, the institute cogenerates its electricity with a 40 kilowatt microhydro turbine located on its premises. Its director,. Ramiro Cabrera, strongly supports the project. Mr. Peña has his own workshop and was responsible for assisting the communities of Zapallo and Alto Tena.

4.27 Luis Vitteri was selected as the dealer for Las Caucheras. He is the community leader and has vast experience in electromechanical installations. For many years he was in charge of operating the hydroelectric power stations that existed in the area. He also has a workshop in Cosanga City.

Installation of Picohydro Pilots

4.28 After the 30 picohydro units (descriptions of each of the machines are in annex 4) had been installed in the two provinces as described above, “end-user manuals” were disseminated to the end users. On commissioning the projects, the end users also signed a “terms of reference,” which showed the responsibilities of the various parties involved in the project. It was also signed by the project’s international and national consultants and the dealers that helped install the picohydro units.

[31] The term “dealer” was used to describe local developers who could lend construction, electrical, and other technical support to installation, operation, and maintenance of the picohydro units.

4.29 These terms of reference indicated that after the 12 months warranty offered under the project, a transfer of the picohydro systems would be made to the end users. This was an agreed-on situation because the end users had contributed their time and labor setting up the pilots and had purchased the appropriate wiring, bulbs, switches, and electrical sockets for their houses and had taken on the long-term maintenance of the civil works and equipment.

4.30 Photos 4.10 and 4.11 give some impression of the two types of picohydro systems (low-head [or LH] and medium-head [or MH]) installed in the following communities:

- Guaslan Training Centre—two units (1 LH, 1 MH)
- Ozogoche Alto—eight units (7 LH, 1 MH)
- Las Caucheras—eight units (3 LH, 5 MH)
- Zapallo—eight units (8 LH)
- Alto Tena—five units (4 LH, 1 MH)

Photo 4.10: Vietnamese 200 Watt Low-Head Picohydro "Propeller" Unit Installed in Ecuador

Photo 4.11: Vietnamese 200 Watt Medium-Head Picohydro "Turgo" Unit Installed in Ecuador

Analysis of Picohydro Pilot Costs

4.31 The cost analysis of the installation work has been divided into six categories, and estimates have been made on the operation and maintenance (O&M) costs for the pilots:

1. Costs at origin
2. Importation and nationalization costs
3. Cost of parts built locally
4. Civil works costs
5. Electricity distribution costs
6. Installation costs

4.32 This will help potential investors to analyze the feasibility of developing the market and how to tackle the different links of the commercialization chain.

1. Costs at origin

4.33 In total there were 35 PowerPal turbines imported from Vietnam, 9 of these were medium-head types (for sites of 6–11 m water head, using a turgo-type runner) and the rest were low-head types (for sites of 1.5 meter water head, using a propeller-type runner). The total amount paid to the manufacturer was $5,075—$145 for each picohydro unit.

2. Importation and nationalization costs

4.34 The transportation costs by sea from Vietnam to Ecuador were $883, including port costs in Guayaquil. The units were under importation taxes when they arrived in Ecuador. The total amount paid as import duty was $612, and the administration costs paid to an importation company (required by Ecuadoran law) were $743. The cost prorated for each of the 35 turbines is equal to $196.27, as shown in Table 4.1.

4.35 It has to be understood that these costs are related to an importation of only 35 units and that the cost of each turbine will diminish if larger quantities of turbines are imported. For example, for a batch four times the size, the transportation costs from Vietnam would rise only by about $200, and although customs costs would be the same (12% of unit price), the administration of customs could be spread over more units, making an estimated in-country cost of $176.

Table 4.1: Costs per Picohydro Unit into Ecuador

Equipment cost	$145.00	73.9%
Transport (Vietnam to Ecuador)	$12.57	6.4%
Customs cost	$17.48	8.9%
Administration of customs	$21.22	10.8%
TOTAL	**$196.27**	**100%**

3. Cost of parts built locally

4.36 The flumes for the low-head turbines were not imported because it was assumed that they could be manufactured locally. PowerPal made drawings available for the flumes that were given to a workshop in Tena (see photo 4.12). The cost of manufacturing them in Ecuador was $70 per unit, as shown in Table 4.2. This value is added only to the low-head units because high-head units do not require a flume.

Photo 4.12: Inlet Flume Made Locally in Tena

Table 4.2: Total Cost Analysis for Picohydro Pilots in Ecuador

Province	**Napo**					**Chimborazo**				**All/Average**
Town	Tena			Cosanga		Riobamba				
Village	Zapallo	Alto Tena		Las Caucheras		Guaslan		Alto Ozogoche		
Type of Pico-hydro systems	LH	LH	HH	LH	HH	LH	HH	LH	HH	
No. of Pico-hydro systems	8	4	1	3	5	1	1	7	1	
Total Pico-hydro systems	8	5		8		2		8		**31**
Per Turbine Costs in-country	$196.27	$196.27	$196.27	$196.27	$196.27	$196.27	$196.27	$196.27	$196.27	
Local transportation	$3.46			$6.25		$18.30				
Locally made flume (LH only)	$70.00	$70.00		$70.00		$70.00		$70.00		
Per Turbine Costs on-site	$269.73	$269.73	$199.73	$272.52	$202.52	$284.57	$214.57	$284.57	$214.57	**$249.74**
Total civil works (pipes, cement etc.)	$783.49			$651.37		$662.13				
Civil works per unit	$60.27	$60.27	$60.27	$81.42	$81.42	$66.21	$66.21	$66.21	$66.21	**$67.79**
Total electrical works (cables etc.)	$1,200.30			$593.77		$1,456.90				
Electrical works per unit	$92.33	$92.33	$92.33	$74.22	$74.22	$145.69	$145.69	$145.69	$145.69	**$107.81**
Installation costs (developers)	$700.00			$400.00		$475.00				
Installation costs per unit	$53.85	$53.85	$53.85	$50.00	$50.00	$47.50	$47.50	$47.50	$47.50	**$50.50**
Total Installed Costs per unit	**$476.18**	**$476.18**	**$406.18**	**$478.16**	**$408.16**	**$543.97**	**$473.97**	**$543.97**	**$473.97**	**$475.85**

Note

LH - Low head (1.5m) The price of LH and HH units is the same

HH - High head (6-11m)

Costs of Pico-hydro to reach Ecuador per unit

Equiment cost (ex-works)	$145.00
Transport (Vietnam-Ecuador)	$12.57
Customs cost per unit	$17.48
Administration of customs	$21.22

4. Civil works costs

4.37 The civil works needed for the installations varied from community to community. The project team accepted the use of local materials if they were safe and did not affect the functioning of the units. Hence there are a variety of installations as is reflected in annex 4. The cost of the civil works includes cement, pipes, bags of sand, and so on; the average cost per unit was $60.27 in Napo (Zapallo and Alto Tena), $81.42 in Cosanga, and $66.21 in Ozogoche. The labor was provided by the community itself under the supervision of the project team and the local dealers.

5. Electricity distribution costs

4.38 The electricity distribution costs covered the distribution wires that link the units with the household. All installations were done with “duplex insulated wires” for security reasons. Wires with the appropriated attenuate voltage drop were required.

4.39 These costs were the single highest costs of the whole process because of the high cost of cables in Ecuador.

4.40 The cost of wooden poles was also included in these categories. However, the labor of digging and raising the post was done by the community. All the work was supervised by the project team and local dealers.

4.41 The average cost per unit was $92.33 in Napo (Zapallo and Alto Tena), $74.22 in Cosanga, and $145.69 in Ozogoche.

6. Installation costs

4.42 Local dealers were paid to supervise the progress of the installation when other members of the project team were not on site. The dealers were asked to reflect the real value that they would charge in the future for installing the picohydro units by themselves. Hence, these costs are proper market values for the installation of picohydro. The installation costs per unit were $53.85 in Napo (Zapallo and Alto Tena), $50.00 in Cosanga, and $47.50 in Ozogoche.

4.43 By adding up all the costs above, the following figures (see also Table 4.2) can be calculated for picohydro units imported from Vietnam and fully installed in Ecuador. The cost of each unit, fully installed, on average was $476.18 in Napo (Zapallo and Alto Tena), $478.16 in Cosanga, and $543.97 in Ozogoche for low-head units; for high-head units the cost was $70 lower. The whole process, from ordering to installation, took approximately seven months.

O&M Costs for the Pilots

4.44 The pilots were monitored for a period of six months following installation, during which time the repair and maintenance were covered by the project consultants and dealers. The costs that end users would expect for operating and maintaining the

PowerPal picohydro systems have been estimated to range between $4 and $5 per year. The only maintenance tasks are detailed below:

- Low-head unit—grease bearings every six months—$2
- Medium-head unit—change bearings (caliber 6203) every two years—$10

4.45 In regard to the life span of picohydro equipment, PowerPal estimates that its equipment could reasonably last 15 years although in the preceding economic analysis for picohydro systems, equipment life span was put at 5 years.

Summary

4.46 The installation of the 31 picohydro pilots in Ecuador in this project followed the complementary research work completed in Vietnam and the Philippines[32] and benefited from the experiences there. A deeper understanding of the latest picohydro technology has been gained through the pilot projects; all equipment was successfully operating one year after installation.

4.47 After the pilot demonstrations were completed, the costs associated with deployment were found to be an average of $475 per unit. The estimated operational and maintenance costs are between $4 and $5 per year, not including the time spent by the end user to carry out the tasks. Given a conservative equipment life span of five years, end users need to save $40 per year to purchase another picohydro system worth $200. Given those costs, the opportunities for further expansion of the market for good-quality picohydro products in Ecuador clearly now exists in certain segments; this information should be used to guide both the neighboring Andean region countries and other parts of Latin America.

4.48 After the successful demonstration of Vietnamese picohydro technology in association with local dealers in Ecuador (as will be presented in chapter 5 in more detail), with support from the government to further stimulate the local market, work should now be focused on expanding the use of picohydro technology in Ecuador and the Andean region as a whole. That could be part of a process that begins to recognize that picohydro is a major potential contributor to energy service options in rural areas of all developing countries.

[32] DFID KaR project, R8150. http://www.dfid-kar-energy.org.uk/html/r8150.htm.

5

Building a Sustainable Local Commercial Infrastructure

5.1 To build the foundation for a sustainable local commercial infrastructure for picohydro technology in Ecuador, two levels of action were implemented during the project.

5.2 First, a training course for installation and maintenance aimed at engineers and technicians was carried out and, second, business discussions about picohydro business opportunities were conducted with potential importers and companies that have the rural infrastructure in place that would enable them to eventually act as dealers.

5.3 The objectives of the training course were as follows:

- Provide participants with technical assistance and training on installation and maintenance of the picohydro systems
- Make a detailed assessment of the viability of transferring the low-head picohydro technology to Ecuador

5.4 The objectives of the business discussions were as follows:

- Engage local potential picohydro retailers, dealers and developers, companies, and importers in Ecuador
- Provide them with technical information about the technology, present the results of the project and the response of the potential users, show and discuss a market analysis done by the project team, and share commercial information about picohydro manufacturers

5.5 The goal of this activity was also crucial in achieving the overall aims of the project, which seeks to encourage the Ecuadoran market for picohydro development as one of the important options for family-level electrification and to replicate that in the Andean region.

Training Seminar

5.6 The technical assistance to train a local technician base was planned to consist of a seminar to be held at such a time so that by the middle of December 2003, the pilot projects could be put in place. The training seminar was targeted at community members, university/polytechnic students and researchers, electric utilities, government line agencies, NGOs, and private sector businesses; it took place, under the leadership of the director of DEREE-MEM in early September 2003.

5.7 The community members invited to the event were identified during the four field visits. Six community members were chosen from three areas: Zapallo (canton Tena) and Las Caucheras (canton Cosanga) in Napo province and Ozogoche (canton Alausi) in Chimborazo province.

5.8 The cross-sectoral nature of the participants was seen as key to the training because the end users in the communities identified would be able to gain assistance with installation, operation, and maintenance from a wide range of trained people. By including universities and polytechnic staff, the longer-term aim of transferring picohydro technology to Ecuador was addressed, because academic institutions are willing and able to support this aim. Involving CONELEC personnel was also crucial because CONELEC is the regulatory body that will assess the inclusion of picohydro as a valid technology for rural electrification plans.

5.9 The seminar was held at Centro de Capacitación of the Ministry of Agriculture in San Luis, south of Riobamba. The event was led by the consultant and Ing. Jorge Alava from DEREE-MEM; 44 people attended from the following sectors (see photo 5.1):

- Dealers/technicians (who were subsequently involved in the pilots)—8
- Private sector—6
- Community members—7
- Government—9
- Academe—7
- Church/NGOs—3
- Project consultants—4

5.10 The training session consisted of the following topics:

- Principles of the picohydro technology oriented toward low-head units and high-head units

- Civil work required to install the machines, with examples of the flume and draft tube required for the low-head machines
- Operation and maintenance of picohydro developments
- Basics of domestic electrical installation (aimed at community members because they were responsible for in-house electricity installations)
- Resource assessment—measuring head and flow at potential picohydro sites

Photo 5.1: Open Forum at the Picohydro Training Seminar

5.11 After the formal teaching was completed, there was an open debate on how to accelerate the uptake of picohydro technology in Ecuador. The main points discussed were as follows:

1. Technology transfer

How can picohydro have new uses in agricultural communities, for example, electric fences, communal workshops, spinning mills, dairies, and so on?

Final use of the energy has to add to the progress in the rural residential sector. People need continual training to be able to optimize the energy for productive options beyond lighting and entertainment.

To establish a mechanism for the administration of the picohydro, there are the “Juntas Parroquiales,” to whom the law grants certain rights. For the pilot project, the equipment could be dedicated to the community and a “Comité de Administración,” equivalent to the already existing experience in the rural water services.

2. Plan for financial assistance to further picohydro development

Establishing subsidies to create mechanisms for sustainability, based on an evaluation of the final use of the energy

The Fondo de Electrificación Rural y Urbano Marginal (FERUM) program can provide financing to promote electrification projects in rural areas (and urban margins), preferably in populations located in frontier provinces such as in the Amazon region.[33] FERUM stipulates that projects should benefit a minimum of 8 permanent inhabited houses, with per-household costs below $600 for areas in which it is possible to extend the grid or $1,000 for areas in which a new grid would be required, and they should not be used for public lighting systems. Because the kilowatt-level picohydro can benefit about 10 households and capital cost is lower than for other renewables (solar, wind energy, geothermal, biomass), picohydro projects could qualify for support under FERUM.

Consejo Nacional de Modernizacion del Estado (CONAM), conscious of its responsibility to establish electrical services as a way to eradicate poverty, is taking forward several programs related to rural energy services. For example, institutional strengthening and social support for rural electrical services can tie in with picohydro projects incorporating new users. Another project of CONAM (financed by Global Environment Facility [GEF] and the World Bank) is to establish pilot projects toward sustainable rural solutions that serve as a base to define the plan of rural electrification for which picohydro could be a good technology.

3. Assessment of the market

An evaluation is needed of the actual locations in which picohydro could add value to products.

The most important aspect is to analyze the capacity and will of potential users to pay for picohydro services.

Picohydro encourages ecotourism, and ecotourists want to stay in rural dwellings. These huts now use diesel generators that are noisy and do not encourage ecotourism.

4. Determination of typical end users

The communities themselves can establish a form of internal organization so that rights and obligations in pursuing picohydro projects are defined for sustainable schemes. Different communities have different cultural behaviors depending on the region of the country. Mountain communities (sierra) tend to be more communal and organized in addressing problems with microhydro

[33] FERUM funds can be used for new works, for enlargement and improvement of electrical distribution systems in rural sectors or urban margins, for system construction of renewable energy generation projects destined for the exclusive service of rural sectors, and also for the operation and maintenance of stand-alone electrical systems located in poorer and remote parts of Ecuador.

equipment for the beneficiaries, whereas in the Amazon (oriente) communities are less communal and equipment may last only as long as it operates.

Picohydro projects are replicable, and the technology can establish itself as a connection between dealers, community, and government and their various roles and responsibilities in bringing energy services to the rural poor. The universities also have shown their willingness to collaborate in the monitoring of projects and technology progress.

5.12 The following were the main concerns raised by participants:

- How will the community divide responsibility for the operational aspects of the picohydro systems?
- What actual added value can be found for the electricity?
- How sustainable is the project? Who will be responsible for maintenance and repair? How will the community pay for the maintenance? Who will lead with the communication required with dealers?
- What subsidies will be available for future installations?
- Is Ecuador cost competitive enough to develop a picohydro manufacturing capability?
- Voltage variations from picohydro systems are known to burn out appliances in the house. An electronic load controller (ELC) is therefore important to the successful operation of the technology. This technology is now becoming available at low cost,[34] and academic institutions should help develop this new technology locally to give support to end users.

5.13 These discussions were used as an input for the following actions at the community, government, technical, and business level.

5.14 After this event, a field visit was organized to demonstrate in situ how to estimate the water resource at a site being considered for a picohydro installation and the basic steps of the installation procedure. The community of Ozogoche was chosen for the field visit.

5.15 After the field exercise organized by the project team, the community representative who attended the training session explained to the whole community the technology and installations that were to be done there. This discussion allowed the project team to assess the level of comprehension of community members.

[34] For example, PowerPal has just developed and now manufactures a fully automatic ELC that overcomes overvoltage problems. The price for these units is $10 for the 200 watt unit, $25 for the 500 watt, and $50 for the 1, 000 watt version. These have been tested and sold for one year to date and have proved to be trouble-free.

5.16 The capacity-building activities that followed this seminar were carried out with dealers and installers. The project team trained each of the dealers selected via hands-on training conducted during the actual installation work. In this way eight accredited installers passed two levels of training, theoretical training at the seminar and practical training during the actual installations.

Business Opportunities for Picohydro in Rural Areas of Ecuador

5.17 Six months after the picohydro turbines were installed, a survey was carried out among key participants at the seminar and among potential investors contacted during the project.

5.18 The objective of this survey, which was conducted via a series of interviews, was to understand potential dealer's perceptions of the technology, the potential market, and how to develop it. A week before the interview, material containing information about the manufacturers and about the projects and their most relevant results was distributed to the dealers. Annex 5 provides responses from private companies and transcripts of interviews with individual dealers as part of the impact assessment that was done at the end of the project.

5.19 The main points to come out of this survey are summarized in Table 5.1.

Table 5.1: Summary of Interviews with Potential Picohydro Dealers

Negative perceptions	**Positive perceptions**
More information is required about technical specifications and technical support services from manufacturers.	Even without any marketing campaign, at least two picohydro turbines could be installed per month per dealer.
Development of picohydro businesses may be impossible without substantial amounts of financing.	Some dealers will initiate a market effort by installing demonstration units around the country.
Dealers need details of the commercial and financial conditions for importation and delivery/importation channels.	Picohydro is a brand-new business and could interest dealers as a very good business opportunity.
To some, the picohydro market is not profitable as a business. They recognize that hydro turbines represent an economic solution for isolated households, but the market is for microturbines connected to a minigrid, not picohydro connected to single households.	They are certain that a large market exists for picohydro, especially in the oriental region, where there is a strong market for rural, isolated households and distant cattle estates. These potential users are very interested in this technology and find its cost reasonable.
Although the cost of manufacturing a picoturbine in Ecuador could be quite high ($300), potential dealers may not be interested in importing or commercializing picohydro turbines because there are some risks in that business.	With only a small initial investment for picohydro one could have an excellent business. One dealer could have installed at least 10 units during the past year in communities of the oriente if the systems had been available.
The biggest problem is the time required to make field visits and to carry out an evaluation of the user's necessities and available hydro resources.	The low relative cost of picohydro systems allows low-income users to have access to an indispensable service that could improve their

This work needs to be initially carried out in several provinces. However, the costs associated with this market evaluation are too high to provide profitability to any private business.	living conditions.
It is difficult to motivate people to participate in projects unless they can be offered a range of possibilities for productive uses.	If training can be provided to users, then the market infrastructure should develop quickly. It is also important to locally manufacture some components (e.g., electronic controls).

Summary

5.20 The main result of this activity on building a local infrastructure for commercialization of picohydro in Ecuador was the confirmation that many people and companies are interested in acquiring these units and that they recognize that a potential market exists in the country. In the Amazon region (oriente) especially, there is a strong picohydro market for rural, isolated households and distant cattle estates. The low-head technology can be a solution there for much of the current demand for modern electricity services because it can fit the need for productive uses, such as dairies and small-scale milling.

5.21 There are interested companies that have sufficiently strong financial capacity to be able to stock units at their sale points distributed throughout the country. It is recognized that it is important to have units physically exhibited and, even better, in operation, to generate sales interest.

5.22 Some potential dealers do not believe that picohydro units offer a solution that would be of interest in their market because the systems have a very low power capacity and may not be very profitable for them. They believe the best choice for isolated communities with hydraulic resources is micro- or minihydro connected to an isolated grid.

5.23 There is also a requirement from some potential dealers for technical support services and clarity about the commercial and financial conditions for importation and delivery channels before they risk a new business. They believe that much more evaluation of the market as a whole in Ecuador would have to be done along with training and information dissemination about picohydro to potential beneficiaries in rural areas, highlighting the impact the technology could have on livelihoods through power for productive uses.

5.24 Overall in this project, a strong technical capacity was built up with a small but very highly qualified base of installers distributed throughout Ecuador. Also, dealers report that the pilot units installed in the communities are in operation and users are pleased with the systems.

6

Impact Assessment

6.1 The main objective of this project is to make picohydro systems more accessible to low-income households in the pilot areas and eventually in all areas of Ecuador and the Andean region that have sufficient hydro resources.

6.2 As such, one of the most important activities of this project was to conduct an impact assessment of the potential of these systems for end users (who were also in the low-income bracket). This exercise sought to clarify whether the technology was appropriate and attractive to end users and to highlight key issues in the adoption of picohydro energy by such households. That information would indicate how the overall project goal of market development would be achieved in practice.

6.3 The assessment covered the following:

- Sources of energy that households used before the project and after the installation of the pilots and the role of energy in daily livelihoods
- How communities perceive and understand this new technology
- Affordability of such systems to poor households
- Expectations of the technology and customer satisfaction with the system
- Main socioeconomic impacts on the household from system use
- Local availability of operation and maintenance support services

6.4 The following sections will discuss the methodology and the main results of the participatory exercises and survey carried out with local communities that installed the picohydro systems.

Methodology

6.5 The impact assessment used both quantitative and qualitative techniques, employing surveys (with open and closed questions, see annex 6), semi-structured interviews, and focus group discussions using participatory methods as described below.

Design of Impact Assessment

6.6 Two types of surveys were developed for the assessment:

1. For users of the picohydro systems
2. For dealers and engineers involved in the project

6.7 The assessment was carried out by IT Power's social scientist accompanied by a social scientist from TTA-Ecuador. Visits were made to the target populations before, and a year after, the installation of the picohydro systems to measure the changes and effects of the technology on the households.

6.8 Two rapid rural appraisal (RRA) exercises were carried out in each community. Each exercise took approximately two days. The whole community participated in these meetings. During the interactive sessions with the community, advice and recommendations on best practices and maintenance of the picohydro systems were provided by the team. The leaders of each community were given specific explanations about their overall responsibility for the systems.

6.9 In the second field visit, interviews were carried out with the persons directly responsible for the picohydro systems. Members from the other households using the system were also asked to contribute their opinions, particularly on the theme of energy consumption before and after installation. Women have important roles in interactions at the household level, but their contribution in the participatory community meetings tended to be less than that made by the men.

Visits to Project Sites

6.10 Visits were made to each site where a picohydro had been commissioned. These sites were visited in the following order:

Chimborazo Province

- Ciudad de Riobamba (centro Guaslan)
- Cantón Alausí Parroquia Achupallas (comunidad de Alto Ozogoche)

Napo Province

- Cantón Tena Parroquia Pano (comunidad de Zapallo)
- Cantón Tena Parroquia Alto Tena (comunidad de Alto Tena)
- Cantón Quijos Parroquia Cosanga (río Arenillas y Las Caucheras)

6.11 The geographical description of these locations was outlined in chapter 4.

Profile of Beneficiaries

6.12 The beneficiaries of the picohydro systems are rural farmers engaged mostly in agriculture and livestock rearing. The original intent of the project was to have low-income families as the main beneficiaries of the picohydro systems. However, during the implementation phase, the middle-income farmers of Cosanga were also included as beneficiaries because they were involved in productive agricultural activities. The following section will provide a brief description of the direct beneficiaries of the picohydro systems (a more general description of the beneficiary communities and sites are provided in chapter 4).

Guaslan Training Centre

6.13 In Guaslan the main beneficiaries of the two picohydro systems are the Guaslan Training Centre and the family of Marina Luquinga. In addition to the training facilities, the center is involved in livestock and agricultural development. It was found to be an appropriate venue for a picohydro system because it is a national institution used for meetings and training for groups and the owners want to develop it into a significant ecological center with an increased focus on renewable energy. The other beneficiary, Mrs. Luquinga, has five family members and they are engaged primarily in agriculture. The family could not afford to connect to the grid electricity, but is now connected to the electricity from the picohydro system.

Alto Ozogoche

6.14 The beneficiaries of the eight picohydro systems in Alto Ozogoche number 33 inhabitants, a church, and a school that provides education facilities to 44 families. The communities of Ozogoche are mostly poor. Most of the houses in Ozogoche are made of adobe, concrete, and straw and have two rooms each; therefore, they do not need many electrical connections. Farming and livestock rearing are the main means of livelihood, and women are involved in craft work also. Most of the farmers sell any excess milk produced to the cheese factory.

Las Caucheras, Parroquia Cosanga

6.15 The beneficiaries of the eight picohydro systems in Cosanga are members of a small farmers' cooperative and mostly middle- to high-income farmers who live in the cities. However, it is the caretakers of the farms who directly benefit from the picohydro systems. From the RRA assessments it was seen that the seven picohydro systems benefited 39 inhabitants directly. Most of the houses in Cosanga are made of concrete or wood with tin roofs and have on average three rooms. The president of the community is an active leader, and one of the picohydro systems is used to provide electricity to his house. That is important because he has been able to determine how useful the systems are and can inform others in the village or neighboring communities. Some of the picohydro systems benefit more than one household. The main income for the inhabitants in Cosanga is from agricultural products, livestock, fish breeding, and ecotourism.

Zapallo

6.16 The eight picohydro systems benefit about 68 inhabitants in Zapallo. They are mostly agricultural farmers who are also involved in producing craft work for their own consumption. The houses in Zapallo are all made of wood and straw and have an average of two to three rooms. Only three members of the community have completed secondary education.

Alto Tena

6.17 In Alto Tena the five picohydro systems benefit 48 inhabitants. Each unit is shared by two or three houses. The houses are made of wood and straw and have two to three rooms. As in all the other communities, community members are subsistence agricultural farmers.

Socioeconomic Impacts

6.18 Results from visits to the households before and after the picohydro systems were installed showed a consensus in the main socioeconomic impacts of the picohydro technology. These impacts were felt mostly in health, communication, education, recreation, social cohesion, economics, and technical knowledge, as outlined in Table 6.1.

Table 6.1: Expectations and Actual Impact of Picohydro Pilots on Social and Economic Aspects in Chosen Communities

Theme	Expectations before implementation	Recipients' assessment of actual impact after implementation	Comments
Health	It would be possible to avoid eye irritation and to counteract the risks of fires as well as burns.	Clearer vision and less irritation. Increased feeling of security with a reduced risk of fires. No burns.	
Commun-ication	The use of the radio would increase (~3–4 hours) because there would be no need to purchase batteries. Use in specific hours would increase to listen to local radio messages sent by family or friends.	Radios are being used for an average of 8 hours per day. TV is being used for 4 hours. Can now listen for messages at any time.	
Education	It would be possible to study at night by correspondence, by using the radio, or by attending school in those areas that have schools (time for school activities at night was limited).	Possible to study at night and also attend night school. Knowledge of the Spanish language increased (the native language is Quichua) by means of the radio and TV.	
Recreation activities	There would no longer be a need to spend money hiring a genset for parties, and some sports activities would be possible after dark.	Able to celebrate all local events without the necessity of hiring gensets. Able to play sports (volleyball and football) at night.	The men spend more time at home during weekends; they don't feel the necessity to leave.

Theme	Expectations before implementation	Recipients' assessment of actual impact after implementation	Comments
Social Cohesion	There would be a greater ability to exchange ideas concerning the community, its improvements, and daily problems	Meetings take place at night to discuss diverse issues of the community or to organize celebrations and festivities.	The main comment here was, "Now it seems that we are in the city." People comment that they are happy they have the service.
Economic/ Income	Costs for fuels, candles, kerosene, and batteries would decrease. It would be possible to work in the evenings. Improved light source would allow more handicraft activities than are possible in the few moments available during daylight hours. The domestic economy would thus be improved.	Expenditure on candles, batteries, or fuel for lighting is not needed. It is possible to work a little bit more in the field or the house during the evenings. Craftwork is done at night, but only for domestic purposes. Initiatives that are incremental to the domestic economy such as the opening of the grocery store and the hatchery of chickens in Alto Tena show positive results.	Each family knows exactly how much it has saved by the nonacquisition of candles, kerosene, batteries, etc.
Technical Knowledge	People would be incapable of understanding technical topics and maintaining the picohydro systems.	They have come to an agreement to pay for maintenance and management of the picohydro systems.	People are proud of being the experts and beneficiaries of picohydro.

6.19 To summarize the main impacts from the table above, communities mentioned that the reduced use of kerosene and candles was one of the most important impacts, as they could save money. The electric lights also helped them to avoid the deterioration of their eyes and lowered the risk of fires. They could knit the *chumbis* (waist strips-crafts) at night, and children could complete school tasks and learn Spanish from the radio. They could easily work in the evenings. Cheese makers were found to benefit particularly from the electricity service. After the picohydro systems were installed, social gatherings and meetings took place at night and farmers could work the whole day.

6.20 In Zapallo the community has started to collect $0.50 to cover the maintenance expenses of the picohydro systems. The community members were glad to be the owners of their own picohydro systems, which brought a sense of empowerment. In Cosanga the main impact for the richer farmers from the cooperative was that they could find people to work in the properties easily.

6.21 The picohydro systems were delivered only to those areas designated by MEM as being unlikely to be connected to the grid in the foreseeable future. However, in Ozogoche, the national grid was extended to cover the region after the picohydro systems were installed. Nevertheless, the people who had a picohydro system have said that they distrust the irregular grid service and did not want to pay $50 for the meter as well as the monthly fee.

6.22 The Guaslan Training Centre has been providing an important function in increasing the awareness of an alternative energy-producing system. According to the director of the community center, the picohydro systems were used for the conference rooms, which have between 300 and 400 visitors every month and open four days a week. There are currently 16 lamps in the conference rooms. The picohydro unit is also used to power the lights in the kitchen and dining room facilities. Therefore, in addition to the demonstrative capacity of the picohydro unit, the center also benefits financially.

6.23 Most of the immediate impacts outlined in the table above are positive. However, users also said that the system damaged lighting and electrical devices. That is the case when the system voltage varies significantly.

Use of Picohydro Systems for Productive Activities

6.24 In addition to lighting, the power was used for productive activities by owners of the picohydro systems.

6.25 In Cosanga a battery-powered electric fence was powered by the electricity supplied by the picohydro system. The owner, knowing the importance of the picohydro system for his production, built a safe and protective powerhouse where the unit is located. The electric fence has been used continuously for more than a year.

6.26 In Cosanga another farm owner has finished building two pools, one to hatch trout eggs and another big pool for mature trout. Since the picohydro has been installed, the oxygenation mechanism needed for this activity has been installed. In another site in Cosanga located only two hours by foot from a national park, the picohydro system powers an ecolodge dedicated to bird watching. The facilities are advertised on the Internet, and some tourists, mainly from Europe, regularly spend their holiday in it. However, the fact that they did not have electricity was a barrier to have full occupancy at the lodge. After the picohydro system was installed, lamps in the kitchen and common rooms were installed, creating a favorable environment for the workers and visitors.

6.27 In Ozogoche two cheese factories owned by members of the community are now being powered by the picohydro systems. Most of the families of the community have cows, and the milk produced is sold to these cheese factories. However not all the milk produced can be processed by the factories. The regular electricity and the lighting have extended the hours of production, and all the milk produced daily is being processed. In this way the community has benefited as a whole because more milk and cheese are sold.

6.28 In Alto Tena there was some poultry farming, which was immediately identified as a potential activity that could be aided by the picohydro units. A 120 watt lamp has been installed to speed the hatching process; it is turned on only when the loads of the two households powered by the picohydro unit are not being used.

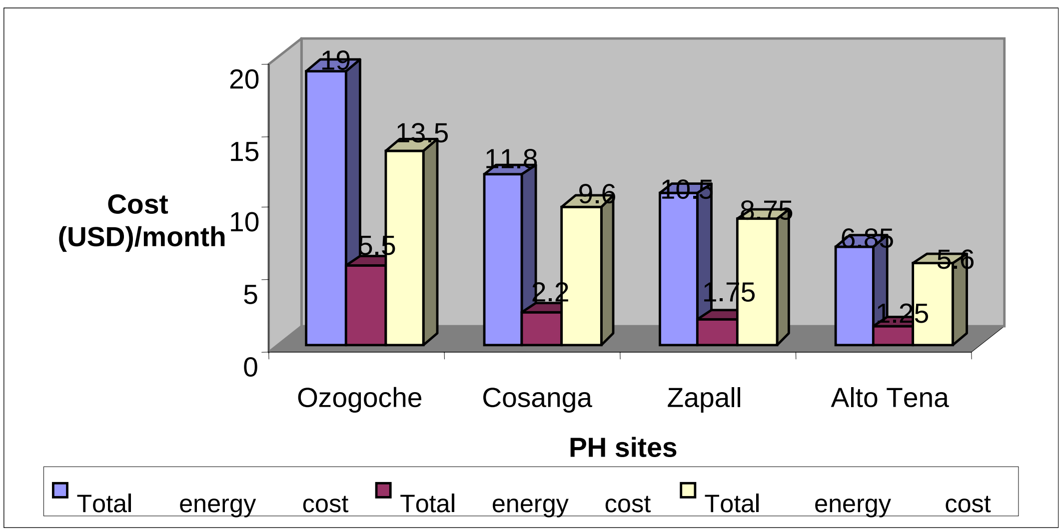
Energy Use, Costs, and Savings

6.29 The participatory impact assessment of the consumption and costs of energy fuels was conducted in six communities. The communities noted the following changes in their energy consumption patterns after the picohydro installation (see Figure 6.1).

6.30 The overall savings from the change of energy fuel use patterns came mainly from kerosene (explained separately below). The average savings of kerosene in a household is about $9 per month. In Zapallo, group discussions concluded that there was an average monthly savings of $15 on all fuel replacement costs per household as a result of the picohydro system installation.

6.31 The community of Alto Tena shows low spending and savings on fuel costs, primarily because it a poor community in comparison with the others. However, although the electricity service from the picohydro system is free, the communities will have to gradually start paying a tariff to maintain an operation and maintenance fund. One community has already started to collect money for maintenance purposes.

Figure 6.1: Total Energy Cost per Community



6.32 There is a disparity in the costs of energy among the different villages in the study for the following reasons:

- Between regions a gallon of kerosene can vary from $0.75 to $1.5 per gallon.
- For a middle- to high-income farming community, Cosanga displays a low energy cost because the people that live on site are farm keepers and not the owners. The cost of their fuel is provided by the absentee owners.

- In Ozogoche the cost is high for kerosene and, in particular, for wood used for heating and cooking, because it is in a very cold area and there are few trees available to provide fuelwood.

6.33 As shown in Table 6.2 fuelwood is used mostly for cooking purposes by all communities. In Alto Tena wood was also used for drying fish. Dried straw was used only in Ozogoche. Ozogoche used more fuelwood in comparison with the other communities because the weather is colder. Most of the other communities used either one or two bunches of wood a day. Fuelwood is usually not paid for but is gathered by community members, except in Ozogoche, where community members buy a truckload of wood and share it among themselves. There was no change in fuelwood replacement. The picohydro system did not make any difference in energy use because the picohydro systems used do not allow for electric cooking, which is a highly intensive energy-consuming activity.

Table 6.2: Use of Dried Straw and Wood

PH sites	Dried straw		Wood		Cost/month ($)
	Y/N	Bunch/day	Bunch/day	Use	
Ozogoche	Y	1	5	Cooking/heating	5
Cosanga	N	-	1	Cooking	0
Zapallo	N	-	2	Cooking	0
Alto Tena	N	-	2	Cooking/drying fish	0

6.34 Candles, diesel, and kerosene were used for lighting purposes before the picohydro systems were installed. An average of $2 per month was saved from the replacement of candles (see Table 6.3).

Table 6.3: Use and Cost of Candles

Sites	Before		After		Savings ($)
	Bunch/ month	Costs/ month ($)	Bunch/mo nth	Costs/month ($)	
Ozogoche	4	4	0	0	4
Cosanga	3	2.2	0	0	2.2
Zapallo	1	1	0	0	1
Alto Tena	1	1.25	0	0	1.25

6.35 After the picohydro installation, an average household saved about $2.8 per month from kerosene and diesel replacements alone (see Table 6.4).

Table 6.4: Use and Cost of Kerosene and Diesel

PH sites	Before		After		Savings ($)
	Liters/month	Cost/month ($)	Liters/month	Cost/month ($)	
Ozogoche	16	4	0	0	4
Cosanga	12	3.25	0	0	3.25
Cosanga*	16	5	0	0	5
Zapallo	8	2.5	~0.5	0.75	1.75
Zapallo*	4	1	0	0	1
Alto Tena*	4	1.6	0.5	~0.25	1.35

* Diesel

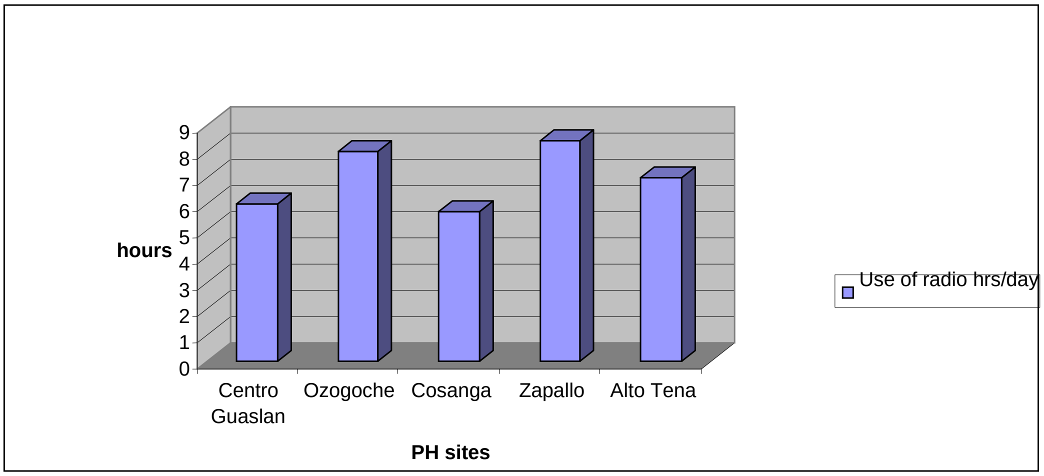
6.36 The households deriving benefit from the picohydro system explained that the use of batteries for radios and lanterns was almost fully replaced, as shown in Table 6.5. According to the communities, the radio was the major medium for receiving information.

Table 6.5: Use and Cost of Batteries Before and After Project

PH Site	Before			After			Savings ($)
	Unit/ month	Use	Costs/ month ($)	Unit/ Month	Use	Costs/ month ($)	
Ozogoche	8	Radio & lantern	4	2	Lantern	1	3
Cosanga	10	Radio & lantern	5	4	Lantern	2	3
Zapallo	12	Radio & lantern	6	2	Lantern	1	5
Alto Tena	8	Radio & lantern	4	2	Lantern	1	3

6.37 As seen in Figure 6.2, the radio was used for seven hours on an average day after the picohydro systems were installed. However, in the more remote areas of Ozogoche and Zapallo the radio was used for about eight hours. It must be noted that the more economically well-off farmers of Cosanga who traveled to the town more often, used the radio less (5.7 hours). Their use was lower because their information channel was more expanded in comparison with the other villages, such as in Ozogoche, where people had to travel at least three hours to reach a market. The participatory assessment with each community showed that a household saved an average of $3 to $4 per month from battery replacement. That is confirmed from the survey conducted, which shows a monthly average of $3.5 saved from the replacement of batteries.

Figure 6.2: Use of Radio (hours/day)



Operation and Maintenance of the Picohydro Systems

6.38 Users of the picohydro systems perceived that preventive maintenance was easy and did not require much work. However, the corrective maintenance was perceived to be more complicated because spare parts of the picohydro systems were not locally available.

6.39 A common inconvenience encountered after the installation was the fluctuation of voltage from the system that often led to the burnout of electric lamps and devices. Many users had replaced the low-wattage lamps provided for the picohydro schemes with regular incandescent lamps. However, the owners were adapting quickly to the technology. They devised ways to regulate the turbine in line with the flow variation of the river and the electricity consumption. In that way they avoided the frequent burnout of lamps.

6.40 Some owners also encountered unforeseen changes in the river flow. In Alto Ozogoche the rivers overflowed and canals were filled with mud. Owners of the picohydro units in Napo faced a similar situation, and they had to remove the turbine because the river had swept away parts of the powerhouse. However, the units were replaced after civil work maintenance was done.

6.41 The community in Zapallo agreed with the dealer to pay for maintenance services. A fee of $50 plus travel costs per visit and a menu of options according to different maintenance labor costs were fixed. The project team made a detailed list of best practices and presented it to the leader of each community. The community is taking preventive maintenance steps and collecting funds to pay for the technical services.

Market Development

6.42 The demonstrative nature of the current project is creating a positive image for picohydro; several neighboring communities have requested installations (see Table 6.6).

Table 6.6: Requests for Picohydro Installations

Site	Requests for installations
Guaslán	Canton Chambo, community of Cugillines (60 families), and Titaicum (40 families). Representatives visited the Centre of Guaslán to learn about picohydro.
Ozogoche	There are many interested families in the nearby regions. The interested parties visited the dealer on many occasions. He has taken them to Alto Ozogoche to show them the picohydro sites.
Cosanga	A neighboring alcalde from canton Chaco visited the sites and formally expressed interest with local authorities. Farmers from the region also expressed interest in the picohydro systems.
Zapallo & Alto Tena	Many people from nearby communities have come to see the installed units. All were referred to the local dealer.

6.43 The community of Chimborazo in Ozogoche wanted more systems for the community center, school-kindergarten teacher's house, school workshop, and two cheese factories.

6.44 Although there is growing interest from areas neighboring the picohydro system installation sites, the dealers have been unable to assist them because there are no units available to sell. Detailed information about the feasibility of potential installations cannot be provided because each site needs technical evaluation. It is clear that markets are evolving in the region.

6.45 The current project did not cover the cost of any special marketing campaign or dissemination plan or activities at the community level. However, the following was undertaken:

- Training workshop at the Guaslan Centre–Riobamba (see chapter 4)
- Local radio interview of the president of Parroqui de Cosanga explaining the project and the benefits of the picohydro technology
- Seminar by Angel Samaniego (director of Guaslan Centre) for decision makers and key officials of the Ministry of Agriculture. Ing. Samaniego explained the project and the benefits of the picohydro technology.

Summary

6.46 The project has been successful in showing that small hydro resources can be tapped efficiently to produce electricity and replace traditional fossil fuel use.

6.47 The benefits also show an increase in the quality of life, because the better lighting systems made community activities possible during the evenings. The beneficiaries have pointed out that fuel savings were made and that there was an increase in the productive output as well as increased opportunities for educational and social activities.

6.48 Users were apprehensive at the beginning of the project; however, the information provided during the RRA assessment (see Photo 6.1through 6.4) and the training of users, along with the actual implementation of the project, added to their confidence in maintaining the picohydro systems. The communities also acquired additional skills and have been able to overcome problems encountered in maintaining the system.

6.49 Some of the lessons learned from implementing the pilot projects are that it is important that technical feasibility surveys include a proper assessment of river flows during different seasons. Proper assessments can lead to better operation of the systems and less voltage fluctuation. Social factors such as leadership skills and cohesiveness of the communities are important criteria to be assessed in feasibility surveys for long-term maintenance of the picohydro systems.

6.50 As was demonstrated for the pilots, it is also important to provide users with safety and best-practice guidelines. These guidelines should preferably be developed in the local dialect or language with pictorial representations. Guidelines could include procedural requirements for the people who maintain the picohydro systems. Both the owner and maintenance operator should be offered in-depth training on the operation and maintenance of the system. And most important, users should be made aware of the limitations of the picohydro systems in providing electricity for higher loads and in achieving productive outcomes.

Photo 6.1: Impact Assessment in Zapallo

Photo 6.2: Impact Assessment in Alto Tena

Photo 6.3: Impact Assessment in Ozogoche

Photo 6.4: Impact Assessment in Las Caucheras

7

Conclusions and Recommendations

7.1 There is no doubt that picohydro can provide services to low-income families in rural areas in Ecuador. There is a segment of the rural population for which picohydro is certainly affordable, but most people are not yet aware of the potential of the technology and often revert to buying gensets. Financing and technical assistance may still be required to enable the poorest customers to be able to afford a picohydro system, particularly if good-quality technology is to be used and installed properly.

7.2 There are a few countries that have large numbers of picohydro systems being used in rural areas, most notably Vietnam, Nepal, Lao PDR, and South West China. These are also extremely poor regions of Asia with annual household incomes as low as $300 to $400 per year.[35] Yet there have been more than 120,000 picohydro units (low-head types) installed in the past 10 to 15 years in Vietnam alone, and more than a thousand Peltric sets installed in Nepal.

7.3 The majority of these systems have been paid for through pure cash-and-carry without any subsidy intervention. The prices of the most popular (Chinese) picohydro units are as low as $15 to $20 (excluding the cost of installation).[36]

7.4 This cash-and-carry (commercial) model may have worked for huge numbers of rural poor, but the reality is that less than half of the low-head picohydro systems purchased are still in operation, because of the low quality and short life span of the equipment. In addition, there have been serious safety issues including some recorded deaths by electrocution from poorly installed equipment.

7.5 It is clear from the experience gained in this project that a "dealer" energy service model, with postsales maintenance support fed by good-quality equipment, would provide a more useful product to rural people in general and to the "poor" rural population that can buy picohydro units only if they can pay over a period of time.

[35] Field analysis from Yunnan, SW China, and Hao Binh, NW Vietnam, 2003–2004.

[36] The 200 watt low-head picohydro units are low quality from China at $15 to $20, better quality from Vietnam at $50 to $80, and best quality from Nepal at $1,000 per kilowatt (equivalent to $200 for 200 W).

7.6 Despite the large potential market for low-head picohydro technology and the perception by many that it provides a good business opportunity, some obstacles do remain in pursuing this model, as highlighted through interviews with potential private sector players in Ecuador. There is a requirement for a more thorough understanding of the technology itself to instill trust, which may need technical input from manufacturers and suppliers from Asia. In Ecuador the conditions for importation and delivery channels for bringing picohydro to the market need to be clear before people risk a new business.

7.7 Many potential dealers would come forward if a proper evaluation was done of the actual market locations in Ecuador and of how picohydro can add value to products and make productive uses possible in these locations. At the same time, to motivate participation in projects this study should be complemented with training and information dissemination about picohydro to potential beneficiaries.

7.8 Various technical solutions for the picohydro technology to support this model emerged in the early 1990s in China and Vietnam, and many have been refined since that time into mature, good-quality products (Peltric sets and low-head units) although some still require more development (e.g., pico-cross-flow turbines). What is now required is concentration on establishing standards and certification/licensing for these products, which urgently need to be put in place.

7.9 Finally, the following are important issues that need to be resolved for a dealer-based energy service model for picohydro to be "bankable" in developing countries:

- Manufacturers—Equipment suppliers must be able to provide systems that meet established standards.
- Dealers—There must be a market for the sale and maintenance of a minimum number of systems to enable the dealership to be profitable.
- Engineering support—This support must be available to provide for site visits, prefeasibility studies, installation advice, repair and maintenance, and warranty.
- Community liaison—Support needs to be provided to local communities to help them determine whether picohydro units are useful in their situation and how best to organize payment.

7.10 As shown in Table 2.1 and 2.2, picohydro, though not necessarily the least-cost option, has emerged as a technology that can provide relatively inexpensive power. Subsidy for the capital costs of the technology, therefore, is not a priority (as it has been for PV systems). Some support is needed, however. The areas requiring support and the various institutions identified by this project that could be involved at each stage follow:

- Quality assurance, certification, licensing of picohydro equipment
    - National energy ministries together with universities that have appropriate testing facilities, international bodies (e.g., the International Network on Small Hydro Power [IN-SHP])
- Financial assistance to the very poor
    - National renewable energy programs (e.g., FERUM), financial institutions with international lending programs, local rural banks
- More conducive environment for importation of new technologies
    - Regional bodies (e.g., Pacto Andino), government policies
- Support to sales infrastructure
    - National government (e.g., Department of Science and Technology), local government units, and local entrepreneurs
- Seed money to help institutions set up engineering support services
    - Multi- and bilateral agencies, government departments (e.g., CONAM)

7.11 Further support for the picohydro sector could be used for establishing repair and maintenance and sales infrastructure, as well as business management and accounts, to encourage sustainable development of the picohydro market. This should be done in participation with the private sector (dealers, RESCOs, developers, rural banks, entrepreneurs, etc.) and NGOs. However, subsidies have to be carefully managed, because often when assistance comes in, equipment suppliers can raise the price of turbines, which can defeat the purpose of lowering the costs of electricity to a level that the poor in developing countries can afford.

7.12 If action is taken to ensure that good-quality equipment is promoted and installed properly, picohydro will be able to provide hundreds of thousands of households living in rural areas with a reliable and relatively cheap form of electricity that can help to improve their standard of living and quality of life.

Annex 1

Picohydro Product Specifications

PowerPal—Canada

The equipment used in the Energy Sector Management Assistance Program (ESMAP) project in Ecuador, both for low-head and medium-head sites, is from a company called PowerPal; the specifications are described here.

Supplier—Asian Phoenix Resources Ltd.

Suite 2, 416 Dallas Road, Victoria, B.C. Canada V8V 1A9

Tel: +1-250-361 4348 Fax: +1-250-360 9012

Contact: David Seymour dlseymour@shaw.ca

Web: www.powerpal.com

PowerPal Picohydro Products Technical Description

Low Head

Model	**MHG-200LH**	**MHG-500LH**	**MHG-1000LH**
Nominal Power	200 W	500 W	1,000 W
Turbine	Propeller	Propeller	Propeller
Design Head	1.5 m	1.5 m	1.5 m
Flow	35 L/s	70 L/s	130 L/s
Output voltage	110/220 V single phase	110/220 V single phase	110/220 V single phase

High Head

Model	MHG-200HH	MHG-500HH	MHG-T1
Nominal Power	160–200 W	275–500 W	660–1,000 W
Turbine	Turgo	Turgo	Turgo
Design Head	5–6 m	7–11 m	8–11 m
Flow	6.3–6.4 L/s	7.4–9.1 L/s	21–23 L/s
Output voltage	110/220 V single phase	110/220 V single phase	110/220 V single phase

Features

- PowerPal units provide competitively priced, reliable, robust solutions to rural electrification in developing countries.

- Units are supplied with voltage regulator.

Costs

- For export, PowerPal can supply the various picohydro models at these discounted ex-works costs (from Hanoi, Vietnam):

Low head	**Cost**	**w/ ELC**		**High head**	**Cost**	**w/ ELC**
200 W	$160	$175		200 W	$175	$190
500 W	$295	$315		500 W	$310	$230
1,000 W	$560	$580		1,000 W	$850	price includes **[[Missing info]]**

- Systems now come with an automatic electronic load controller (ELC), with prices indicated above.

Additional Information

- PowerPal products are made in Vietnam but have been exported to more than 30 countries, and there are now dealers in many countries.

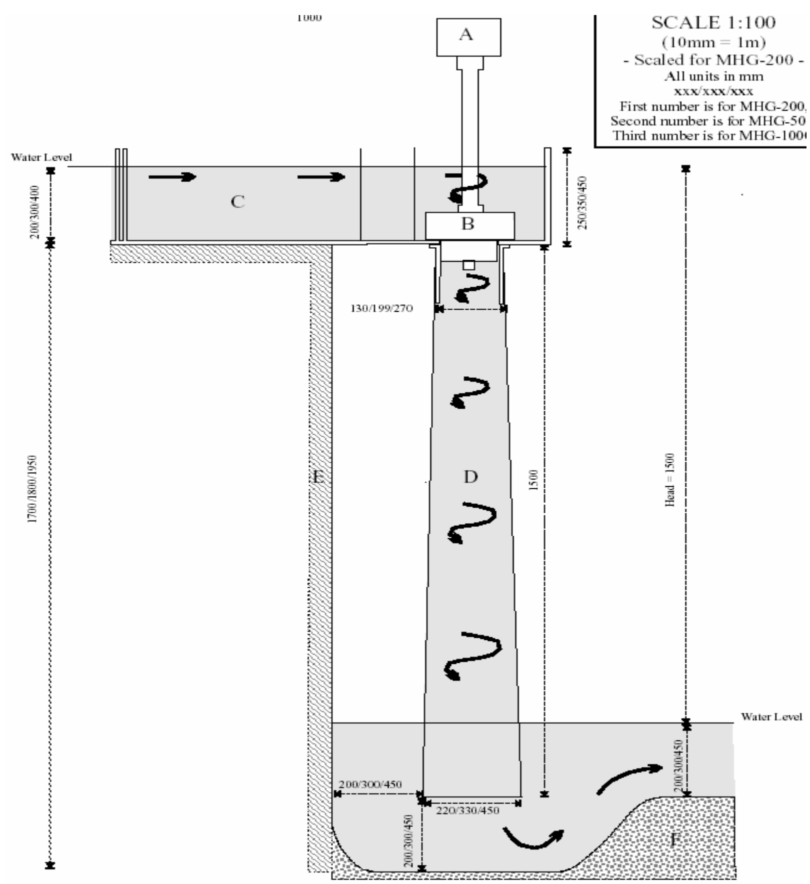
- Picohydro manuals are available in English and Spanish from PowerPal's Web site.

- PowerPal is involved in the manufacture and supply of various types of microhydro systems up to 16 kilowatts (turgo) and 100 kilowatts (cross flow).

Photo A1.1. A: 200 Watt Low-Head PowerPal Delivered to Ecuador in 2003

Photo A1.2. A: 200 Watt High-Head PowerPal Installed in Ecuador in 2003

Figure A1.1: Cross-Section of Typical Low-Head PowerPal Picohydro Installation



MTG Series of RERC — Vietnam

The following is the specification for picohydro equipment of the Renewable Energy Research Centre (RERC), which is manufactured in Vietnam and targeted primarily at the higher-cost, better-quality market in Vietnam.

Supplier—Vietnam Support Programme for Sustainable Energy Development (VSED)

c/o Professor Nguyen duc Loc

e-mail: ndloc@yahoo.com

Based at the Renewable Energy Research Centre (RERC) at the Hanoi University of Technology, 1 Dai Co Viet Road, Hanoi, Vietnam

Telephone: +84 4 864 2519

Fax: +84 4 943 2664 or +84 4 869 1256

RERC Picohydro Products Technical Description

Low head

Nominal power	200 W	500 W	1,000 W
Design head	1.5–1.6 m	1.5–1.6 m	1.5–1.7 m
Flow	28–30 L/s	64–70 L/s	120 L/s
Propeller diam.	120 mm	180 mm	220 mm
Output voltage	220 V single phase	220 V single phase	220 V single phase
Rated current	~ 1 A	~ 2.4 A	~ 4.3 A
Tested efficiency	52%	52%	54%

Features

- RERC holds a copyright on the hydroturbine design of the picohydro unit and has collaborated with the Institute of Material Science (IMS) at the National Centre for Science and Technology for the generator design.
- The RERC product is more efficient than the cheap Chinese units because it uses rare earth magnets for the generator.
- The RERC product has a higher power output than the typical underperforming, cheap Chinese units, delivering the actual rated power.
- The RERC product is proved to be more reliable, with a longer life span, and has overcome the shortcomings of the cheap Chinese units.

Costs

- In Vietnam the 200 watt system currently costs $47 to the end user and therefore has not yet gained a significant market share among rural households that are short of cash.

- For export, RERC (in partnership with the Hydro Power Centre [HPC]) can supply picohydro at the following costs:
  - 200 W—$80
  - 500 W—$140
  - 1,000 W—$260

PT Series—Nepal

Nepal has a number of picohydro systems developed locally, many suitable for the higher heads of the Himalayas, such as "Peltric" sets. A robust low-head picohydro system using an induction motor rather than a permanent magnet generator is also available locally.

Supplier—Nepal Hydro & Electric Pvt. Ltd. (NHE)

Sales: Roshan Soti

Engineering and Sales Department, NHE, PO Box 1, Butwal, Nepal

Tel: +977-71-540212 or 540386 Fax: +977-71-540465

E-mail: roshan.soti@nhe.com.np Web: www.nhe.com.np

Product Development: Purushottam Panthee

NHE, P.O. Box 1, Butwal, Nepal

Tel: +977-71-540212 or 540386 Fax: +977-71-540465

E-mail: purushottam.panthee@nhe.com.np Web: www.nhe.com.np

NHE Picohydro Products Technical Description

Model	PT02	PT1
Nominal power	200 W	1,100 W
Design head	2.15 m	3.1 m
Flow	30–32 L/s	85 L/s
Generator	Induction motor as generator (IMAG). Electronic load controller with overload and short-circuit protection. Ballast load comprises air heater rod.	Induction motor as generator (IMAG). Electronic load controller with overload and short-circuit protection. Ballast load comprises air heater rod.
Output voltage	230 V single phase (±5 V)	230 V single phase (±5 V)
Draft tube weight	24 kg *	40 kg *
Turbine weight	42 kg	110 kg

* Lighter-weight options may be available for export. Inquire with NHE.

Features

- Turbine and generator are located in a simple "open flume" arrangement. There is no penstock pipe, and the intake can be taken directly from a supply channel or irrigation canal.

- Cost is low enough to make it affordable for rural farming communities to purchase and operate.

- Simple, low-cost installation and civil construction from locally available materials.

- It is easy to use with simple maintenance (one serviceable part).

- NHE can provide full specifications for civil construction, transmission line, and village distribution networks.

Costs

- Costs are available from NHE on request.

Additional Information

- NHE is the sole supplier of the PT02 and PT1 models. A number of demonstration PT02 and PT1 sites are operating in Nepal, and NHE can provide information about them on request.

- The unit is designed to operate in continuous service for at least 10 years.

- A pictorial instruction manual with Nepali and English notes covering operation and maintenance is provided.

Photo A1.3: Complete PT02 Turbine Assembly

Photo A1.4: PT1 Installation in Operation

XJ13-L-11/1 x 2 Microturbine — China

China has been the source of most picohydro units; most of them are of poor quality but are very cheap. There are emerging new picohydro systems, however, that are of better quality, supported by the Ministry of Agriculture in Nanjing.

Supplier—Yueqing Machinery Factory, Zhejiang, China

This microturbine comprises a turgo runner, an inclined jet, and a single-phase induction generator, suitable for heads of 10 to 20 meters and flows of 4.2 to 6.0 liters per second, with an output of 0.2 to 0.8 kilowatts, at 220 volts and 50 hertz. It has a control box mounted on the generator.

With its one nozzle and vertical shaft, the turbine has many advantages: compact construction, light weight, easy to mount, and convenient to operate. The turbine requires a small investment, and it can be used for lighting or motive power for processing small agricultural products in mountain villages in which hydraulic resources are limited.

Yueqing Picohydro Technical Description

Turbine	Runner diam. (mm)	110	**Generator**	Rated power (W)	750
	No. buckets	15		Voltage (V)	220
	Head (m)	10–20		Current (A)	3.3
	Flow (L/s)	4.2–6.0		Freq. (Hz)	50
	Rated speed	1,500			
	Output (W)	200–800	**Dimensions**	L x W x H (mm)	380x380x410
	Inlet tube diam. (in.)	2		Weight (kg)	35

Photo A1.5: Yueqing 750 Watt Microturbine

Annex 2

Experience of Picohydro in Vietnam and the Philippines

Available Picohydro Equipment in Vietnam

Chinese Imports

Picohydro systems in Vietnam are imported mostly from China, illegally, where they are manufactured near Nanning City using conventional permanent magnets in the generator. The most common units come with nameplate outputs of 300, 500, and 1,000 watts, but actual outputs are typically 100, 200, and 450 watts, respectively. No guarantees are given on any part of the system; the only instructions, if any, are in Chinese, and sales service is scarce, being the sole responsibility of local picohydro dealers. The installation is done by customers themselves with the help of friends or local technicians, and although there are no Vietnamese installation instructions, there are already so many units installed that buyers can refer to those that are already in operation.

Prices of Chinese picohydro units in the local marketplace are typically in the range of $14 to $16 for the 300 watt unit, $20 for the 500 watt unit, and $40 for the 1,000 watt unit. This price does not include the draft tube for the turbine or the transmission cable, and it excludes any civil works costs. These balance-of-system elements can cost in the range of $40 to $60 and hence are the more significant cost element for the 100 watt unit.

The Chinese 300 watt units (see Photo A2.1) dominate the market, with more than 90 percent coverage, achieved through the very low unit price (illegally avoiding tax and import duty) and a well-established distribution network of importers and retailers in the provinces and district towns. However, the technical quality of the system is low. Total repair and maintenance cost for the 300 watt unit for one year is estimated to be about the same as the purchase price of the product (~$25). The lower bearing is the most frequent cause of failure, and generator windings and seals also fail regularly. However, owners seem to be able to fix their units with the help of a local repair shop. In general most systems become unusable after two or three years and have to be completely replaced, although many units last only six months.

Photo A2.1: Chinese-Made Family-Hydro Systems for Sale on the Street In Hanoi (300 and 500 watts)

Vietnamese Products

There is a more efficient and reliable Vietnamese design that attempts to overcome most of the shortcomings of the Chinese units. The product uses rare earth magnets in the generator and is available from the Renewable Energy Research Centre (RERC) at the University of Hanoi. This design has a higher output and a longer life span, but the system currently costs $45 to the end user for a 200 watt output and therefore has not yet gained a significant market share among rural households short of cash. For export, RERC also supplies 200, 500, and 1,000 watt units for $80, $140, and $260, respectively (see Photo A2.2).

Photo A2.2: Vietnamese Family-Hydro Systems Made by RERC and Material Institute (200, 500, and 1,000 watts)

By mid-2003 RERC in cooperation with the Hydro Power Centre (HPC) of the Institute of Hydro Resources, Ministry of Agriculture and Rural Development, had manufactured numerous types of picohydro units, as well as small hydropower systems up to 1,000 kilowatts in capacity (see Photo A2.3).

Photo A2.3: New Vietnamese Family-Hydro Systems Made by RERC and HPC (200, 500, and 1,000 watts)

In the past five years a Canadian company, Asian Phoenix Resources Ltd, identified the market potential for improved quality picohydro units in Vietnam and nearby countries and developed the PowerPal 200, 500, and 1,000 watt propeller turbine unit manufactured in Hanoi.[37] The unit sells for $90 in Vietnam and between $100 and $200 for export to other countries. Sales volumes achieved in Vietnam are unknown, although more than 300 units have been sold throughout the world since 1999.[38] The advantage of these units is that they come with a voltage regulator that can be set at the appropriate voltage once the typical load has been connected. That offers protection against the voltage and frequency fluctuations from which the Chinese imports suffer. Their life span is also regarded as being longer than other picohydro products.

Picohydro Market in Vietnam

Vietnam has more than 2,200 rivers that have a length of more than 10 kilometers. The most important of these for hydropower are the Da River Basin in the north, Xexan in the center, and the Dong Nai in the south. The majority of picohydro developments are found along the Da in the north and in the central highlands because of the high incidence of hydro resources near population centers.

37 See www.powerpal.com.
38 Source: Whalan, 2003.

Picohydro technology is naturally finding its market in areas where other hydro development (or grid extension work) is not taking place owing either to remoteness or to low local affordability. In the north of the country local incomes are very low, so only low-cost picohydro units are affordable; whereas in the south, where average incomes are higher and communities are likely to live higher up in the valleys, larger (village) microhydro units are found, generally between 5 and 50 kilowatts. Although microhydro power stations are playing a positive role in the electrification of the midland mountainous areas, the equipment costs are still high compared with the incomes of the inhabitants. So in the central highlands, where the farmers are relatively poor, the smallest hydro systems are preferred.

It is estimated that 120,000 family-hydro units have been installed in Vietnam during the past 10 to 15 years, supplying 130,000 households, mostly in the northwest corner, near the border with China. This high number appears to suggest that many suitable locations have already been equipped with a picohydro unit, but for the following reasons, there still may be a significant market for new equipment in the region:

- As the units have such a short life span, it is doubtful that more than 40 percent of these machines (50,000) are actually still in operation.

- Many of the units have been installed in unsuitable locations because there was no better alternative to gain access to electricity and households accepted the low output, poor quality, and low availability of the picohydro units to have a source of electricity.

- Because the purchase price of picohydro is comparatively low, people tend to buy units regardless of the suitability of their sites. They accept the risk of failure more easily than with more expensive energy conversion equipment.

Figures on the remaining market potential in Vietnam have been put forward by the Hydropower Department of the Institute of Energy. Its estimates are as follows:

- A total of 40,000 to 50,000 existing picohydro units in the range of 200 to 500 watts need to be rehabilitated.

- A total of 60,000 to 80,000 new picohydro units of the same power range could be installed in the next five to eight years.

Thus, the estimate of the total market size for picohydro is between 100,000 and 130,000 units, making the potential market in Vietnam on the order of 20,000 to 25,000 units annually. This concurs roughly with research done under a Department for International Development (DFID) (UK) project, which estimated a potential (and economic) market of 154,000 units.

An important push factor is that grid electricity prices were subsidized until 1995 and were only $0.04/kW, but have since increased to double that amount. That increase in cost coupled with the unreliability of the grid in rural areas has caused many more rural people to consider alternative options for electricity supply even in grid areas, boosting the sales of pico- and microhydro equipment.

However, it may be that this total market size of 100,000 to 130,000 units will shrink during the coming years owing to the following:[39]

- Grid extension efforts by the Vietnamese government are likely to provide electricity services in the next five years to more than half a million households currently not connected to the grid. Out of these, up to an estimated 10,000 households would be potential picohydro users.

- The national electricity utility Electricité de Vietnam (EVN) is telling people through village committees that their commune will be connected to the grid soon. A considerable number of households delay their investment decisions for the purchase of a picohydro unit in expectation of the arrival of the grid.

- The picohydro units are basically a product suitable for poorer households. The labor input required to build and maintain the weir and the intake flume in the water course is considerable. As soon as rural incomes increase, the opportunity costs for the households to provide such labor input are higher, making the picohydro less competitive with alternatives such as diesel generators or larger picohydro systems (1 to 5 kilowatts) built as communal efforts or with a few neighbors, as seen in the south of the country.

Other considerations that are affecting the market sustainability in Vietnam are listed below and if addressed could improve the market situation:[40]

- The absence of a policy or coordinated development planning at the national and local level is a considerable barrier to the sustainable market development of picohydro. The Institute of Energy, which is responsible for formulating strategies and policies on the development of electricity, has been quite inactive in that respect.

- The absence of plans for financing and subsidies of picohydro programs for remote rural areas and the lack of training and information dissemination on appropriate (safe, long-lasting, productive) development of picohydro systems are also a problem.

- No real concerns have been voiced about the social and environmental issues relating to picohydro, although a number of people have been electrocuted because of poor installation and operating practices. In cases in which picohydro is used for battery charging, the disposal of worn-out lead acid batteries is a consideration notwithstanding the fact that there are no environmental laws relating to this issue in force in Vietnam.

[39] Source: Micro Hydro Turbine Manufacturing Business ENTEC AG, Switzerland, 1999.
[40] Source: http://www.aseanenergy.org/pressea/vietnam/vietnam.htm.

Despite these factors, the market for picohydro is expected to remain robust (many thousands of units being sold each year), and efforts are still being made by Vietnamese institutions to ensure that better-quality, safer units enter the market. However, it is expected that the vast majority of the market for picohydro units will be met by extremely cheap imports from across the border in China. That is due simply to the inability of the average rural household to purchase the better-quality equipment (costing about $45 for 200 watts) without having access to rural credit facilities. And despite findings from the field, most rural people would prefer not to have to buy the Chinese equipment, because of its technical weaknesses and short life span. This situation will continue to hinder the development of indigenous manufacturers until they can substantially lower their manufacturing costs.

Picohydro Market Potential in the Philippines

The Department of Energy (DoE) has been promoting a rural electrification program in recent years, led by the O'Ilaw program (bringing light into the countryside), where penetration of the grid had risen to 89 percent of all villages in 2003.[41] However, despite these impressive gains as much as 30.5 percent[42] of households remain without a connection; the DoE can claim "village electrification" if a minimum of only 10 houses are given a connection.

So there is significant potential for picohydro in the Philippines to provide cost-effective energy services to households that are unlikely to be connected to the grid system in the next few years. These households currently rely on often expensive and polluting fuels, such as kerosene and diesel, for the provision of their energy services. Picohydro could provide a low-cost, clean replacement for these fossil fuels and provide rural households with useful power for lighting, television, radio, and small productive uses.

Given the comparatively low number of installations of low-head picohydro in the Philippines compared with Vietnam, the market is quite different. More community-shared projects have been promoted using the larger 500 and 1,000 watt picohydro units, and this approach is likely to provide a strong market in the future. A project in the village of Igputoy in Antique, Panay Island, serves as an example of the method of setting up an electrification system based on picohydro.[43]

A cluster of 35 households in Igputoy was chosen for an electrification project based on the use of low-head picohydro equipment, because of the village's location next to a low-lying, large river where it was possible to obtain only a few meters head of water. Before the picohydro intervention, the households were dependent on kerosene and automotive batteries for lighting and the village suffered under a difficult economic situation, requiring men in the community to go outside the village for at

[41] Rural Electrification Program of the DoE:
www.doe.gov.ph/servlet/page?_pageid=679,681,683&_dad=portal30&_schema=PORTAL30 .
[42] www.nea.gov.ph/accomplishments_of_re.html.
[43] Source: Navarro, 2002.

least five months a year to work in the sugar cane farms to earn extra income for their families. The objective of the project was to address the needs of the community for electricity and lighting and to encourage income generation at home (for example, from the processing of root crops) rather than villagers having to seek labor far from their homes.

The original design of the system was to install one 1,000 watt picohydro turbine to provide electricity to 25 households with two 14 watt lights each, but this was later expanded to accommodate another 500 watt turbine to provide electricity to all households. The project was organized so that the community worked together, giving free labor ("dagyaw") to the project (worth P80,000 = $2,560), to develop a communal hydroelectricity system. The work was supported financially by the local (municipal) government (P20,000 = $640), REAP (P100,000 = $3,200), and the NGO leading the work, the Antique Development Foundation (ANIAD), all contributing their engineering and community organizing work free. Engineering support was also given by Solar Electric Co. Ltd., a company based on the same island that had experience in installing picohydro systems.

The project, which was successfully completed in six months, is characteristic of the way picohydro has been exploited for "community" use. This is due to the presence of many NGOs (such as ANIAD) that have experience in community-level organization and the mobilization that is required in rural development, the cooperative nature of people in Philippine villages, and the possibility of obtaining local government funding to support rural electrification and economic development in poor areas.

Photo A2.4: Igputoy Picohydro System for Community Electricity Supply, Antique Province (Solar Electric Co. Ltd.)

Despite these good pilot examples, initial assessment has found that "good-quality" picohydro systems (in regard to operation and reliability) are likely to be too expensive for many low-income households in the Philippines because of their high upfront cost, in comparison with the regular small payments required for purchasing kerosene. However, these households may be able to afford cheaper versions, such as those regularly sold in local markets in Vietnam imported mostly from China. However, as discussed above, these systems have a short lifetime, often do not supply their design capacity, and have a number of factors affecting their reliability. Early demonstration of picohydro by the Renewable Energy Association of the Philippines (REAP) has avoided using these cheaper, less reliable systems in the Philippines because they could jeopardize the overall picohydro market potential through negative experiences by consumers.

The first installations in the Philippines are using imported equipment (from Vietnam), but the long-term aim is to stimulate the market demand to an extent that local manufacture can be initiated to reduce system costs. In addition, a pilot study in the Philippines is aiming to “buy down” the cost of good-quality picohydro units to a cost similar to those of the cheaper, less reliable units by using carbon finance obtained through the clean development mechanism (CDM).

Annex 3

Picohydro Market Analysis in the Andean Region

Ecuador

As outlined in chapter 3, Ecuador has been divided into three natural regions: sierra, Amazonia, and coastal.

Step 1

The references detailed in chapter 3 were used to estimate the total rural population without electricity in each natural region of Ecuador. The results are shown in Table A3.3.

Step 2

The categorization of Ecuador's natural regions into the reference areas is shown in Table A3.1. On the basis of that assumption and by using the results of step 1, the total number of potential households that could benefit from picohydro (PH) technology is shown in Table 3.6 (second column from the left). It also shows the total number of picohydro units, by size and configuration that could be used to meet that demand.

Step 3

According to World Bank data,[44] 47.7 percent of Ecuador's rural population earns more than $2 per day (or $730 per year). It is assumed that this percentage of the population could afford to buy a picohydro unit and that between 25 percent and 50 percent would be willing to pay. This genuine picohydro market range (measured in number of households) is shown in the right-hand side column in Table 3.6 and is calculated considering that the 500 watt picohydro supplies a microgrid of five households and the 200 watt picohydro supplies a single household (family-hydro).

[44] World Development Indicators–World Bank, 2001.

Table A3.1: Categorization of Ecuador's Natural Regions into Reference Areas

Region	% upland	% lowland	% coastal
Coastal	40	40	20
Amazonas	40	60	0
Sierra	100	0	0

Table A3.2. Market Size for Picohydro Units and Number of Households Benefiting in Ecuador

Region	Technical market (no. of PH units)	Composed of				Range of genuine household market based on capacity and willingness to pay
		Low-head 500 W PH	Med-head 500 W PH	Low-head 200 W PH	Med-head 200 W PH	
Coastal	**29,791**	3,125	1,344	17,706	7,616	**5,684–11,368**
Amazon	**12,421**	1,304	559	7,391	3,167	**2,370–4,740**
Sierra	**43,110**	4,311	2,156	24,429	12,215	**8,225–16,451**
Total	**85,322**					**16,379–32,559**

The minimum household market for picohydro in Ecuador is therefore estimated to be 16,000.

Table A3.3: Location of Rural Households Without Electricity in Ecuador

Province	Population Census 2001	Rural population Census 2001 (%)	Persons per household Census 2001	Rural households per province	Rural households without electricity	Rural households without electricity by natural region			% estimated electrification (2003)
						Costa	Sierra	Amazonia	
Azuay	599,546	48	4.1	70,191	10,529	0	10,529	0	85
Bolivar	167,370	74	4.3	28,803	12,385	12,385	0	0	57
Cañar	206,981	63	4.2	31,047	8,072	0	8,072	0	74
Carchi	152,939	47	4	17,970	3,414	0	3,414	0	81
Chimborazo	403,632	61	4	61,554	15,388	0	15,388	0	75
Cotopaxi	349,540	73	4.3	59,341	10,088	0	10,088	0	83
El Oro	525,763	24	4.2	30,044	3,004	0	3,004	0	90
Esmeraldas	385,223	59	4.5	50,507	18,183	18,183	0	0	64
Galapagos	18,640	15	3.5	799	16				98
Guayas	3,309,034	18	4.3	138,518	13,852	13,852	0	0	90
Imbabura	344,044	50	4.2	40,958	9,011	0	9,011	0	78
Loja	404,835	55	4.3	51,781	17,088	0	17,088	0	67
Los Rios	650,178	50	4.4	73,884	28,815	28,815	0	0	61
Manabi	1,186,025	48	4.7	121,126	38,760	38,760	0	0	68
Morona Santiago	115,412	67	4.7	16,452	8,884	0	0	8,884	46
Napo	79,139	67.5	5.2	10,273	5,650	0	0	5,650	45
Orellana	86,493	69.7	4.8	12,560	8,164	0	0	8,164	35
Pastaza	61,779	56	4.5	7,688	2,998	0	0	2,998	61
Pichincha	2,388,817	28	3,9	171,505	15,435	0	15,435	0	91
Sucumbios	128,995	61	4.4	17,883	10,909	0	0	10,909	39
Tunguragua	441,034	57	4	62,847	3,771	0	3771	0	94
Zamora Chinchipe	76,601	64	4.7	10,431	4,798	0	0	4,798	54
Total	**12,082,020**	**Total rural hh**	**4,629,840**	**1,086,161**	**249,215**	**111,995**	**95,801**	**41,403**	

Bolivia

Bolivia was divided into four regions for this analysis: sierra, Amazonia, chaquenia, and chiquitania.

Step 1

The national census of 2001 undertaken by the Instituto Nacional de Estadística[45] was used as a reference to estimate the total rural population without electricity in each natural region. The results are shown in Table A3.4.

Step 2

The categorization of Bolivia's natural regions into reference regions is shown in Table A3.5. On the basis of this assumption and by using the results of step 1, the total number of potential households that could benefit from picohydro (PH) technology is calculated, and Table A3.6 shows the total number of picohydro units, by size and configuration, that could be used to meet this demand.

Step 3

According to World Bank data,[46] 61.4 percent of Bolivia's rural population earns more than $2 per day (or $730 per year). It is assumed that this percentage of the population could afford to buy a picohydro unit, but also that between 25 and 50 percent of these would actually be willing to purchase one. This genuine picohydro market range (measured in number of households) is shown in the right-hand side column of Table A3.6 and is calculated considering that the 500 watt picohydro supplies a microgrid of five households (hh) and the 200 watt picohydro unit supplies a single household (family-hydro).

Table A3.4: Rural Households without Electricity in Bolivia

Province/Department	Rural area		No. of hh without electricity in rural areas	No. of hh without electricity in rural areas by region			
	Population	Household		Region Andina	Amazonas	Region Chiquitana	Region Chaqueña
Chuquisaca	**313,396**	**86,184**	**52,002**				
Machareti	7,386	2,031	1,159	0	0	0	1,159
Chiquisaca (Region Andina)	306,010	84,153	50,843	50,843	0	0	0
La Paz	**798,320**	**245,883**	**163,254**				
Abel Iturralde	9,564	2,946	1,370	0	1,370	0	0
La Paz (Region Andina)	788,756	242,937	161,884	161,884	0	0	0
Cochabamba	**599,302**	**174,397**	**92,760**				
Villa Tunari (Am)	24,743	7,200	5,456	0	5,456	0	0

[45] Censo Nacional de Poblacion y Vivienda 2001: Distribucion de la Poblacion.
[46] 10. World Development Indicators–World Bank, 2001.

Province/Department	**Rural area**		**No. of hh without electricity in rural areas**	**No. of hh without electricity in rural areas by region**			
	Population	**Household**		Region Andina	Amazonas	Region Chiquitana	Region Chaqueña
Villa Tunari (RA)	24,743	7,200	5,456	5,456	0	0	0
Chimore	11,390	3,314	1,789				
Cochabamba (Region Andina)	538,427	156,682	80,058	80,058	0	0	0
Oruro	**155,760**	**51,401**	**31,586**	31,586	0	0	0
Potosi	**469,930**	**147,088**	**93,268**	93,268	0	0	0
Tarija	**143,490**	**37,164**	**15,879**				
Gran Chaco	35,594	9,219	2,927	0	0	0	2,927
Tarija (Region Andina)	107,896	27,945	12,952	12,952	0	0	0
Santa Cruz	**483,823**	**113,698**	**52,356**				
Guarayos (Amazonas)	16,069	3,776	2,590	0	2,590	0	0
German Busch (Chiquitana)	6,206	1,458	421	0	0	421	0
Angel Sandoval (Chiquitana)	7,703	1,810	734	0	0	734	0
Nuflo de Chavez (Chiquitana)	66,971	15,738	9,443	0	0	9,443	0
San Miguel de Velazco (Chiquitana)	30,760	7,229	3,244	0	0	3,244	0
San Jose de Chiquitos (Chiquitana)	7,388	1,736	536	0	0	536	0
Robore (Chiquitana)	5,321	1,250	371	0	0	371	0
Pailon (Chaco)	20,789	4,885	2,496	0	0	0	2,496
Cordillera (Chaco)	67,366	15,831	9,323	0	0	0	9,323
Santa Cruz (Region Andina)	255,250	59,984	23,198	23,198	0	0	0
Beni	**113,369**	**22,560**	**11,899**				
Rurrunabaque	5,208	1,036	488	488	0	0	0
Beni (Region Amazonica)	108,161	21,524	11,411	0	11,411	0	0
Pando	**31,705**	**7,546**	**4,600**	0	4,600	0	0
Total	**3,109,095**	**885,921**	**517,604**	**459,733**	**25,427**	**14,749**	**15,905**

Table A3.5: Categorization of Bolivia's Natural Regions into Reference Regions

Region	% upland	% lowland	% coastal
Andina	100	0	0
Amazonas	40	60	0
Chiquitana	20	80	0
Chaqueña	20	80	0

Table A3.6: Market size for Picohydro in Bolivia

Region	Technical market (no. of PH units)	Composed of				Range of genuine household market based on capacity and willingness to pay
		Low-head 500 W PH	Med-head 500 W PH	Low-head 200 W PH	Med-head 200 W PH	
Andina	**206,880**	20,688	10,344	117,232	58,616	**50,810–101,619**
Amazonas	**7,628**	801	343	4,539	1,945	**1,873–3,747**
Chiquitana	**3,687**	398	155	2,257	878	**906–1,811**
Chaqueña	**3,976**	429	167	2,433	946	**977–1,953**
Total	**222,171**					**54,565–109,131**

The minimum household market for picohydro in Bolivia is therefore estimated to be 55,000.

Peru

Peru was divided into three natural regions for this analysis: sierra, Amazonia (selva), and coastal.

Step 1

The projections to the year 2004 undertaken by the Instituto Nacional de Estadísticas e Informática based on Census 2000 (ENDES IV)[47] were used as a reference to estimate the total rural population without electricity in each natural region. The results are shown in Table A3.9.

Step 2

The categorization of Peru's natural regions into the reference regions is shown in Table A3.7. On the basis of this assumption and by using the results of step 1, the total number of potential households that could benefit from picohydro (PH) technology was calculated; Table A3.8 shows the total number of picohydro units, by size and configuration, that could be used to meet this demand.

Step 3

According to World Bank data,[48] 58.6 percent of Peru's rural population earns more than $2 per day (or $730 per year). It is assumed that this percentage of the population

[47] Encuesta Demografica y de Salud Familiar 2000, INEI.
48 World Development Indicators–World Bank, 2001.

could afford to buy a picohydro unit, but also that only 50 percent of them would actually be willing to purchase one. This genuine picohydro market range (measured in number of households) is shown in the right-hand side column of Table A3.8 and is calculated considering that the 500 watt picohydro supplies a microgrid of five households, and the 200 watt picohydro unit supplies a single household (family-hydro).

Table A3.7: Categorization of Peru's Natural Regions into Reference Regions

Region	% upland	% lowland	% coastal
Coastal	0	0	100
Amazonas (selva)	50	50	0
Sierra	100	0	0

Table A3.8: Market Size for Picohydro in Peru

Region	**Technical market (no. of PH units)**	**Composed of**				**Genuine hh market based on capacity and willingness to pay**
		Low-head 500 W PH	Med-head 500 W PH	Low-head 200 W PH	Med-head 200 W PH	
Coastal	**9,203**	1,380	-	7,823	-	**2,157–4314**
Amazonas	**285,869**	29,686	13,194	168,223	74,766	**67,008–134,015**
Sierra	**124,389**	12,439	6,219	70,487	35,244	**29,157–58,314**
Total	**419,461**					**98,322–196,643**

The minimum household market for picohydro in Peru is therefore estimated to be 98,000.

Table A3.9: Rural Households without Electricity in Peru

Department	Population	Rural (%)	Rural Population	Population by Natural Region			Persons per hh in rural areas	No. of hh in rural areas [[OK?]]	HH without electricity in rural areas (%)	HH without electricity in rural areas by natural region		
				Costa (%)	Sierra (%)	Selva (%)				Costa	Sierra	Selva
Amazonas	406.060	76.20	309,418	0.00	18.50	81.50	4.60	67,265	81,1	0	10,092	44,460
Ancash	1,067,282	57.90	617,956	29.00	71.00	0.00	4.50	137,324	70,5	28,076	68,737	0
Apurímac	426,904	75.80	323,593	0.00	100.00	0.00	4.10	78,925	68,6	0	54,143	0
Arequipa	1,072,958	17.20	184,549	14.30	85.70	0.00	3.60	51,264	52,1	3,819	22,889	0
Ayacucho	527,480	63.80	336,532	0.00	93.90	6.10	3.90	86,290	88,1	0	71,384	4,637
Cajamarca	1,411,942	79.30	1,119,670	4.20	78.80	17.00	4.90	228,504	88,2	8,465	158,814	34,262
Cusco	1,158,142	67.00	775,955	0.00	91.40	8.60	4.20	184,751	58,1	0	98,109	9,231
Huancavelica	431,088	86.20	371,598	0.00	100.00	0.00	4,10	90,634	73,7	0	66,797	0
Huánuco	776,727	75.10	583,322	0.00	72.70	27.30	5.00	116,664	88,2	0	74,807	28,091
Ica	649,332	18.00	116,880	100.00	0.00	0.00	4.10	28,507	39,3	11,203	0	0
Junín	1,190,488	49.30	586,911	0.00	79.90	20.10	4.90	119,778	41,1	0	39,334	9,895
La Libertad	1,465,970	40.20	589,320	67.30	32.70	0.00	4.60	128,113	84,8	73,115	35,525	0
Lambayeque	1,093,051	30.60	334,474	98.90	1.10	0.00	5.20	64,322	78,5	49,937	555	0
Lima	8,239,891	5.80	477,914	96.40	3.60	0.00	4.10	116,564	49,8	55,959	2,090	0
Loreto	880,471	41.20	362,754	0.00	0.00	100.00	6.00	60,459	87,1	0	0	52,660
Madre de Dios	84,383	40.80	34,428	0.00	0.00	100.00	3.60	9,563	58,1	0	0	5,556
Moquegua	147,374	26.90	39,644	69.90	30.10	0.00	3.10	12,788	58,1	5,194	2,236	0
Pasco	247,872	47.70	118,235	0.00	78.40	21.60	4.00	29,559	56,8	0	13,163	3,627
Piura	1,545,771	37.90	585,847	89.60	10.40	0.00	5.20	112,663	64,7	65,312	7,581	0
Puno	1,199,398	67.20	805,995	0.00	100.00	0.00	3.90	206,666	72,5	0	149,832	0
San Martin	743,668	45.90	341,344	0.00	5.30	94.70	4.90	69,662	87,5	0	3,231	57,724
Tacna	277,188	15.40	42,687	92.80	7.20	0.00	3.40	12,555	30,6	3,565	277	0
Tumbes	193,840	17.50	33,922	100.00	0.00	0.00	4.30	7,889	26,9	2,122	0	0
Ucayali	424,410	40.60	172,310	0.00	0.00	100.00	5.20	33,137	79,3	0	0	26,277
Total	**25,661,690**	**36.30**	**9,315,193**	**51.80**	**36.10**	**12.10**		**2,053,845**		**306,767**	**879,596**	**276,420**

Colombia

Colombia was divided into three natural hydrographic regions for consideration: Amazonía, Orinoquia, and Pacífico.

Step 1

The national census of 1993[49] and the Colombian Strategic Plan for the Noninterconnected Regions of the Country[50] were used as references to estimate the total rural population without electricity in each natural region. The results are shown in Table A3.10.

Step 2

The categorization of Colombia's natural regions into reference regions is shown in Table A3.11. On the basis of that assumption and by using the results of step 1, the total number of potential households that could benefit from picohydro technology was calculated, and Table A3.12 shows the total number of picohydro units, by size and configuration, that could be used to meet this demand.

Step 3

According to World Bank data,[51] 71.3 percent of Colombia's rural population earns more than $2 per day (or $730 per year). It is assumed that this percentage of the population could afford to buy a picohydro unit, but also that only 50 percent would actually be willing to purchase one. This genuine picohydro market range (measured in number of households) is shown in the right-hand side column of Table A3.12 and is calculated considering that the 500 watt picohydro supplies a microgrid of five households and the 200 watt picohydro supplies a single household (family-hydro).

Table A3.10: Rural Populations and Households without Electricity in Colombia

Department	Total pop.	Rural pop.	Rural pop. without electricity	No. hh without electricity
Amazonas	37,764	18,740	11,806	2,361
Caquetá	311,464	168,320	63,625	12,725
Guainía	13,491	9,393	5,918	1,184
Guaviare	57,884	36,552	23,028	4,606
Putumayo	204,309	133,591	50,497	10,099
Vaupés	18,235	13,712	8,639	1,728
Arauca	137,193	49,982	18,893	3,779
Casanare	158,149	71,596	27,063	5,413
Meta	561,121	202,202	76,432	15,286
Vichada	36,336	27,585	17,379	3,476

[49] XVI Censo Nacional de Poblacion y V de Vivienda, 1993.
50 Establecimiento de un plan estructural, institucional y financiero, que permita el abastecimiento energético de las zonas no interconectadas con participación de las comunidades y el sector privado, Departamento Nacional de Planeacion, Unidad de Infraestructura y Energia, Noviembre 2000.
[51] World Development Indicators–World Bank, 2001.

Cauca	979,231	620,294	117,236	23,447
Choco	338,160	207,875	78,577	15,715
Nariño	1,274,708	728,168	137,624	27,525
Total	**4,128,045**	**2,288,010**	**636,716**	**127,343**

Table A3.11: Categorization of Colombia's Natural Regions into Reference Regions

Region	% upland	% lowland	% coastal
Amazonia	30	70	0
Orinoquia	30	70	0
Pacifico	20	0	80

Table A3.12: Market Size for Picohydro in Colombia

Region	Technical market (no. of PH units)	Composed of				Genuine hh market based on capacity and willingness to pay
		Low-head 500 W PH	Med-head 500 W PH	Low-head 200 W PH	Med-head 200 W PH	
Amazonia	8,992	957	392	5,420	2,224	2,565–5,130
Orinoquia	7,687	818	335	4,633	1,901	2,792–4,385
Pacifico	7,603	840	300	4,761	1,701	2,168–4,336
Total	**24,282**					**6,925–13,851**

The minimum household market for picohydro in Colombia is therefore estimated to be 7,000.

Venezuela

Only two natural regions of Venezuela, llanos and orinoquia, have been analyzed. However, these regions represent the areas in which most of the rural population is without electricity and has access to hydro resources lives. Hence, it is believed that the numbers presented in this report underestimate the real market potential of the country, though only by a small amount.

Step 1

The national census of 1990[52] and the Strategic Plan Poder B2000[53] were used as references to estimate the total rural population without electricity in each natural region. The results are shown in Table A3.13.

[52] Censo de Poblacion y Vivienda, 1990

53 Plan Operativo de Energias Renovables-Bolivar 2000.

Step 2

The categorization of Venezuela's natural regions into reference regions is shown in Table A3.14. On the basis of that assumption and by using the results of step 1, the total number of potential households that could benefit from picohydro technology was calculated, and Table A3.15 shows the total number of picohydro units, by size and configuration, that could be used to meet that demand.

Step 3

According to World Bank data,[54] 64 percent of Venezuela's rural population earns more than $2 per day (or $730 per year). It is assumed that this percentage of the population could afford to buy a picohydro unit, but that only 50 percent would actually be willing to purchase one. This genuine picohydro market range (measured in number of households) is shown in the right-hand side column of Table A3.15 and is calculated considering that the 500 watt picohydro supplies a microgrid of five households and the 200 watt picohydro supplies a single household (family-hydro).

Table A3.13: Rural Households without Electricity in Venezuela

State	Municipalities	Population centers		Population			Households without electricity
		Total	Without electricity	Total	Total Rural	Without electricity	
Amazonas	3	233	119	55,679	19,572	7,631	1,907
Anzoategui	19	1,107	791	845,132	120,005	41,591	10,397
Apure	7	855	754	281,257	122,602	81,071	20,267
Bolivar	11	701	518	898,867	97,225	35,838	8,959
Delta Amacuro	3	431	350	83,783	39,891	21,590	5,397
Guarico	15	1,257	1,031	482,444	113.645	57,551	14,387
Monagas	12	651	265	465,517	116,591	13,682	3,420
Sucre	15	1,044	500	678,965	191.849	29,727	7,431
Total	**85**	**6,279**	**4,328**	**3,791,644**	**821,380**	**288,681**	**72,170**

Table A3.14: Categorization of Venezuela's Natural Regions into Reference Regions

Region	% upland	% lowland	% coastal
Orinoquia	20	80	0
Llanos	20	80	0

[54] World Development Indicators–World Bank, 2001.

Table A3.15: Market Size for Picohydro in Venezuela

Region	**Technical market (no. of PH units)**	**Composed of**				**Genuine hh market based on capacity and willingness to pay**
		Low-head 500 W PH	Med-head 500 W PH	Low-head 200 W PH	Med-head 200 W PH	
Orinoquia	**2,717**	293	114	1,663	647	**961–1,382**
Llanos	**14,872**	1,611	619	9,132	3,510	**3,784–7,682**
Total	**17,589**					**4,475–9,064**

The minimum household market for picohydro in Venezuela is therefore estimated to be 4,500.

Annex 4

Picohydro Pilots Established in Ecuador

Guaslan Training Centre

The hydro resource for the Guaslan Training Centre comes from an irrigation channel out of the river Cebadas. The channel is 1 meter wide and 0.5 meters deep and has a measured flow of 120 liters per second and a natural fall of 1.90 meters near the training facilities. Civil works can provide a head of up to 50 meters.

It was decided to install two picohydro units (a low head and a high head) for demonstration purposes to disseminate the technology among visitors to the training center. The board of the center agreed to look after the units and to actively promote the technology.

	**Province:** Chimborazo **Place:** Ciudad de Riobamba **Altitude:** 2,725 meters **Coordinates:** S01.667170 W078.634638
Unit number: 6123	**Responsible:** Centro de Capacitación y Granja Integral "GUASLAN"

Source of water	Irrigation channel	**Uses**
Flow	60 L/s	This is a demonstration unit that powers three 20 watt lamps in the main hall of the training institution.
Head	1.5 m	
Distance to user	80 m	

Province: Chimborazo

Place: Ciudad de Riobamba

Altitude: 2,725 meters

Coordinates:

S01.667170

W078.634638

Unit Number: 6550		**Responsible:** Centro de capacitación y granja integral "GUASLAN"
Source of Water	Irrigation channel	**Uses**
Flow	6 L/s	This is a demonstration unit that powers two 20 watt lamps and a radio for a small household inside the training institution.
Head	6.2 m	
Distance to user	280 m	

Ozogoche Alto Community

The hydro resource for the Ozogoche Alto community comes from two rivers, the river Ozogoche and its tributary, the river Pichauiña. The rivers both originate at the Ozogoche lagoons and are located 250 meters away from the community. The measured flow was 450 liters per second.

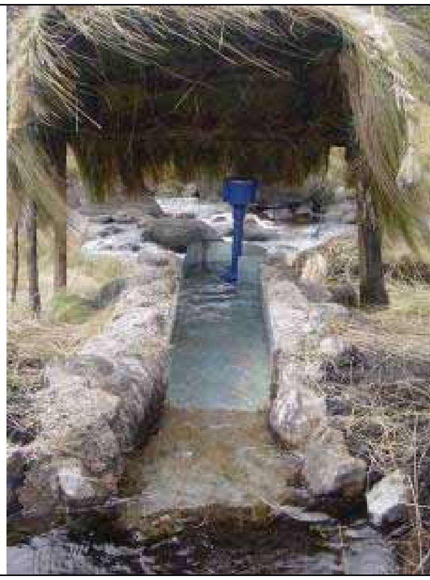
To achieve the required head of 1.5 meters for the low-head units, it was necessary to build a minimum infrastructure that consists mainly of channels to deviate water from the main streams. There is also a site at which a head of 6 meters could be achieved with minimum additional work.

The decision was made to install six low-head units plus a high-head unit. Because the community is highly organized, the ownership of each unit and the number of houses or facilities each unit will power was decided. Priority was given to communal buildings such as the church, school, community center, and craftsman workshops.

<table>
<tr><td colspan="2"></td><td>Province: Chimborazo
Canton: Alausí
Parroquia: Achupallas
Place: Comunidad de Ozogoche Alto
Altitude: 3,450 meters
Coordinates:
S02.252460
W078.601357</td></tr>
<tr><td colspan="2">Unit Number: 6128</td><td>Responsible: Segundo Quishpe</td></tr>
<tr><td>Source of Water</td><td>Rio Pichauiña</td><td rowspan="4">Uses
The unit powers four households with a 20 watt lamp and a radio each.</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>250 m</td></tr>
</table>

<table>
<tr><td colspan="2"></td><td>Province: Chimborazo
Canton: Alausí
Parroquia: Achupallas
Place: Comunidad de Ozogoche Alto
Altitude: 3,450 meters
Coordinates:
S02.252460
W078.601357</td></tr>
<tr><td colspan="2">Unit Number: 6350</td><td>Responsible: Jose Bejarano</td></tr>
<tr><td>Source of Water</td><td>Rio Pichauiña</td><td rowspan="4">Uses
The unit powers four households with a 20 watt lamp and a radio each.</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>240 m</td></tr>
</table>

		**Province:** Chimborazo **Canton:** Alausí **Parroquia:** Achupallas **Place:** Comunidad de Ozogoche Alto **Altitude:** 3,450 meters **Coordinates:** S02.252460 W078.601357
Unit Number: 6557		**Responsible:** Communal church
Source of Water	Rio Ozogoche	**Uses:** The unit powers the main hall of the church (two lamps and a small sound system), its kitchen (one lamp [20 W]), and two households with a 20 watt lamp and a radio each.
Flow	6 L/s	
Head	6.1 m	
Distance to user	260 m	
		**Province:** Chimborazo **Canton:** Alausí **Parroquia:** Achupallas **Place:** Comunidad de Ozogoche Alto **Altitude:** 3,450 meters **Coordinates:** S02.252460 W078.601357
Unit Number: 6359		**Responsible:** Jose Antonio Bejarano
Source of Water	Rio Ozogoche	**Uses:** The unit powers three households (one 20 W lamp and a radio each) and a cheese factory (one 20 W lamp and a radio).
Flow	35 L/s	
Head	1.5 m	
Distance to user	280 m	

<table>
<tr><td colspan="2"></td><td>Province: Chimborazo
Canton: Alausí
Parroquia: Achupallas
Place: Comunidad de Ozogoche Alto
Altitude: 3,450 meters
Coordinates:
S02.252460
W078.601357</td></tr>
<tr><td colspan="2">Unit Number: 6134</td><td>Responsible: Manuel Quishpe</td></tr>
<tr><td>Source of Water</td><td>Rio Ozogoche</td><td rowspan="4">Uses
The unit powers four households with a 20 watt lamp and a radio each.</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>220 m</td></tr>
<tr><td colspan="2"></td><td>Province: Chimborazo
Canton: Alausí
Parroquia: Achupallas
Place: Comunidad de Ozogoche Alto
Altitude: 3,450 meters
Coordinates:
S02.252460
W078.601357</td></tr>
<tr><td colspan="2">Unit Number: 6127</td><td>Responsible: Feliciano Bejarano</td></tr>
<tr><td>Source of Water</td><td>Rio Ozogoche</td><td rowspan="4">Uses
The unit powers four households with a 20 watt lamp and a radio each.</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>240 m</td></tr>
</table>

<table>
<tr><td colspan="2"></td><td>Province: Chimborazo
Canton: Alausí
Parroquia: Achupallas
Place: Comunidad de Ozogoche Alto
Altitude: 3,450 meters
Coordinates:
S02.252460
W078.601357</td></tr>
<tr><td colspan="2">Unit Number: 6357</td><td>Responsible: School and community center</td></tr>
<tr><td>Source of Water</td><td>Rio Pichauiña</td><td rowspan="4">Uses
The unit powers the school (two 20 W lamps), the teacher’s house (20 W lamp and a radio), a workshop (two 20 W lamps), and a community center (two 20 W lamps and a small sound system).</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>250 m</td></tr>
</table>

Las Caucheras Community

The hydro resource for the Las Caucheras community comes from a small stream originating as runoff from the forested hills in the area. Because the area is quite steep, heads of 6 meters were easily achieved.

For that reason five high-head picohydro units plus three low-head units were installed.

		**Province:** Napo **Canton:** Quijos **Parroquia:** Cosanga **Place:** Rio Arenillas **Altitude:** 1,898 meters **Coordinates:** S00 33 36.8 W077 52 29.6
Unit Number: 6138		**Responsible:** Luis Vitteri
Source of Water	Rio Arenillas	**Uses** The unit powers a household with three 20 watt lamps and a radio.
Flow	35 L/s	
Head	1.5 m	
Distance to user	30 m	

		**Province:** Napo **Canton:** Quijos **Parroquia:** Cosanga **Place:** Rio Arenillas **Altitude:** 1,898 meters **Coordinates:** S00 33 36.8 W077 52 29.6
Unit Number: 6352		**Responsible:** Nancy Erazo
Source of Water	Rio Arenillas	**Uses** The unit provides electricity for a household.
Flow	35 L/s	
Head	1.5 m	
Distance to user	260 m	

<table>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Quijos
Parroquia: Cosanga
Place: Las Caucheras
Altitude: 2,205 meters
Coordinates:
S00 36 44.7
W077 53 54.0</td></tr>
<tr><td colspan="2">Unit Number: 6551</td><td>Responsible: Marco Silva</td></tr>
<tr><td>Source of Water</td><td>Spring</td><td rowspan="4">Uses
The unit powers two households; one is an ecolodge. In total there are 11 lamps, 15 watts each; a radio; and a small sound system.</td></tr>
<tr><td>Flow</td><td>6 L/s</td></tr>
<tr><td>Head</td><td>6.5 m</td></tr>
<tr><td>Distance to user</td><td>50 m</td></tr>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Quijos
Parroquia: Cosanga
Place: Las Caucheras
Altitude: 1,913 meters
Coordinates:
S00 33 42
W077 52 16.5</td></tr>
<tr><td colspan="2">Unit Number: 6125</td><td>Responsible: Luis Alberto Vega</td></tr>
<tr><td>Source of Water</td><td>Spring</td><td rowspan="4">Uses
The unit provides power for a house with six 20 watt lamps, a radio, and an electric fence (18 W).</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>90 m</td></tr>
</table>

Province: Napo

Canton: Quijos

Parroquia: Cosanga

Place: Las Caucheras

Altitude: 2,218 meters

Coordinates:

S00 39 36

W077 55 06

Unit Number: 6553

Responsible: Luis Aguilar

Source of Water	Spring
Flow	6 L/s
Head	12 m
Distance to user	30 m

Uses

The unit powers seven 15 watt lamps, a television set (90 W), a VHS unit (40 W), and a sound system (100 W).

Province: Napo

Canton: Quijos

Parroquia: Cosanga

Place: Las Caucheras

Altitude: 2,226 meters

Coordinates:

S0037 03.3

W077 52 16.5

Unit Number: 6559

Responsible: Edilberto Ayovi

Source of Water	Spring
Flow	6 L/s
Head	8 m
Distance to user	40 m

Uses

The unit powers a household with two 20 watt lamps and a radio.

<table>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Quijos
Parroquia: Cosanga
Place: Las Caucheras
Altitude: 2,134 meters
Coordinates:
S00 31 22.1
W077 52 67.8</td></tr>
<tr><td colspan="2">Unit Number: 6555</td><td>Responsible: Samuel Llulluma</td></tr>
<tr><td>Source of Water</td><td>Spring</td><td rowspan="4">Uses
The unit powers a household with two lamps (20 W each) and a radio.</td></tr>
<tr><td>Flow</td><td>6 L/s</td></tr>
<tr><td>Head</td><td>8 m</td></tr>
<tr><td>Distance to user</td><td>150 m</td></tr>
</table>

Zapallo Community

The Zapallo community’s hydro resource comes from the rio Yatunyacu, a tributary of the river Napo. The topography allows most of the houses to be very close to the river. The measured flow was 350 liters per second, and the drop of the river in its trajectory around the community is 15 meters.

To achieve the required head of 1.5 meters for the low-head units, it was necessary to build diversion channels for each unit. To simplify the civil work needed and to have another installation model available for future assessment, it was decided to build two small dams, each about a meter high. The walls of the dams were built of stones and sandbags.

On the first dam, a 50 meter long side channel was built to provide a 1.5 meter head. Three units were installed at the end of this channel. A hundred meters below the first dam, a second one was built. The same construction material was used. After a 400 meter long side channel, four units were installed. The remaining unit was installed out of the side channel.

The interesting feature of these installations is that they require additional maintenance because the side channels have to be looked after and the dams have to be maintained regularly.

	**Province:** Napo **Canton:** Tena **Parroquia:** Pano **Place:** Zapallo **Altitude:** 510 meters **Coordinates:** S01 04 50 W077 52 50
Unit Number: 6131	**Responsible:** Venancio Shiguango

Source of Water	Rio Yatunyacu	**Uses**
Flow	35 L/s	The unit provides power for a household with six 20 watt lamps; two sockets are available.
Head	1.5 m	
Distance to user	40 m	

<table>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Tena
Parroquia: Pano
Place: Zapallo
Altitude: 510 meters
Coordinates:
S01 04 50
W077 52 50</td></tr>
<tr><td colspan="2">Unit Number:
6356
6341
6122</td><td>Responsible:
Elena Tapuy
Clemente Andi
Ines Tapuy</td></tr>
<tr><td>Source of Water</td><td>Rio Yatunyacu</td><td rowspan="4">Uses
Each unit powers a household with three 20 watt lamps and a radio.</td></tr>
<tr><td>Flow</td><td>105 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>60, 142, and 110 m</td></tr>
</table>

<table>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Tena
Parroquia: Pano
Place: Zapallo
Altitude: 510 meters
Coordinates:
S01 04 50
W077 52 50</td></tr>
<tr><td colspan="2">Unit Number:
6136
6355
6130
6132</td><td>Responsible:
Pedro Andi
Jose Andi
Luis Andi
Carlos Andi</td></tr>
<tr><td>Source of Water</td><td>Rio Yatunyacu</td><td rowspan="4">Uses
Each unit powers a household. Three of the households have two lamps (20 W each) and a radio.
Unit 6136 powers a household with five lamps, a television set, and a radio.</td></tr>
<tr><td>Flow</td><td>140 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>139, 119, 239, and 112 m</td></tr>
</table>

Alto Tena Community

The Alto Tena community’s hydro resource comes from a small stream created by runoff from the forested hills in the area. Two of the units were installed on the rio Pashishi Chico, and the other two on streams that are its tributaries.

On the rio Pashishi Chico, two units were installed side by side. That was done to avoid excessive civil works and to take advantage of a small dam (1 m high) built to secure a constant flow of water into the turbines. A 40 meter long diversion channel runs from the dam to the two units.

The other two units, installed on small streams that are tributaries of the rio Pashishi Chico, were installed at sites where there was a natural 1.5 meter head.

<table>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Tena
Parroquia:
Place: Alto Tena
Altitude: 604 meters
Coordinates:
S00 56 29.7
W077 52 52.9</td></tr>
<tr><td colspan="2">Unit Number:
6120
6353</td><td>Responsible:
Nicolas Grefa
Carlos Grefa</td></tr>
<tr><td>Source of Water</td><td>Rio Pashishi Chico</td><td rowspan="4">Uses
Each unit powers two households with two 20 watt lamps and a radio each.</td></tr>
<tr><td>Flow</td><td>70 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>70 and 120 m</td></tr>
</table>

<table>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Tena
Parroquia:
Place: Alto Tena
Altitude: 604 meters
Coordinates:
S00 56 29.7
W077 52 52.9</td></tr>
<tr><td colspan="2">Unit Number: 6121</td><td>Responsible: Francisco Aguinda</td></tr>
<tr><td>Source of Water</td><td>Rio Pashishi Chico</td><td rowspan="4">Uses
The unit powers three households. In total, there are four 20 watt lamps and two radios.</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>40 m</td></tr>
</table>

<table>
<tr><td colspan="2"></td><td>Province: Napo
Canton: Tena
Parroquia:
Place: Alto Tena
Altitude: 604 meters
Coordinates:
S00 56 29.7
W077 52 52.9</td></tr>
<tr><td colspan="2">Unit Number: 6351</td><td>Responsible: Francisco Tapuy</td></tr>
<tr><td>Source of Water</td><td>Stream</td><td rowspan="4">Uses
The unit powers three households and a poultry breeding hut. In total, it powers six lamps (20 W each), a radio, and a television.</td></tr>
<tr><td>Flow</td><td>35 L/s</td></tr>
<tr><td>Head</td><td>1.5 m</td></tr>
<tr><td>Distance to user</td><td>50 m</td></tr>
</table>

Annex 5

Summaries of Interviews with Dealers, Potential Investors, and other Key Participants

The following is a summary of responses given by companies, dealers, potential investors, and other key participants at interviews in Ecuador.

Electro Ecuatoriana

Electro Ecuatoriana was founded in 1953. It is a company devoted to providing energy services to industrial and agricultural markets. It develops turnkey projects and represents several international companies specializing in diesel generation, electric engines, hydroelectric turbines, and solar energy (the company is the local representative of Solar Shell) among other products.

Perception of the Technology

Electro Ecuatoriana installs systems with industrial capacity and is used to higher-power specifications than are found with picohydro technology. However, the company was involved many years ago in a similar project managed by the National Institute of Energy (INE). Hence, it may consider being involved with picohydro technology again.

Market Perception

The company is considering establishing a team to deal with small-scale systems (particularly solar PV) because it perceives that the market is large. The company has the infrastructure; it has offices and professionals mobilized around the country.

The perception is that even without any marketing campaign, at least two picohydro turbines could be installed per month.

Market Development

The company will initiate a market effort by installing demonstration units around the country.

Hidrovo Estrada

Hidrovo Estrada is a company devoted to the construction of highways, and it is the representative of BP Solar in Ecuador.

Perception of the Technology and the Market

Hidrovo Estrada has knowledge about the technology because it was contacted by the project team during the team's first mission to Ecuador. The company found the technology interesting then, and now after reviewing the main results of the project, it believes that it does have a serious future in Ecuador, mainly in the east where hydro resources are most favorable.

Market Development

Hidrovo Estrada is always looking for new businesses, and one based on picohydro turbines could be of interest. More information is needed, however, about technical specifications, technical support services from manufacturers, possible financing, and delivery and importation channels.

It is Hidrovo Estrada's policy not to stock the products it represents, but the company may agree to build up a small stock and a distribution network throughout towns all over Ecuador and to look for potential clients.

Isofoton-Ecuador

Isofoton Ecuador represents Isofoton in Ecuador. The company also has a production line to produce solar hot water systems.

Market Perception

The company is certain that a large market exists for picohydro, especially in the oriental region, which has an enormous potential, making the import and sale of the turbines a very good business opportunity.

Market Development

Isofoton is not interested in the importation and commercialization of picohydro because it sells its own products exclusively. In the hypothetical case that it would be involved in the commercialization of these units, it would look for some distributors with the capacity to install the turbines and it would buy some units to start the business and carry out field visits to disseminate the technology.

The attractiveness of this opportunity is that a small initial investment could result in an excellent business.

Cagmin

Cagmin is a company dedicated to the installation of electricity grids and transformers.

Perception of the Technology

Cagmin has never seen a working turbine.

Market Perception

The company works mainly in the northwest of the country, where the hydro resource is important. It has detailed knowledge of that region and believes providing energy to isolated properties is a good solution.

The low cost of the systems allows low-income users access to an indispensable service that could improve their living conditions.

Market Development

The first step in developing the market should be a big dissemination campaign.

The company believes that a good opportunity exists for business and is very interested in commercializing the technology. The company would like to have more technical information from manufacturers, along with details of the commercial and financial conditions for importation.

The company is interested in buying two turbines to test them, carry out demonstrations, and show clients the benefits of the technology.

Sertecpro

Sertecpro is a consultancy company specializing in electrification.

Perception of the Technology

The company attended the seminar in 2003, so it knows the project very well. Sertecpro is working on a study financed by World Bank–PROMEC (project of modernization of the electric sectors and rural services) for the National Council of Modernization (CONAM).

World Bank–PROMEC will finance a pilot project with micro- and picohydro technologies, and the company therefore wanted to assess the installations carried out by this ESMAP project.

The company’s main view of the technology is that it is neither economically viable nor reliable to install systems so small and that there are difficulties in offering continuity to these kinds of installations. The company would recommend systems of more than 1,000 watts because it perceives that systems with more power capacity are more reliable and have better manufacturing quality and lower generation costs.

Moreover, maintenance is easier if a single unit is connected to a microgrid and distributed to the entire community and difficult if several units of smaller capacity are used to supply individual households.

Picohydro presents problems in controlling the voltage, the regulator is too simple, and resulting voltage variations damage appliances.

Market Perception and Market Development

The company does not think the picohydro market is profitable as a business. It recognizes that hydro turbines represent an economic solution for isolated households, but the market is for microturbines connected to a minigrid, not picohydro connected to single households.

Ing. Carlos Cantuña

Carlos Cantuña is a mechanical engineer. He participated in the seminar organized in 2003 as an independent potential dealer.

Perception of the Technology

Ing. Cantuña knows the project and visited the installations in Ozogoche.

He recognizes the benefits and advantages that the technology brought to the community, but he disagrees with the technical concept. He believes that it would have been cheaper to install a hydro unit to generate electricity for the whole community. The costs of civil work would have been smaller because a single penstock and water intake would have been necessary instead of the 15 that were built.

Market Perception and Market Development

He believes that the cost of manufacturing a picoturbine in Ecuador could be $300. However, he is not interested in importing or commercializing picohydro turbines.

Ing. Luis Loza

Luis Loza is a mechanical engineer. He attended the 2003 seminar as an independent dealer.

Perception of the Technology

Ing. Loza considers the capacity of the installed turbines to be very low, and he believes that power in the range of 8 to 10 megawatts has to be targeted instead. The country has many hydro resources, and hydro turbines are definitely an excellent solution.

Market Perception and Market Development

The biggest problem he sees is the time required to make field visits and evaluate users' necessities and available hydro resources. This work should be done in several provinces. However, the costs associated with this market evaluation are too high to provide profitability to any private business.

Ing. Milton Balseca

Milton Balseca participated in the early stages of the project as one of the people responsible for installing the equipment in Cosanga. He is currently the national coordinator of SILAE, a European-funded project that promotes the participation of communities of Ecuadoran Amazonia in their rural electrification projects.

Perception of the Technology

He knows the technology very well because he was involved in installation and training activities of this project. He thinks it is an appropriate technology for vast regions of Ecuador.

Market Perception

Ing. Balseca has done a detailed market assessment in some strategically located regions.

The east of Ecuador, because of its hydro resources, is the ideal region for picohydro turbines, as is the northwest. The market demand for these turbines ranges from 200 to 1,000 watts. In some cases, such as Provincia del Oro, because of the characteristics of the rural community's use of energy (they are fishermen and process shellfish), picohydro technology with higher power may be required.

However, the market is definitely for rural, isolated households and distant cattle estates. These potential users are very interested in this technology and find its cost very reasonable.

After the installations were completed and the systems were working, he saw that the interest in the technology rose enormously. He has so many requests that he decided to ask to be the PowerPal representative in Ecuador.

Market Development

The technology should be built locally. Ing. Balseca has contacted several companies in Quito, Guayaquil, and Cuenca inquiring about manufacturing costs. However, the cost of manufacturing the picohydro turbines for the Ecuador market is higher than the value of the imported turbines. A regional effort has to be implemented, especially in the Andean region where the socioeconomic characteristics of the population are similar and the hydro resources are similar as well.

Another key aspect is the guarantee offered by installers. Dealers and installers should offer a comprehensive guarantee that could be sustained only with good technology, well-qualified installers, and user training.

A distribution network has to be created with selling points in strategic cities. These selling points should have permanent stock, training capabilities to new dealers, and exhibits of the technology.

MEM should, on the basis of the success of this project, launch a large dissemination campaign aimed at local governments, municipalities, and local communities.

Technology Assessment and Social Acceptance

He stated that people in Chimborazo particularly valued the fact that they now have lighting and that in Napo people value their ability to watch television.

All users started to use low-consumption lamps, but many changed to incandescent lamps because they tend to burn out less frequently.

Ing. Fausto Moreno, Dealer of Chimborazo

Fausto Moreno has installed nine picohydro units (two in Guaslan and seven in Ozogoche) and he committed to maintaining them.

Technology Assessment and Social Acceptance

Ing. Moreno considers that the project has allowed users to be in control of their own service, to control their consumption, and to carry out the respective preventive maintenance. He thinks that the electricity has changed the life of the community; however, in Ozogoche the arrival of grid electricity has created a certain instability.

He believes that people should be motivated to participate more in projects and that they should be offered a range of possibilities for productive uses.

Market Perspective

He visited Ozogoche, which has many potential users, and he had many requests for further installations, resource assessments, and quotations.

Mr. Marco Peña, Dealer of Napo

Marco Peña installed 12 picohydro units in Zapallo and Alto Tena. He is a very well known technician in the region because many people come to his mechanical and electrical workshop.

Technology Assessment and Social Acceptance

What Mr. Peña considers most positive in relation to this service is the fact that it provides support to communal services such as education, health, economic savings, and social cohesion.

He said that the two communities have a good appreciation of the advantages of having the service; they are managed and maintained well and in the case of Zapallo, people have been organized in such a way that they contribute $0.50 for any corrective maintenance that is needed. As requested by users in Zapallo, he developed a service chart for corrective maintenance.

He sees that the service has radically changed the life of the communities and that productive uses of the technology should be promoted, mainly among the youth who are already interested in the technology. It is important to reinforce the knowledge with training workshops and motivate people to make the best use of the resource.

The biggest inconvenience of the service is the fact that the lamps and appliances burn out because of the variation in the voltage, which is a result of the units being installed without an automatic regulator. Users have learned to overcome this problem by listening to the flow of the river and changing the settings of the regulator according to their consumption.

Market Perspective

Mr. Peña thinks that there is a great business opportunity. He could have installed at least 10 units during the past year in the nearby communities if the systems had been available. He also received many requests from communities in Chaco, Guamaní, and even Cosanga.

As a marketing tool he would like to be able to have a unit in his workshop and, even more, he would like to investigate the possibility of reproducing a unit in his workshop.

Ing. Juan Galarza, TTA-Ecuador

Juan Galarza, as an engineer at TTA, has carried out technical visits to inspect all picohydro units installed during this project.

Technology Assessment and Social Acceptance

Ing. Galarza believes that the most important aspect, independent of the energy benefit to the population, is the support that the technology offers for communal services (health, education, communication, etc.). He also values the very easy preventive maintenance, with the added value of the low cost per generated watt.

The inconvenience that he sees is the corrective maintenance. There are no spare parts available locally; they must be imported or brought from Quito. He also notes the issue of the voltage variation, which has caused many lamps and some appliances to burn out.

Market Perspective

Training should be provided to users, and he insists that market infrastructure should be developed quickly. He believes that it is important to locally manufacture alternators, electronic controls, and so forth.

Annex 6

Rapid Rural Appraisal Questionnaires

This annex presents the English translation of the rapid rural appraisal questionnaires given to end users before and after the installation of the picohydro units.

Questionnaire A—User Profile *(before installation)*

Introduction

Thank you for giving us the time to conduct this interview with you. We are from -------------, a partner in the ESMAP World Bank picohydro pilot project. We have selected you because you have been chosen to have a picohydro system installed for your household and we would like to understand what impacts this system has on your household and your experiences with the technology. This is an independent study and anything you tell us will remain anonymous. The interview will take about 20 minutes.

Overview

Name of the interviewer: ....

Interview date: ....

Name of the province: ….…………………………………….Name of the canton: ….……………………….

Name of the parroquia: ....Name of the village: ………………………….

Name of the interviewee: ……………………………………Sex of the interviewee: MALE / FEMALE

Role of interviewee in the household…………………………………………………………………………

Household description

Name of the head of household: ....

Profession: …………………….

Size of household: Number of adults……………. Number of children…………………

Household income is available from which resources?
Agriculture Forestry Handicraft Services Salary Others

Income bracket approximately………………………………

Energy costs

Describe your usual household monthly energy needs. What types of energy sources do you use, and how much do you spend on each source per month? Also indicate any time spent on battery charging, purchasing kerosene, etc. Specify which others.

Energy source	Unit	Quantity used per month	Cost per unit	Cost per month
Candles	Pieces			
Kerosene	Liters			
Diesel/petrol	Liters			
Batteries (large)	Charges			
Gas (LPG)	Bottles			
Other				
Other				

Additional Comments:

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………

Questionnaire B—Users (after installation)

Introduction

Thank you for giving us the time to conduct this interview with you. Now that your picohydro system is installed and you have been using it for at least six months we would like to have another interview with you. Again this is an independent study and anything you tell us will remain anonymous. The interview will take about 45 minutes.

Overview

Name of the interviewer: ....

Interview date: ....

Name of the province: ……………………………………Name of the canton: ....

Name of the parroquia:……………………………………Name of the village: ……………………………

Name of the interviewee: …………………………………Sex of the interviewee: MALE / FEMALE

Role of interviewee in the household……………………………………………

Technical issues

When was your PH unit installed?………………………………………………………………

What is the usual running time of the picohydro unit every day?

No. of hours:……… ……From..………..To...……...

When picohydro stops running, what is the substituted power supply? ....…………......

Energy costs

Describe your household's monthly energy needs since the installation of your picohydro system. What types of energy sources do you now use, and how much do you spend on each source per month? Also indicate any time spent on battery charging, purchasing kerosene, etc. Specify which others.

Energy source	Unit	Quantity used per month	Cost per unit	Cost per month
Candles	Pieces			
Kerosene	Liters			
Diesel/petrol	Liters			
Batteries (large)	Charges			
Gas (LPG)	Bottles			
Picohydro unit	Hours			
Other				
Other				

SOCIOECONOMIC IMPACTS

(To fill in: collection of data from socioeconomic indicators to be collected)

1

2

3

4

5

6

7

- What do you feel has been the most important impact?

Electricity use of the household

Please describe which electrical devices you run from your picohydro unit.

Devices	Capacity (watts)	Use duration every day (hours)	Note
Bulb 1			
Bulb 2			
Bulb 3			
Fluorescent 1.2 m			
Fluorescent 0.6 m			
Fluorescent 0.3 m			
DC lamp 12 V, 6 W			
Radio			
Cassette			
TV			
Video			
Electric Fans – Desk fan – Stand fan – Ceiling fan			
Battery charger			
Others			
Others..........			

BE SURE TO PROBE WHETHER THERE ARE ANY OTHER USES.

Customer Satisfaction

Has the PH system met your expectations? (collect data on the indicators of expectations agreed in participatory 1)

1.
2.
3.
4.
5.
6.
7.

Would you recommend it to friends and family?

What are the main advantages of PH?

What are the main problems?

Are you managing maintenance costs—are these higher than expected?

Thank you for your time.

Comments and evaluations of the interviewer:

....
....

....
....

Joint UNDP/World Bank

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

LIST OF TECHNICAL PAPER SERIES

Region/Country	***Activity/Report Title***	***Date***	***Number***
	SUB-SAHARAN AFRICA (AFR)		
Africa	Power Trade in Nile Basin Initiative Phase II (CD Only): *Part I: Minutes of the High-level Power Experts Meeting; and Part II: Minutes of the First Meeting of the Nile Basin Ministers Responsible for Electricity*	04/05	067/05
Cameroon	Decentralized Rural Electrification Project in Cameroon	01/05	087/05
Chad	Revenue Management Seminar. Oslo, June 25-26, 2003. (CD Only)	06/05	075/05
Côte d'Ivoire	Workshop on Rural Energy and Sustainable Development, January 30-31, 2002. (French Only)	04/05	068/05
Ethiopia	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Ethiopia - Action Plan.	12/03	038/03
	Sub-Saharan Petroleum Products Transportation Corridor: Analysis And Case Studies	03/03	033/03
	Phase-Out of Leaded Gasoline in Sub-Saharan Africa	04/02	028/02
	Energy and Poverty: How can Modern Energy Services Contribute to Poverty Reduction	03/03	032/03
East Africa	Sub-Regional Conference on the Phase-out Leaded Gasoline in East Africa. June 5-7, 2002.	11/03	044/03
Ghana	Poverty and Social Impact Analysis of Electricity Tariffs	12/05	088/05
Kenya	Field Performance Evaluation of Amorphous Silicon (a-Si) Photovoltaic Systems in Kenya: Methods and Measurement in Support of a Sustainable Commercial Solar Energy Industry	08/00	005/00
	The Kenya Portable Battery Pack Experience: Test Marketing an Alternative for Low-Income Rural Household Electrification	12/01	05/01
Malawi	Rural Energy and Institutional Development	04/05	069/05
Mali	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Mali - Action Plan. (French)	12/03	041/03
Mauritania	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Mauritania - Action Plan. (French)	12/03	040/03
Nigeria	Phase-Out of Leaded Gasoline in Nigeria	11/02	029/02
	Nigerian LP Gas Sector Improvement Study	03/04	056/04
	Taxation and State Participation in Nigeria's Oil and Gas Sector	08/04	057/04
Regional	Second Steering Committee: The Road Ahead. Clean Air Initiative In Sub-Saharan African Cities. Paris, March 13-14, 2003.	12/03	045/03
	Lead Elimination from Gasoline in Sub-Saharan Africa. Sub-regional Conference of the West-Africa group. Dakar, Senegal March 26-27, 2002 (French only)	12/03	046/03
	1998-2002 Progress Report. The World Bank Clean Air Initiative in Sub-Saharan African Cities. Working Paper #10 (Clean Air Initiative/ESMAP)	02/02	048/04
	Landfill Gas Capture Opportunity in Sub Saharan Africa	06/05	074/05
	The Evolution of Enterprise Reform in Africa: From State-owned Enterprises to Private Participation in Infrastructure —and Back?	11/05	084/05
Senegal	Regional Conference on the Phase-Out of Leaded Gasoline in Sub-Saharan Africa	03/02	022/02
	Elimination du Plomb dans I'Essence en Afrique Sub-Saharienne		

Region/Country	*Activity/Report Title*	*Date*	*Number*
Senegal	Conference Sous Regionales du Groupe Afrique de I'Quest. Dakar, Senegal. March 26-27, 2002.	12/03	046/03
	Alleviating Fuel Adulteration Practices in the Downstream Oil Sector in Senegal	09/05	079/05
South Africa	South Africa Workshop: People's Power Workshop.	12/04	064/04
Swaziland	Solar Electrification Program 2001—2010: Phase 1: 2001—2002 (Solar Energy in the Pilot Area)	12/01	019/01
Tanzania	Mini Hydropower Development Case Studies on the Malagarasi, Muhuwesi, and Kikuletwa Rivers Volumes I, II, and III	04/02	024/02
	Phase-Out of Leaded Gasoline in Oil Importing Countries of Sub-Saharan Africa: The Case of Tanzania - Action Plan.	12/03	039/03
Uganda	Report on the Uganda Power Sector Reform and Regulation Strategy Workshop	08/00	004/00

WEST AFRICA (AFR)

Regional	Market Development	12/01	017/01

EAST ASIA AND PACIFIC (EAP)

Cambodia	Efficiency Improvement for Commercialization of the Power Sector	10/02	031/02
	TA For Capacity Building of the Electricity Authority	09/05	076/05
China	Assessing Markets for Renewable Energy in Rural Areas of Northwestern China	08/00	003/00
	Technology Assessment of Clean Coal Technologies for China Volume I—Electric Power Production	05/01	011/01
	Technology Assessment of Clean Coal Technologies for China Volume II—Environmental and Energy Efficiency Improvements for Non-power Uses of Coal	05/01	011/01
	Technology Assessment of Clean Coal Technologies for China Volume III—Environmental Compliance in the Energy Sector: Methodological Approach and Least-Cost Strategies	12/01	011/01
Philippines	Rural Electrification Regulation Framework. (CD Only).	10/05	080/05
Thailand	DSM in Thailand: A Case Study	10/00	008/00
	Development of a Regional Power Market in the Greater Mekong Sub-Region (GMS)	12/01	015/01
Vietnam	Options for Renewable Energy in Vietnam	07/00	001/00
	Renewable Energy Action Plan	03/02	021/02
	Vietnam's Petroleum Sector: Technical Assistance for the Revision of the Existing Legal and Regulatory Framework	03/04	053/04

SOUTH ASIA (SAS)

Bangladesh	Workshop on Bangladesh Power Sector Reform	12/01	018/01
	Integrating Gender in Energy Provision: The Case of Bangladesh	04/04	054/04
	Opportunities for Women in Renewable Energy Technology Use In Bangladesh, Phase I	04/04	055/04

Region/Country	Activity/Report Title	Date	Number

EUROPE AND CENTRAL ASIA (ECA)

Russia	Russia Pipeline Oil Spill Study	03/03	034/03
Uzbekistan	Energy Efficiency in Urban Water Utilities in Central Asia	10/05	082/05

MIDDLE EASTERN AND NORTH AFRICA REGION (MENA)

Regional	Roundtable on Opportunities and Challenges in the Water, Sanitation And Power Sectors in the Middle East and North Africa Region. Summary Proceedings, May 26-28, 2003. Beit Mary, Lebanon. (CD)	02/04	049/04
Morocco	Amélioration de d´Efficacité Energie: Environnement de la Zone Industrielle de Sidi Bernoussi, Casablanca	12/05	085/05

LATIN AMERICA AND THE CARIBBEAN REGION (LCR)

Brazil	Background Study for a National Rural Electrification Strategy: Aiming for Universal Access	03/05	066/05
Bolivia	Country Program Phase II: Rural Energy and Energy Efficiency Report on Operational Activities	05/05	072/05
Chile	Desafíos de la Electrificación Rural	10/05	082/05
Ecuador	Programa de Entrenamiento a Representantes de Nacionalidades Amazónicas en Temas Hidrocarburíferos	08/02	025/02
	Stimulating the Picohydropower Market for Low-Income Households in Ecuador	12/05	090/05
Guatemala	Evaluation of Improved Stove Programs: Final Report of Project Case Studies	12/04	060/04
Mexico	Energy Policies and the Mexican Economy	01/04	047/04
Nicaragua	Aid-Memoir from the Rural Electrification Workshop (Spanish only)	03/03	030/04
	Sustainable Charcoal Production in the Chinandega Region	04/05	071/05
Regional	Regional Electricity Markets Interconnections — Phase I Identification of Issues for the Development of Regional Power Markets in South America	12/01	016/01
	Regional Electricity Markets Interconnections — Phase II Proposals to Facilitate Increased Energy Exchanges in South America	04/02	016/01
	Population, Energy and Environment Program (PEA) Comparative Analysis on the Distribution of Oil Rents (English and Spanish)	02/02	020/02
	Estudio Comparativo sobre la Distribución de la Renta Petrolera Estudio de Casos: Bolivia, Colombia, Ecuador y Perú	03/02	023/02
	Latin American and Caribbean Refinery Sector Development Report – Volumes I and II	08/02	026/02
	The Population, Energy and Environmental Program (EAP) (English and Spanish)	08/02	027/02
	Bank Experience in Non-energy Projects with Rural Electrification Components: A Review of Integration Issues in LCR	02/04	052/04
	Supporting Gender and Sustainable Energy Initiatives in Central America	12/04	061/04
	Energy from Landfill Gas for the LCR Region: Best Practice and Social Issues (CD Only)	01/05	065/05

Region/Country	Activity/Report Title	Date	Number
	Study on Investment and Private Sector Participation in Power Distribution in Latin America and the Caribbean Region	12/05	089/05
	GLOBAL		
	Impact of Power Sector Reform on the Poor: A Review of Issues and the Literature	07/00	002/00
	Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries	08/00	006/00
	Mini-Grid Design Manual	09/00	007/00
	Photovoltaic Applications in Rural Areas of the Developing World	11/00	009/00
	Subsidies and Sustainable Rural Energy Services: Can we Create Incentives Without Distorting Markets?	12/00	010/00
	Sustainable Woodfuel Supplies from the Dry Tropical Woodlands	06/01	013/01
	Key Factors for Private Sector Investment in Power Distribution	08/01	014/01
	Cross-Border Oil and Gas Pipelines: Problems and Prospects	06/03	035/03
	Monitoring and Evaluation in Rural Electrification Projects: A Demand-Oriented Approach	07/03	037/03
	Household Energy Use in Developing Countries: A Multicountry Study	10/03	042/03
	Knowledge Exchange: Online Consultation and Project Profile from South Asia Practitioners Workshop. Colombo, Sri Lanka, June 2-4, 2003	12/03	043/03
	Energy & Environmental Health: A Literature Review and Recommendations	03/04	050/04
	Petroleum Revenue Management Workshop	03/04	051/04
	Operating Utility DSM Programs in a Restructuring Electricity Sector	12/05	058/04
	Evaluation of ESMAP Regional Power Trade Portfolio (TAG Report)	12/04	059/04
	Gender in Sustainable Energy Regional Workshop Series: Mesoamerican Network on Gender in Sustainable Energy (GENES) Winrock and ESMAP	12/04	062/04
	Women in Mining Voices for a Change Conference (CD Only)	12/04	063/04
	Renewable Energy Potential in Selected Countries: Volume I: North Africa, Central Europe, and the Former Soviet Union, Volume II: Latin America	04/05	070/05
	Renewable Energy Toolkit Needs Assessment	08/05	077/05
	Portable Solar Photovoltaic Lanterns: Performance and Certification Specification and Type Approval	08/05	078/05
	Crude Oil Prices Differentials and Differences in Oil Qualities: A Statistical Analysis	10/05	081/05
	Operating Utility DSM Programs in a Restructuring Electricity Sector	12/05	086/05

Last report added to this list: ESMAP Technical Paper 090/05.