# FLOK policy paper on distributed energy

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## Executive Summary

This policy paper examines the application of the principles of a social knowledge economy to the energy sector. The *Introduction* explains the importance of the energy sector, the general principles underlying this policy document and the concept of the knowledge economy, underlining the distinction between capitalist knowledge economies and social knowledge economies.

The next section, *Critique of Capitalist Models*, looks at how the energy system has developed under two centuries of capitalist domination and argues that neoliberal policies have created unregulated energy markets and a process of global privatization, which has weakened social control over key sectors of production and reproduction of modern societies in both the Global North and South.

In the follow-up section, *Alternative models: distributed energy,* we explore the distributed energy model as a viable alternative to centralized models based on private property and describe briefly its main features: (a) the use of renewable energy sources, (b) the empowerment of consumers through the democratization of the means of energy production and distribution and (c) the communal management of the relevant infrastructure. Our analysis suggests that power generation could be much more efficiently organized as a *commons,* rather than as a commodity, the recognition of which should be the fundamental principle underlying all public policy proposals aimed at the transformation of the energy sector.

In the next section, *Preliminary general principles for policy making,* we illustrate the distributed energy model through four case studies and sum up the conclusions drawn from the case studies in the form of general policy principles and enabling conditions for the development of a post-fossil fuel society which respects the Rights of Nature.

In the *Ecuadorian policy framework*, we provide an overview of the energy sector in Ecuador and discuss the policy framework that pertains to national energy policy. Last, in the *Ecuadorian policy recommendations*, we put forward a series of policy recommendations for enabling the transition of already existing policies into the paradigm of distributed energy and a set of pilot project proposals which are designed to operationalize these policy recommendations and provide a testing ground for their effectiveness.

# Introduction and focus

This policy paper examines the application of social knowledge economy principles to the energy sector of the economy. This section underlines, first, the importance of the energy sector and the general principles upon which this policy document is based. Furthermore, it discusses the concept of the knowledge economy, drawing a critical distinction between social knowledge economies and capitalist knowledge economies.

## *Energy: Strategic sector of the economy and blood flow of the production system*

The energy sector is a strategic sector in all economies: it forms the 'blood flow' of the production system and is a key factor for the satisfaction of human needs. A sustainable approach to the energy sector should pursue energy sovereignty and the participation of all stakeholders of the surrounding ecosystem. Energy must be understood as a common good, and approached in a way that addresses multiple dimensions (temporal, geographic, etc.) while prioritizing local benefits.

The current global energy sector is facing serious physical and environmental limitations, of which two undeniable examples are the depletion of fossil fuel resources and the threat of climate change. The energy sector requires a transition to a sustainable paradigm, a process in which universal access to appropriate sources of energy for all people should be the priority. Proposing alternatives which harmonize energy needs with ecological sustainability requires a re-consideration of the concept of development and a search for new evolutionary paradigms for society. Moreover, it is clear that a sustainable energy paradigm must rely on renewable sources to ensure their renewability. In this sense, Latin America faces a difficult challenge: almost half of its energy supply depends on oil, and this demand is expected to increase. However, it must be emphasized that the scarcity and cost of this source of energy will increase, and even if it proves possible to access it, the environmental effects will be detrimental. The fantasy of a 'flat earth economy' without entropy or biophysical limits brings society inevitably to a dead-end. To develop the good life, we must be able to examine what alternative perspectives exist for a socio-ecological transition (Guayanlema et al. 2014).

The generation, access and dissemination of information which is disaggregated, geo-referenced, and open about territorial energy systems should underpin a new paradigm of energy planning and protocols. These protocols should consider the needs, capacities, renewable resources and methods of resource conservation, as well as the use of appropriate and appropriable types of open technologies.

Crucially, the transition to a sustainable energy matrix requires the development of institutions and technological capacities to effectively and fairly manage the flow of energy which is reproduced naturally through the biosphere (CEDA 2012). The priority is the creation of spaces and mechanisms which facilitate the partnership of the state and civil society with regard to training, research, innovation and the production and management of energy. To this end, a regulatory agenda must be agreed upon to facilitate the reciprocal transformation of energy and productive structures and the democratization of energy service provision.

An essential factor for the success of this transition is the recognition of the fact that the sustainability of this structure is not only determined by the energy supply but also by its demand. The strategy must combine the promotion of efficient energy savings based on changing consumer habits, of new ways of exchanging goods and services, of territorial re-arrangement, etc. It is essential, therefore, to pay attention to the education and energy literacy of all people so as to ensure their active participation in the process.

## *The concept and forms of the knowledge economy*

In contrast to traditional conceptions of the factors of production centered on land, labor and capital, the concept of the knowledge economy emphasizes the role of knowledge as the key driver of economic activity (Bell 1974; Drucker 1969; for a critical analysis of the concept, see Webster 2006). This implies, of course, that the decisive means of production in a knowledge economy is access to knowledge. From this standpoint, it is precisely the question of how access to knowledge is being managed that largely determines the character of an economic system. Capitalist knowledge economies use the institution of intellectual property to create conditions of scarcity in knowledge: thus, knowledge is privatized and locked up in property structures which limit its diffusion across the social field. A social knowledge economy, by contrast, is characterized by open access to knowledge (Ramirez 2014) and so reconfigures the application of intellectual property rights to prevent the monopolization and private enclosure of knowledge:

'knowledge must not be seen as a means of unlimited individual accumulation, nor a treasury generating differentiation and social exclusion' but as 'a collective heritage [which] is...a catalyst of economic and productive transformation' (National Plan for Good Living 2013-2017, english version, p. 61, italics ours) and 'a mechanism for emancipation and creativity' (Ibid, p. 41). In a nutshell, a social knowledge economy is an economy in which knowledge is seen as a public and common good; an economy which thrives on the ‘open commons of knowledge’ (National Plan for Good Living 2013-2017, spanish version, p. 67, italics ours).

This social knowledge economy, however, requires natural resources and energy for the sustainability of its 'social metabolism' (Giampietro et al. 2009; Martinez-Alier 1987, Fischer-Kowalsky 1997). The growth of the service economy and the relative 'de-materialization' of the Global North under the model of cognitive capitalism has occurred at the expense of an *unequal ecological exchange* with the Global South. The outsourcing of polluting activities, which has benefited the environment in the North, has been possible largely due to the shift of activities and the import of raw materials extracted in the South at cheap prices (Giljum 2004; Hornborg et al. 2007). Far from not needing resources, the social knowledge economy, like all economies, requires a change in the production model aimed at integrating the productive sectors with the tertiary knowledge sector, combining the potential of knowledge with the productive economy. As this requires material resources, it is necessary to analyze in depth the 'materiality' of this economy.

## Critique of capitalist models

Energy production has been marked by a tendency towards increased scale and centralization for the greatest part of its history since the industrial age (Mumford 1963). In the case of electricity, this model though, in which power is generated at central power stations that deliver electricity to sites of demand through the electricity grid, began to falter in the 1960s, as environmental concerns about the use of non-renewable fuels and the increased potential to realize efficiency gains by locating productive units closer to sites of demand strongly favored decentralization in power generation and system management. In parallel, the strain placed upon centralized models by the growing demand for energy in the 21st century has reinforced this thrust towards distributed models, as did the increased availability of small-scale power generation technologies (Takahashi et al. 2005). However, in spite of these pressures for the adoption of decentralized structures, the mode of energy production remains to this day predominantly centralized.

To put this tendency for increased scale and centralization into perspective, one must understand that the (centralized) architecture of the existing infrastructure is a 'legacy' inherited from the industrial age and the system of mass production. Based on the same logic that characterizes the way in which the production of goods is organized and centralized in factories in the system of mass production, the design of the existing energy system is essentially the same model adapted to the production and distribution of energy. As a result, it is subject to the very same problems that beset the mass production model: first, as this model is oriented towards the production of an undifferentiated commodity for a homogeneous market, it is incapable of covering the diverse needs of different users. In a word, it is unfit for a market characterized by a diversity of user needs.[1] Second, like the system of mass production, the model of centralized, mass production of energy depends on the continued availability of cheap fossil fuels—coal, oil, and natural gas (Bauwens 2009, 2012). Without doubt, that is a very dangerous dependence because by ignoring the underlying reality of the fact that an era of scarcity in fossil fuels—especially oil—is upon us, it maintains the irrational and environmentally-destructive use of those natural resources.

In addition to its inability to meet the diverse needs of users and their self-destructive dependence on fossil fuels, the current model of energy generation contravenes the development of a post-consumer society. This is most evident in those cases where the power sector is privatized and operates through the centralization of the means of production in large power plants, effectively causing dependence on the corporate delivery of electricity service, which reinforces and perpetuates a consumerist lifestyle.[2] Locked in a relationship of passive energy consumption, users are condemned to remain in a state of “energy illiteracy”, ignorant of the environmental implications and operations of the energy system. The resulting indifference which accompanies the present mode of energy production and consumption is, of course, a dangerous form of ignorance, in that it promotes an environmentally irresponsible and irrational mode of energy consumption.

Much the same criticism applies to centralized models of renewable energy which are currently in vogue among proponents of 'green capitalism' (e.g. Hawken et al. 1999) and 'green growth' (e.g. OECD et al. 2012; World Bank 2012). Although they are based on the

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[1] Because competing service providers can not offer different 'service packages' as in telecommunications, they are forced to compete through marketing and advertising, which results in additional costs for consumers and, to some extent, cancels the supposed benefits of competitive markets. Against expectations, competition in energy markets around the world has not led to reduced prices or improvements in the quality of the product (electricity) for the consumer. Rather, the creation of open energy markets today implies increased prices for end consumers.

[2] This consumerism is not only the result of the management model of the energy sector, but also of the capitalist model that designed a market system for the electricity sector upon the recommendation of the World Bank and International Monetary Fund. Numerous studies reflect on this issue: for example, see Xu, Y. (2005) *Models, Templates and Currents: The World Bank and Electricity Reform*.

use of renewable energy sources and are therefore supportive of the re-orientation of the mode of energy production in the direction of greater environmental sustainability and eco-friendliness, the logic of mass production of a commodity for a homogeneous, mass consumer market remains the organizing principle of those infrastructures. As a result, they do not have the capacity to meet the increasingly more varied needs of energy users. Worse still, by keeping users in a state of passive consumerism and energy illiteracy, the underlying centralization of the means of energy production constitutes a barrier to the emergence of a post-consumerist knowledge society.[3]

To recap, existing centralized models of energy production, including those that make use of renewable energy sources, are based on outdated logics which run counter to the needs and aims of a post-consumerist knowledge society. By contrast, what a post-carbon, post-capitalist society needs is a different mode of energy production that is based not only on the use of renewable energy sources but also on the pervasive participation of users in the production, control and ownership process that can be achieved through the decentralization and democratization of the means of energy generation. This is essentially the model of distributed (or P2P) energy which, aside from the use of renewable energy resources, is characterized by (Papanikolaou 2009):

- the transformation of users into co-producers through the decentralization of the means of production;
- the volunteer participation of individual producers, households and communities;
- and the communal character of the management, control and ownership of the underlying infrastructures.

The adoption of technologies and tools for the distributed generation and management of energy can thus create the enabling material conditions for the emergence of the energy commons in contrast to the traditional state-private ownership models that developed in the course of the 20th century. In addition, a critique of capitalism should highlight the importance of the mode of ownership and of the existence of physical limits to economic growth — two issues that are often absent in debates on energy models.

The question of ownership of energy resources and relevant infrastructures (e.g. grids, production units, control centers, demand site equipment, technology knowledge, etc.) is often overlooked when alternatives to the current, fossil-fuel-based, centralized system of energy production and consumption are discussed. The neoliberal 'shock doctrine' has spawned a broad political program of privatizations, from which the energy sector has not been exempted. This amounts to reduced public regulation and social control over crucial aspects related to energy (e.g. sovereignty, energy dependence, price volatility, energy

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[3] For a more extensive development of these critiques, see Rogers (2010) and Wallis (2010).

access/poverty, climate change implications, etc). On the other hand, new technologies of energy production provide the capacity for more socialized modes of ownership in the form of distributed, small-scale energy infrastructures run by community organizations (e.g. consumer-producer co-ops). This is by no means dictated by technological forces alone but rather by a combination of social, political and economic factors which should not be overlooked. Although smart grids and renewable energies can be the material basis for new forms of collective ownership of energy infrastructures, it is clearly a political process which will shape the future of energy systems and the ability of citizens to own, design, control and regulate their own means of 'metabolism' with nature, in which energy holds a decisive position among other productive processes. Copyrights and patents over energy technology are constantly restricting the development and diffusion of knowledge around the world. Open source tools/technologies for the production of energy are thus essential instruments for the political process described in the previous paragraph, which is why open access methodologies are becoming more and more relevant to the conflicts over the ownership of energy resources and technology. The adoption of such open source/access tools should therefore be a central component of public policies for the development of new technologies for energy production, management and consumption.

It is important to remember that the capitalist system requires constant growth and expansion. However, such infinite growth is not possible in a finite world (Latouche 2006). Despite the 'financialization of Capital', which increases profit through speculation and credit, the financial system, sooner or later, has to recirculate capital into the productive sector, whose expansion has clear biophysical and environmental limits, a prime examples of which is the depletion of oil and climate change. Building the social knowledge economy necessitates a reconsideration of these limits and the development of a process by which social goals will be redirected beyond the single criteria of continuous economic growth. The constant expansion and growth of capitalism is manifested spatially in the global division of labor and unequal ecological exchange in the world system (Hornborg 1998, Wallerstein 2001). The areas of extraction, production and consumption have gradually grown apart, generating an uneven development amongst poles of energy generation and energy consumption (Bunk 1984, 2009). As such, an alternative to centralized energy systems consists in the development of a decentralized and distributed system, which promotes new territorial dynamics.

# Alternative models: distributed energy

## *An introduction to distributed energy*

Although different definitions of distributed energy generation exist (Gómez 2008), the general concept of distributed energy emphasizes small-scale generation, consumer accessibility and end user participation. This is by no means a new concept. The first systems and power grids operated with direct current, limiting both the supply voltage and the distance between the generator and the site of consumption, so that generation plants could only supply electricity to users in the immediate area. The development of the alternating current allowed electricity to be transported over long distances, significantly increasing power generation. With the aim of lowering production and distribution costs, the vast majority of electrical systems evolved over time into a centralized model of power plants and transmission/distribution grids.

Since the 1970s, due to the oil crisis and the realization of the gravity of the effects of environmental degradation, the concept of distributed energy has been receiving increasingly more attention. Furthermore, technological innovations, increased transportation and distribution costs, the changing economic climate, climate change concerns, and, in some contexts, the emergence of regulatory standards, have reinforced the interest in distributed energy infrastructures. Nowadays, the importance of distributed energy systems is indisputable, going well beyond the provision of energy to remote communities. In essence, the paradigm shift in the energy system implies a change in our way of thinking and acting, thereby enabling our communities to propose, design, implement and operate their own infrastructures in a manner that is adapted to the realities of their specific context.

Distributed energy infrastructures could provide great benefits for those areas that have renewable energy resources but are far from major consumption areas, allowing them to benefit from new business models based on the sale of “energy services” (the control of energy quality in the network). Evidently, the roll-out of such schemes would require the development of a new legal framework.

The generation of distributed energy puts special emphasis on demand management and its constant interaction with renewable supply (Kempener et al. 2013). This demand management requires an understanding of the relevant territorial and spatial factors and an identification of who will consume the energy and how it will be consumed in different areas of the territory, as well as of the interplay between different types of energy consumption and production (Ariza-Montobbio et al. 2014). In short, distributed energy promotes a closer connection between energy generation and consumption

(Alanne and Saari 2006). Consequently, this implies a territorial approach to energy, based on the use of geo-referenced information about available renewable resources and consumer dynamics. This new paradigm of planning and organization of energy information suggests to think about energy efficiency not only from a technological point of view, but also from a socio-structural point of view. Changes in the geographical distribution of homes and workplaces, as well as in cultural practices and in the use of time associated with energy consumption can enable significant reductions in the consumption of energy (efficiency). Examples of this include the economic promotion of small and medium urban centers or the collectivization/socialization of consumption (e.g. collective use of household appliances, industrial processes, public transport, etc.).

The social effect of distributed energy depends on, among other factors, the scale of production technologies. At the municipal and city level, changing the energy model to a cooperative energy system may result in the development of projects of up to 100kW of electricity generation (based on solar photovoltaic, grid-connected, low-voltage electricity). At the neighborhood level, solar roofs on houses connected to the local power grid can generate 10kW. In the case of rural areas, autonomous power systems with capacities up to 15kW can be installed in the grid, based on solar photovoltaic, small wind or small hydro power. Mini and micro-wind energy has shown great potential for developing small wind turbines. Of particular importance is the development of micro turbines of up to 1kW, based on the open Hugh Piggot design. Micro-hydro technology is one of the most economical, clean and safe choices for rural electrification if the appropriate technologies are chosen and proper planning of its implementation, operation and maintenance is carried out. There are many successful micro-hydro projects in developing countries, which indicate the adaptability of micro-hydro technology to local conditions, its sustainability, and its contribution to local community development.

Moreover, non-electrical renewable resources, such as low-temperature solar heat, can be use to meet thermal requirements, such as boiling water for sanitation. In rural areas, one can use biogas produced from the anaerobic digestion of livestock and waste. This can also be used for cooking food.

The use of these technologies favors the development of groups of producers and consumers known as 'prosumers'. When citizens, families and communities use renewable technologies to produce some of the energy that they consume, they become aware of the environmental, economic and social effects of the energy system: energy production no longer remains a black box system. In this sense, an energy consumer/producer can be made aware of the real costs of energy and thus reduce their consumption through the adoption of cost-saving and efficiency measures. Additionally, the participation of energy users in its production improves the energy planning process, making it responsive to the needs of the users, especially at the community and municipal level. This bottom-up, participatory process leads to a democratization of energy planning which can satisfy the social, economic and cultural needs of communities without destroying the environment.

## *Microgrids*

A typical example of distributed energy infrastructures is that of microgrids (also known as minigrids), which have been the fastest developing and most dynamic field of the global energy system over the past years.[4] Combining renewable energy production and ICT with a new policy framework for the energy market, microgrids provide scientific, technical, political, organizational and social tools for a fundamental transformation of the energy system both in the local and global level. Future microgrids could exist as energy-balanced cells within existing power distribution grids or as stand-alone power networks within small communities (given that new control capabilities allow distribution networks to operate isolated from the central grid in case of faults or other external disturbances, thus contributing to improved quality of supply).[5]

Microgrids make use of increasingly available microgenerators, such as micro-turbines, fuel cells and photovoltaic (PV) arrays, wind turbines and small hydro gensets together with storage devices, such as flywheels, energy capacitors and batteries and controllable (flexible) loads (e.g. electric vehicles) at the distribution level. Improvements in ICT and end-user technology for power management, load management, remote operation and metering systems, data analysis and billing algorithms have contributed to the increasing deployment of modern microgrids.

The 'Microgrids for rural electrification' report (Schnitzer et al. 2014) published in February 2014 describes the potential of microgrids in rural and peri-urban areas in developing countries: 'Over 1.2 billion people do not have access to electricity, which includes over 550 million people in Africa and 300 million people in India alone...In many of these places, the traditional approach to serve these communities is to extend the central grid. This approach is technically and financially inefficient due to a combination of capital scarcity, insufficient energy service, reduced grid reliability, extended building

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[4] The evolution of electricity grids is referred to as smart grids. According to the Smart Grids European Technology Platform (2006), a smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers as well as those that assume both roles – in order to efficiently deliver sustainable, economic and secure electricity supplies.

[5] The recent handbook by Hatziargyriou (2014) examines the operation of microgrids - their control concepts and advanced architectures including multi-microgrids – based on an overview of successful pilot microgrids in Europe, USA, Japan, China and Chile with centralized or decentralized control architectures. Cost data and different economic models are also included in the book.

times and construction challenges to connect remote areas. Adequately financed and operated microgrids based on renewable and appropriate resources can overcome many of the challenges faced by traditional lighting or electrification strategies'.

Clearly, although the concept of distributed energy is often associated with 'electrical energy', further analysis is required to highlight the relevance of other forms of energy, whose generation and consumption can have a much more significant impact in global terms. In this sense, the importance of the transport sector as an essential component in the global economy is undeniable, as is the mobility of people. Currently, transportation means are primarily based on the burning of fossil fuels, which constitutes a significant source of greenhouse gas pollution.

The implications of the future fossil fuel scenario – notably, the continuous increase in costs and investments attendant upon exploitation, regardless of the severe environmental impacts — can be easily mitigated through its replacement by renewable alternatives for electrical generation or heat. However, oil shortages in other sectors, such as transportation or agriculture, will not be as easily replaceable (CEDA 2012). In particular, the food chain has been identified as one of the most vulnerable sectors (UNEP 2012, FAO 2011). Rising oil prices, due to shortage, increase the price of fertilizers and pesticides, as well as that of fuel for machinery. Agriculture’s growing dependence on these inputs makes this sector even more vulnerable.

## Preliminary general principles for policy making

Under the paradigm of distributed energy, energy planning requires a new approach which considers the spatial, social and ecological specificity of the territory. Meeting energy demands with the available supply of renewable resources requires a transformation in the energy system through social participation and the use of open, geo-referenced information.

Social participation facilitates the identification of renewable resources and their potential to develop appropriate and appropriable technologies. A participatory approach that treats the inhabitants of the territories as major actors also allows for a process of social learning about energy issues, which further facilitates their involvement.

Data that is open, geo-referenced and disaggregated provide information for the development of  appropriate energy policies. This data should have multiple dimensions — social, demographic, economic, energy-related and environmental — so as to identify those interrelationships which are relevant to planning.

The starting point for planning must be the identification of the end uses of energy: domestic, industrial, transportation, agriculture and services. It is also necessary to characterize those renewable energy sources available within the territory: solar, wind, biomass (including forest biomass), watersheds, and geothermal sources or tidal energy. After analyzing the characteristics of the territory in terms of its demand and potential renewable energy resources, one must take into consideration the available stock of appropriate and appropriable technologies so as to ensure energy sovereignty (that is, to ensure that the current dependence on energy resources does not morph into a dependence on technology).

It is important to note that the development of a new industry is accompanied by its own requirements of energy, human skills and financial capital. To achieve the transformation of the productive matrix, it is imperative to undergo a process of diversification within the energy matrix towards a sustainable system through the diversification of renewable resource production, as well as in the end uses of energy. In the same way that changing the energy matrix is a key process in changing the production matrix, this relationship must be reciprocal: the change in the energy matrix requires a change in the production model, which enables the employment of appropriate and appropriable technologies.

For an outline of general principles for policy making, we discuss four case studies as examples of best practice. The first provides insight as to how a small, isolated community has been able to meet its electrical needs through the development of a small-scale, distributed energy infrastructure (known as a microgrid). The second case study focuses on the adoption of small-scale hydroelectric power, illustrating the benefits of distributed energy technology that is locally manufactured and controlled by its users. The third case study presents an assessment of the local manufacturing of wind turbine technology on a small scale, which is developed by a global community of users for use in rural electrification applications. The last case study focuses on BioLAC, the Network for the promotion of Biodigesters in Latin America and the Caribbean. Below is a brief discussion of the aforementioned case studies, which are developed more fully in Appendix 1.

## *Case study 1: The Kythnos island community project*

Kythnos is a small island in the Aegean sea in Greece. As is typical of islands in general, Kythnos is cut off from the national grid on mainland Greece. It has its own island grid, but this does not have the capacity to electrify all settlements on the island. Thus, in the framework of two European Commission projects (PV-MODE, JOR3-CT98-0244 and

MORE, JOR3CT98-0215), a microgrid was installed in 2001, which has since provided electricity for 12 houses in a small valley that is about 4 km from the closest medium voltage line (Hatziargyriou et al. 2007, pp. 80-82; Tselepis 2010). Being one of the very first pilot installations in Europe, the project has been frequently cited as an example of a cost-effective and environmentally sustainable way of providing a small community with electricity through a model of energy generation at the site of demand using renewable sources. The case of the implementation of the microgrid on the island of Kyhtnos illustrates a model of distributed energy which has enabled a small, isolated community to become energy-autonomous in an ecologically-conscious and sustainable fashion.

## *Case study 2: Distributed energy infrastructures in Nepal based on the use of small-scale, hydropower technologies*

Small-scale hydropower, or micro-hydro, is one of the most cost-effective energy technologies for rural electrification. It makes use of a local energy resource, which can be harnessed for rural energy demands from small rivers, where there is a gradient of a few meters and the flow rate is more than a few liters per second. It is an environmentally clean option based on locally available resources and can be reliable and affordable when appropriate technologies and approaches are used for its implementation, operation and management. There are a large number of successful small hydro projects in various developing countries, which show their adaptability to local conditions, their sustainability and their positive contribution to local development. Micro-hydro plants (from 5kW to 100kW) basically just divert flowing river water, with no significant dams, and use the force of gravity and falling water to spin turbines that generate power before churning the water back into the river downstream. Specifically in Nepal where about 63% of the households do not have access to electricity (World Bank 2010), since the industry’s birth in the 1960s some 2,200 micro-hydro plants have been built, totaling around 20MW, which now provide electricity for some 200,000 households (Handwerk 2012). Around 65 private companies provide services related to the implementation of micro hydropower projects under the aegis of the Nepal Micro Hydropower Development Association. The 323 operational RERL (Renewable Energy for Rural Livelihood program) facilities now create more than 600 full-time jobs and about 2,600 people have been technically trained on how to operate a facility. Similar efforts have been performed in Sri Lanka, Peru, Ecuador and other countries. In Ecuador a project by ESMAP (World Bank 2005) has undertaken the groundwork for picohydro development by initiating a market assessment for picohydro in the Andean region, by developing technical capacity to install and maintain picohydro systems at demonstration sites, and by helping a small group of businesses see the commercial opportunities arising from the sale of picohydro systems in the country.

## Case study 3: Distributed energy infrastructures based on open source wind energy technologies

The Rural Electrification Research Group (RurERG), which is part of the Smart grids Research Unit (Smart RUE) of the National Technical University of Athens (NTUA), has been assessing the technology of locally manufactured small wind turbines since 2009, in the context of a wider validation process of open source hardware (OSHW) renewable energy technologies used for rural electrification. The Hugh Piggott (HP) small wind turbine (Piggott 2008) has been used as the 'reference design' of the open-source small wind turbine developed by the rural electrification research group of the NTUA, since the majority of existing locally manufactured small wind turbines have been based on this design. It is estimated that more than one thousand locally manufactured small wind turbines have been constructed based on the Hugh Piggott design and are currently used around the world. Rural electrification has been an obvious application of this technology, so many NGOs and groups have used these design manuals to locally construct small wind turbines in developing countries, while construction seminars for DIY (do-it-yourself) enthusiasts are organized by several groups around the world. Since 2012, the Wind Empowerment association, tries to network most of the organizations involved in locally manufactured small wind turbines in the world, with the aim of building the financial and human resources required for the activities of these organizations, performing joint technical research and sharing technical information.

## Case study 4: Network of Biodigesters for Latin America and the Caribbean (RedBioLAC)

Biodigesters are natural systems that take advantage of organic waste from agricultural activities, mainly manure, to produce biogas (fuel) and organic fertilizer through the process of anaerobic digestion. Biogas can be used as fuel for cooking, heating or lighting. In large installations biogas can be used to power a motor for electricity generation. The fertilizer was initially considered an insignificant byproduct, but is currently considered to be as important as biogas, as it provides communities with a fertilizer that strongly improves crop yield. Low-cost biodigesters are considered to be an appropriate technology due to their low (initial) cost of investment, simple operation, basic maintenance requirements and accessibility to small and large producers. Low cost biodigesters have been used in developing countries since the 80s. The origin of low cost tubular biodigesters is a 'red mud PVC' designed in Taiwan in 1981. Based on that design, the flexible tubular continuous flow biodigester was designed in Ethiopia and then in Colombia (1987) and Vietnam (1994), where it was modified for tropical climates. The Network for the promotion of Biodigesters in Latin America and the Caribbean (REDBioLAC) brings together various institutions involved in the research, development, dissemination and implementation of low cost biodigester in nine Latin American countries. Its members include manufacturers of biodigesters, NGOs, research centers and universities with the shared objective of sharing information and experiences, identifying technical, environmental, social and economic barriers, suggesting ways to spread the biodigester technology in different countries, systematizing research and dissemination among partners and encouraging actions that influence policies related to biodigesters.

Through the above case studies we have come to identify a set of enabling conditions from which we can draw several general principles for the development of policy recommendations aimed at strengthening the development of a post fossil fuel society which respects the Rights of Nature.

**The democratization of the means of energy production** As we saw in the case of the implementation of the microgrid in Kythnos and that of small-scale hydropower infrastructures in Nepal, the most readily visible effect of the adoption of distributed structures of energy generation is that it transforms consumers into producers and their homes into productive units. Distributed models such as those based on microgrids imply the democratization of the means of production through the use of shared and collectively owned systems of production, as the underlying technological infrastructure for the generation of energy is not centralized in large power plants but is installed in the very homes of end users. Energy consumers are thus being made responsible for the daily operation and management of this infrastructure. This investment of users with the means of production is the single most important condition for the emergence of the model of commons-based, peer production in the field of energy.

**The importance of investment in energy literacy** The transition to distributed energy models entails significant switching costs, as individual users (households) and communities are required to invest in familiarizing themselves with new technologies, which they have to learn how to operate. Without the development and diffusion of such an 'energy literacy' across end users, attempts to set up distributed energy projects are bound to fail. That is why the design and implementation of such projects is often accompanied by training courses aimed at investing end users with the skills required to operate the relevant (so-called 'smart') technologies that are to be installed in their homes and communities. In this respect, those training courses are vehicles for the transfer of knowledge to local communities that will enable them to become energy-autonomous.

**Community-driven development and the importance of user participation** Distributed energy models evolved out of the demand to respond to the needs of communities and individual households, located often in remote regions, which were either inadequately supported and provided for by the pre-existing centralized infrastructure or not at all. Their development has been largely 'bottom-up', initiated and carried out by small local communities, which have taken it upon themselves to bootstrap an infrastructure that better suits their needs. Most importantly, the participation of the community and its members is dictated by the fact that distributed energy models and technologies are best adopted when they are not imposed top-down but shared from user to user. As it is the users themselves who will be responsible for operating and managing these technologies on a daily basis, it is essential that they be involved in the process of design and implementation of distributed energy projects. Consequently, it is critical to ensure the participation of end users and local communities in the policy-making process, transforming it into a 'mode of social learning, rather than an exercise of political authority' (Pretty et al. 2002, p. 252). Such participation not only lends legitimacy to transition programs, as they have been co-designed and implemented with end users and their communities, but also empowers them, helping ensure that policies are truly responsive to their needs.

**The significance of open source, appropriate technology** Distributed energy projects are characterized by their extensive use of open source technologies such as open source wind turbines and pico hydroelectric plants. That is so for manifold reasons. First of all, open source technologies – by virtue of the fact that their design information is freely available (under free/open licenses) – allow the broader community to participate in their design and development process, thereby resulting in rapid improvements in performance and reductions in production costs (Benkler 2006; Dafermos 2014). Indicatively, the cost of small-scale, locally-manufactured, open source hydropower technologies is about one third of the equivalent proprietary products (Practical Action 2014) and the same goes for locally manufactured small wind turbine technologies. Yet, the significance of open source technologies is not confined to the realization of cost reductions and performance improvements, which are made possible through their distributed development by a loosely coupled community of researchers, practitioners and hobbyists spread the world over. Equally important, open source technologies are designed with the principle of environmental sustainability in mind and in such a way as to be easily repairable and modifiable by end users. In that regard, they are paradigmatic of what is called *sustainable design* and *appropriate technology* (Pearce 2012; Wikipedia 2014a, 2014b): they are designed to last, rather than throw away and replace by newer technologies, 'they use less energy, fewer limited resources, do not deplete natural resources, do not directly or indirectly pollute the environment, and can be reused or recycled at the end of their useful life' (Wikipedia 2014a).

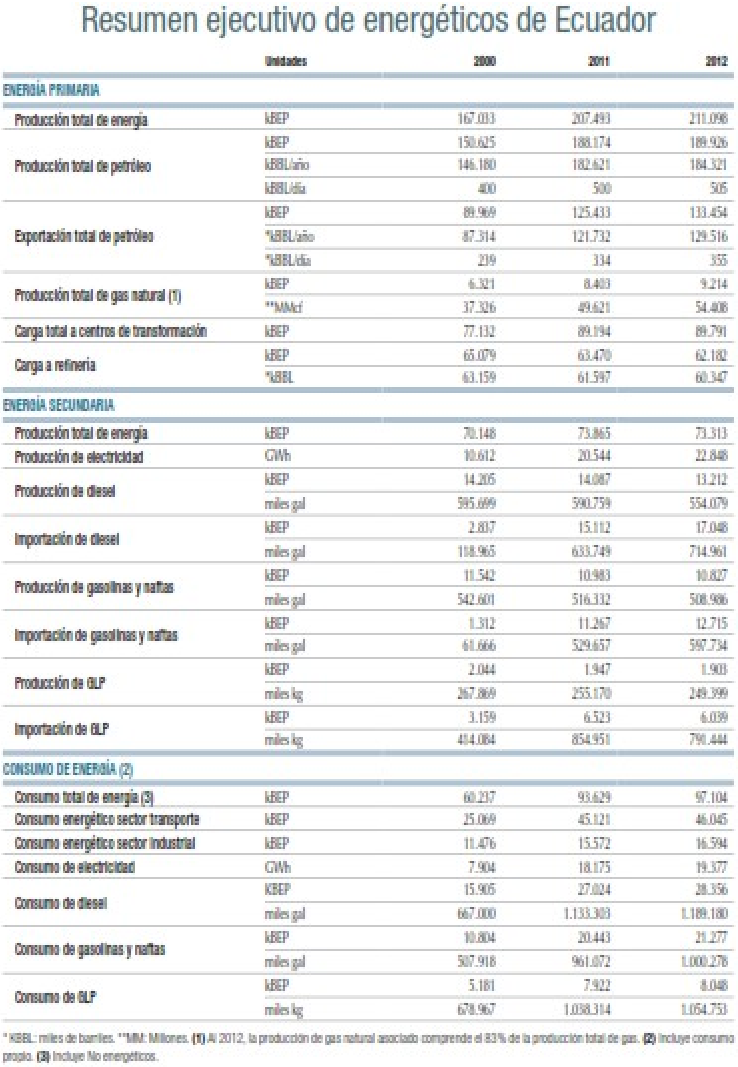
# The Ecuadorian policy framework

## *The energy sector in Ecuador*

The beginning of oil exploitation in the Amazon region in 1972 produced a gradual shift in the productive structure of the country which adopted an extraction model: this model boosted the national economy, yet it was highly vulnerable due to the volatility of oil prices. In consideration of that dependence on a non-renewable resource, the national government has embarked on a policy of transformation of the economic structure of the country in a way that is consistent with the vision of sustainable development and social inclusion.

It should be noted that, the systemization of information and energy forecasts has not been the priority of previous governments, and as a result, there is a dearth of relevant data. An analysis and evaluation of the process of change of the national energy matrix is necessary to get a clear picture of the actual state of energy supply and demand. To address this problem, the Ministry of Coordination of Strategic Sectors has developed the National Energy Balance 2013, which (like the historical series from 1995-2012 [MICSE 2013]) focuses on the collection and analysis of energy data from 1995 to 2012, including data on the transformation and consumption of all energy sources in all economic sectors of the country; in March 2013, all information related to the national energy matrix was updated. At present, the project is carrying out an updated analysis to better understand the long-term evolution of energy (it should be mentioned that it was necessary to hire external consultants for the development of the above activities, given the lack of institutional technical capacities). The management of the national energy balance and energy forecasts will soon be taken over by the National Institute of Energy Efficiency and Renewable Energy (INER), which plans to integrate the country’s energy information, provided by various actors as a key support tool.

The National Energy Balance 2013 looks at the energy supply and demand at the national level, based on data from 1995 to 2012. A comparative summary of the main energy variables for the years 2000, 2011 and 2012 is shown in the table below (MICSE 2013):



## Resumen ejecutivo de energéticos de Ecuador

| | Unidades | 2000 | 2011 | 2012 |
|---|---|---|---|---|
| **ENERGÍA PRIMARIA** | | | | |
| Producción total de energía | kBEP | 167.033 | 207.493 | 211.098 |
| Producción total de petróleo | kBEP | 150.625 | 188.174 | 189.926 |
| | kBBL/año | 146.180 | 182.621 | 184.321 |
| | kBBL/día | 400 | 500 | 505 |
| Exportación total de petróleo | kBEP | 89.969 | 125.433 | 133.454 |
| | *kBBL/año | 87.314 | 121.732 | 129.516 |
| | *kBBL/día | 239 | 334 | 355 |
| Producción total de gas natural (1) | kBEP | 6.321 | 8.403 | 9.214 |
| | **MMcf | 37.326 | 49.621 | 54.408 |
| Carga total a centros de transformación | kBEP | 77.132 | 89.194 | 89.791 |
| Carga a refinería | kBEP | 65.079 | 63.470 | 62.182 |
| | *kBBL | 63.159 | 61.597 | 60.347 |
| **ENERGÍA SECUNDARIA** | | | | |
| Producción total de energía | kBEP | 70.148 | 73.865 | 73.313 |
| Producción de electricidad | GWh | 10.612 | 20.544 | 22.848 |
| Producción de diesel | kBEP | 14.205 | 14.087 | 13.212 |
| | miles gal | 595.699 | 590.759 | 554.079 |
| Importación de diesel | kBEP | 2.807 | 15.112 | 17.048 |
| | miles gal | 118.965 | 633.749 | 714.961 |
| Producción de gasolinas y naftas | kBEP | 11.542 | 10.983 | 10.827 |
| | miles gal | 542.601 | 516.332 | 508.986 |
| Importación de gasolinas y naftas | kBEP | 1.312 | 11.267 | 12.715 |
| | miles gal | 61.666 | 529.657 | 597.734 |
| Producción de GLP | kBEP | 2.044 | 1.947 | 1.903 |
| | miles kg | 267.869 | 255.170 | 249.399 |
| Importación de GLP | kBEP | 3.159 | 6.523 | 6.039 |
| | miles kg | 414.084 | 854.951 | 791.444 |
| **CONSUMO DE ENERGÍA (2)** | | | | |
| Consumo total de energía (3) | kBEP | 60.237 | 93.629 | 97.104 |
| Consumo energético sector transporte | kBEP | 25.069 | 45.121 | 46.045 |
| Consumo energético sector industrial | kBEP | 11.476 | 15.572 | 16.594 |
| Consumo de electricidad | GWh | 7.904 | 18.175 | 19.377 |
| Consumo de diesel | KBEP | 15.905 | 27.024 | 28.356 |
| | miles gal | 667.000 | 1.133.303 | 1.189.180 |
| Consumo de gasolinas y naftas | kBEP | 10.804 | 20.443 | 21.277 |
| | miles gal | 507.918 | 961.072 | 1.000.278 |
| Consumo de GLP | kBEP | 5.181 | 7.922 | 8.048 |
| | miles kg | 678.967 | 1.038.314 | 1.054.753 |

* KBBL: miles de barriles. **MM: Millones. (1) Al 2012, la producción de gas natural asociado comprende el 83% de la producción total de gas. (2) Incluye consumo propio. (3) Incluye No energéticos.

Table 1: Summary of Ecuadorian energy system (Source: MICSE, Energy Balance 2013 [base year 2012])

According to the the 2012 balance sheet, oil accounts for 90% of the total primary energy production in Ecuador. We observe an increase in energy exports, mainly attributable to oil, which accounts for 92.9% of all exports (129.5 million barrels were exported in 2012). Secondary energy imports also manifest an upward trend, largely due to increased imports of gasoline and diesel, accounting for 32.8% and 44% of total imports, respectively. Moreover, a tendential rise in final energy consumption as well as a reduction of energy intensity has resulted in an increased growth rate of GDP in relation to energy consumption.

Overall, between 2007 and 2013, the Ecuadorian government invested more than 21,000 million dollars in the energy sector, 12,600 million of which went to the hydrocarbon sector, and 4,900 million to electricity. Significant change is expected to take place in coming years: by 2016, hydroelectric production is expected to account for 93% of the national system.

Transportation constitutes the sector with the highest energy demand and fastest growth over the past four decades, rising from an average of 33% of total energy during the 1970s to 52% in the 2000s, and reaching 55.3% of total energy in 2012. Policies in favor of petroleum subsidies have exerted a strong influence on this growth. Base fuels in this sector are most commonly petroleum fuels, particularly gasoline (43.9%) and diesel (42.6%).

Currently, the government subsidy on petroleum fuel represents an investment of $4,594 million USD, of which about $700 million are gas subsidies. This grant allows for the differentiation of Ecuadorian LPG (liquefied petroleum gas) price (compared to the international price); the official price of gas in Ecuador is $1.60 USD, compared to $20.00 USD in Peru and $25.000 USD in Colombia. This has encouraged illegal trafficking of fuel to neighboring countries. Recently, however, the government announced its intention to eliminate this subsidy by 2016.

Given the high demand for this type of fuels, the government of Ecuador has promoted an initiative to increase production under the new Pacific Refinery. This strategy allows for a reduction of costly imports of oil products for internal use, but it does not explore alternative resources which could enable the transition of the country into a post-fossil paradigm within the next twenty years.

With respect to other sectors, it should be noted that the industry sector accounts for 20% of overall energy consumption; the residential sector accounts for 15%, and the rest – commercial, agricultural, construction and others – for 10% of total consumption.

Per capita energy consumption has also increased in recent years, reaching an average of 5.18 barrels per household in 2012. Electrical consumption, per capita, has averaged around 1,273kW per household in 2012.

## *A framework for energy policy in Ecuador*

Developing a framework for energy policy in Ecuador requires an extensive overview of the Ecuadorian Constitution, the National Plan for Good Living, the strategy of the energy matrix transformation, a range of policies in strategic sectors and the electric sector's plans for the expansion of energy infrastructures.

The Constitution of the Republic of Ecuador states that energy, in all of its forms, 'is a strategic sector[6] with decisive economic, social, political and environmental influence' (Art. 313), underlining the need to ensure energy sovereignty (Art. 15, 284, 304, 334) under the criterion of environmental sustainability, as explicitly stated in Articles 15 and 408:

*The State shall promote, in the public and private sectors, the use of environmentally clean technologies and nonpolluting and low-impact alternative sources of energy. Energy sovereignty shall not be achieved to the detriment of food sovereignty nor shall it affect the right to water (Article 15).*

*The State shall guarantee that the mechanisms for producing, consuming and using natural resources and energy conserve and restore the cycles of nature and make it possible to have living conditions marked by dignity (Article 408).*

The National Development Plan (2013-2017), better-known as the 'National Plan for Good Living', describes the energy sector as the 'blood flow of the productive system' and underlines the importance of the transition to a paradigm in which sustainability and open common knowledge are fundamental concepts. To this end, it proposes the 'restructuring of the energy matrix under the criterion of transforming the production matrix, inclusion, quality, energy sovereignty and sustainability, with an increased role of renewable energy' (policy 11.1).[7] Sustainability is a key objective, as stated in Goal 7: 'Ensure the rights of nature and promote regional and global environmental sustainability', which includes the following policies:

*7.7 To promote efficiency and greater involvement of sustainable renewable energies, as a measure to prevent environmental pollution.*

a. Implement technologies, infrastructure and tariff schemes to promote energy savings and efficiency in different sectors of the economy.

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[6] Strategic sectors are those under the exclusive control of the State, being of a decisive economic, social, political or environmental significance.

[7] Policy 11.1 is part of the objective 11 of the National Plan, 'Ensure the sovereignty and efficiency of strategic sectors for the industrial and technological transformation'.

b. Promote research in the sustainable production of alternative and renewable energy.

c. Gradually reduce the use of fossil fuels in transportation and substitute conventional vehicles to promote sustainable mobility.

d. Create an inventory of renewable and non-renewable energy sources, with information about their emissions, incorporating technological alternatives.

*7.10. To implement climate change mitigation and adaptation measures to reduce economic and environmental vulnerability with emphasis on priority groups.*

In addition, the objectives of energy policy are oriented towards the transformation of the productive matrix (Objective 10) and the improvement of the quality of life of the population (Objective 3).[8] Moreover, the strategy for the transformation of the energy matrix emphasizes the importance of increasing the employment of renewable energies in national production. To fulfill this objective, the strategy proposes that the hydroelectric project Master Plan of Electricity be implemented without delay; in addition, it encourages the development of projects in other forms of renewable energy: solar, geothermal, biomass, and wind. As the transportation sector represents the largest consumer of energy, it is essential to focus first on this sector.

The transformation of the productive matrix and the Ecuadorian economy places strategically the pursuit of sovereignty within an international context. Sectors of priority and strategic industries, including renewable energy, are considered key factors for this transformation. According to the National Secretary of Planning and Development, this process should:

- Build new schemes for the generation, distribution and redistribution of wealth;
- Reduce the vulnerability of the Ecuadorian economy;
- Eliminate territorial inequalities;
- Incorporate those actors who have historically been excluded from market development.

Finally, the main plans for the expansion of energy infrastructure and for energy imports and exports include the Master Plan of Electricity (2013-2022), the Plan to Reduce Lost Electrical Power, the Environmental Management Plan, the Plan of Distribution Improvement and the Hydrocarbon Master Plan.

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[8] In accordance with Policy 3.9: 'Ensure access to adequate, safe and decent housing'; 'promote housing construction and sustainable facilities that optimize the use of natural resources and use power generation through alternative systems'.

To sum up, both the Ecuadorian Constitution and the National Plan for Good Living give explicit political support to the transformation of the energy matrix and the production economy to a post fossil fuel paradigm powered by renewable energy resources. Using the above policy objectives as a starting point, the next section of this policy paper puts forth several recommendations aimed at catalyzing this transformation.

## Ecuadorian policy recommendations

The aim of this section is to elaborate on policy recommendations for the transition of the energy matrix to a distributed paradigm. However, before we proceed to the development of specific recommendations, some observations should be made regarding the different components of supply and demand in the energy matrix.

First, it is important to note that an electrical matrix with little diversification represents certain risks, the analysis of which is required to understand the implications of climate change adaptation and its impact on hydroelectric generation, given its ability to change rainfall patterns and watershed temperatures. Similarly, attention should be paid to previous studies which question the rationale for the implementation of large-scale hydro projects. Indicatively, a recent study from Oxford University suggests that in most countries, the cost of building of large dams is too high and the construction periods too extensive to realize positive returns (see Ansar et al. 2014). The authors recommend, especially in the case of developing countries, that public policies be developed that prioritize agile energy alternatives, which use renewable energy resources and which can be built in shorter time-frames, as opposed to mega projects.

In the road-map outlined in IRENA, the economic case for energy transition is reinforced by its potential to mitigate climate change and to contribute to the improvement of health and the creation of jobs (IRENA 2014). A greater presence of renewable energy will make Ecuador less dependent on non-renewable resources and make energy supply more reliable and affordable. The report lays special emphasis on housing: in this respect, it is important to combine the dimension of energy with architecture to ensure maximum utilization.

The transport sector is undoubtedly the primary 'field of action': achieving sustainable mobility requires a profound transformation of the sector, including a drastic decrease in fossil fuel consumption, improved planning, and the promotion of different behavior models. Investment in more efficient transport systems is a means to reduce not only fuel imports but also pollution. To improve freight performance, land use must be analyzed in consideration of modified transportation needs. With regard to mass transport, it is necessary to reflect on alternative economic models which reduce the subsidies on petroleum products, thereby discouraging the use of private vehicles. In parallel, the purchase of fuel-efficient cars and quality transportation options based on alternative energy sources should be encouraged. In urban areas, quality public transport should be promoted, including mass transit means such as electric trams, subways or trolley systems. An analysis of the viability of small electric vehicles such as motorcycles and small cars should also be considered. Furthermore, it is necessary for municipalities to promote bicycling initiatives for local commuting. Another option is to evaluate the introduction of biofuels.[9]

In light of this transition, it is also necessary to reconfigure agricultural production so as to reduce its dependency on fossil fuels and re-orient consumption towards locally produced agricultural products, thereby reducing transportation costs. Without such a conversion, the oil crisis is bound to have a destructive social impact. To mitigate this threat, we recommend such measures as the introduction of ecological practices, the reduction in the use of water, chemicals and machinery and the increase of human labor and endogenous energy sources (biogas, biomass, biofuels) as well as the consumption of locally produced foods (CEDA 2012).

To sum up, an analysis of the present state as well as future potential of the Ecuadorian energy sector will contribute to achieving the objectives of the National Plan for Good Living 2013-2017. This will effectively spur the transformation of the production matrix, thus generating quality jobs throughout the country. An appropriate plan, with a territorial approach, undoubtedly constitutes a strategic contribution to the objective of social and regional development that the National Plan promotes, thus exerting a profound effect on Ecuadorian society. This is of particular relevance in the context of renewable energy, which is identified as one of the five priorities of public investment at the national level, with the aim of providing the country with a base of human and material solidarity that will sustain the long-term vision of the National Plan for Good Living.

Within this policy framework, the following strategic guidelines were developed at the Summit of Good Knowledge ('Cumbre del Buen Conocer') that was held in Quito from May 27-30, 2014, with the support of the National Secretariat of Planning and Development (SENPLADES) and the Ministry of Higher Education, Science, Technology and Innovation (SENESCYT):

1. Define and implement a regulatory agenda for energy efficiency and renewable energy.

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[9] This, however, requires an extensive analysis of its technical and economic feasibility as well as its environmental and social effect in order to ensure its successful implementation.

2. Promote energy efficiency and renewable energy through the transformation of the productive matrix and the implementation of appropriate and appropriable energy technologies.
3. Implement a new paradigm of energy planning and protocols based on social and territorial participation in energy assessment (identification of the needs, capacities and resources, with emphasis on the conservation and use of appropriate technologies).
4. Promote the production, access and dissemination of disaggregated, geo-referenced and open information about the energy system.
5. Democratize the distribution of energy services.
6. Create spaces and mechanisms for joint training, research, innovation and production between state and civil society.
7. Prioritize open knowledge in public procurement programs.
8. Promote reverse engineering projects in Ecuadorian public enterprises so as to generate common and open knowledge in the field of energy.

With a view to implementing and testing the effectiveness of these policy recommendations, the Summit of Good Knowledge proposed the following pilot projects:

1. Design a participatory methodology of energy planning and popular education with a territorial focus: identification of end uses and needs, renewable energy resources, and appropriate/appropriable technologies.
2. Create a network of energy innovation laboratories in which to conjoin education, research, innovation and production: productive spaces and training for the production and use of appropriate, open technology.
3. Use of local biomass: the implementation of an extractive palm oil plant has been analyzed for small-scale use with local agricultural machinery in Quinindé. The plant is powered by the oil provided by a co-op of small organic farmers.
4. Carry out a comprehensive analysis of energy resources: a pilot project in Loja could identify the possible energy sources required to design an integrated energy system and an appropriate management model with long-term sustainability.
5. Implement a 'smart-microgrid' network, with the Galapagos island as a possible geographic location for the pilot project.
6. Electrification of a manufacturing plant for agricultural machinery by a small wind turbine. This project could take place in Sigchos.

As stated explicitly in the section of the National Plan for Good Living on open knowledge and education of the productive sector, one of the immediate challenges is the setting up of an interdisciplinary institution for the development and diffusion of knowledge and products. It is essential to promote innovation and collaboration between institutions of research and intellectual property as well as between various public, private and community organizations.

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# APPENDIX 1 - CASE STUDIES

## *Case study 1: The Kythnos island community project*

Kythnos is a small island in the Aegean sea in Greece. As is typical of islands in general, Kythnos is cut off from the national grid on mainland Greece. It has its own island grid, but this does not however have the capacity to electrify all settlements on the island. Thus, in the framework of two European Commission projects (PV-MODE, JOR3-CT98-0244 and MORE, JOR3CT98-0215), a microgrid was installed in 2001, which has since provided electricity for 12 houses in a small valley that is about 4 km from the closest medium voltage line (Hatziargyriou et al. 2007, pp. 80-82; Tselepis 2010). Being one of the very first pilot installations in Europe, the project has been frequently cited as an example of a cost-effective and environmentally sustainable way of providing a small community with electricity through a model of energy generation at the site of demand using renewable sources.

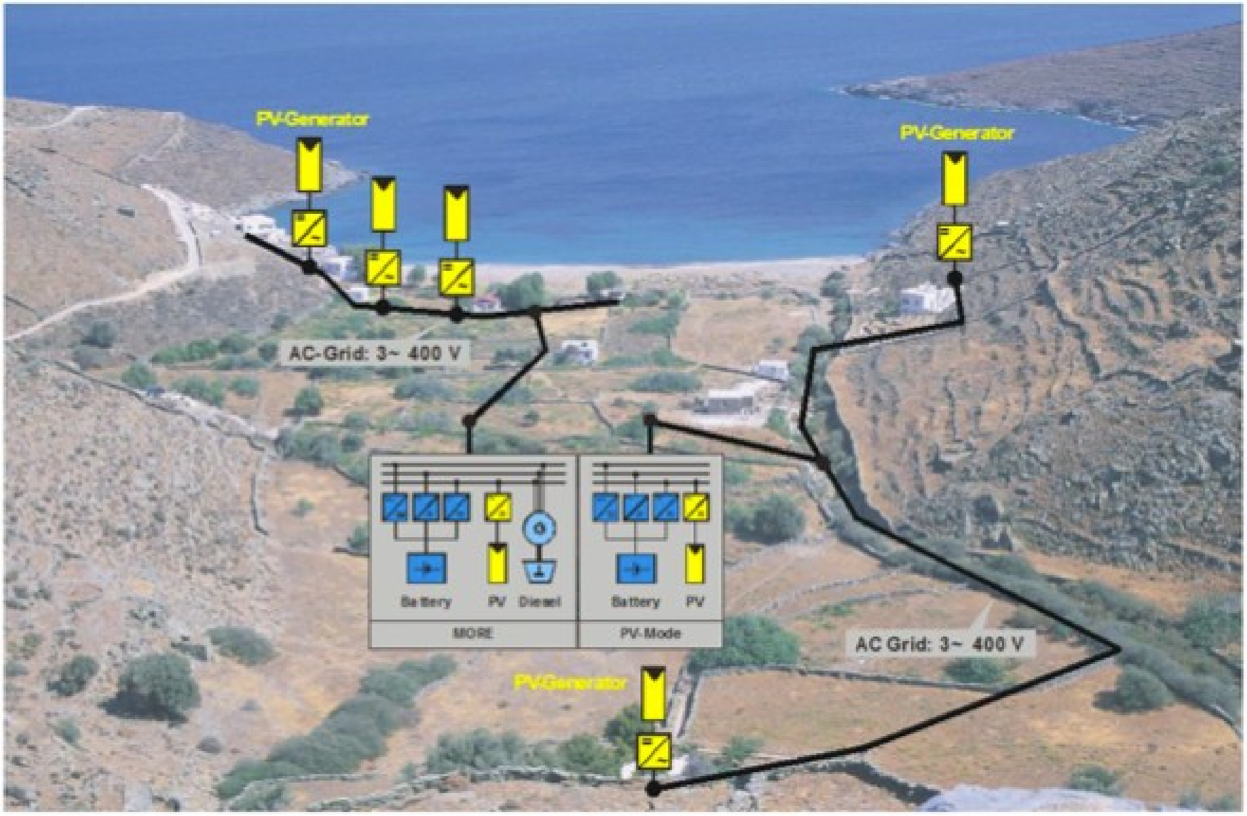

Fig. 1: Kythnos island community microgrid project: supply of 12 houses (R&D european projects: PV-Mode, More Microgrids) (Source: Hatziargyriou et al. 2007, p. 81)

In more technical detail, the roll-out of the project was premised on the installation of a 1-phase Microgrid composed of the overhead power lines and a communication cable running in parallel. The grid and safety specifications for the house connections respect the technical solutions of the Public Power Corporation, which is the local electricity utility. The reason for such a decision was taken on the grounds that in the future the Microgrid might be connected to the island grid. The power in each user's house is limited by a 6 Amp fuse. The settlement is situated about 4 kilometres away from the closest pole of the medium voltage line of the island. A system house of 20 m2 surface area was built in the middle of the settlement in order to house the battery inverters, the battery banks, the diesel genset and its tank, the computer equipment for monitoring and the communication hardware.

The grid electrifying the users is powered by 3 Sunny-island battery inverters connected in parallel to form one strong single-phase grid in a master-slave configuration, allowing the use of more than one battery inverter only when more power is demanded by the consumers. Each battery inverter has a maximum power output of 3.6kW. The battery inverters in the Kythnos system have the capability to operate in both isochronous or droop mode. The operation in frequency droop mode gives the possibility to pass information on to switching load controllers in case the battery state of charge is low as well as to limit the power output of the PV inverters when the battery bank is full.

The users' system is composed of 10kWp of photovoltaics divided in smaller sub-systems and a battery bank of nominal capacity of 53kWh and a diesel genset with a nominal output of 5 kVA. A second system with about 2 kWp mounted on the roof of the system house is connected to a Sunny-island inverter and a 32 kWh battery bank. This second system provides the power for the monitoring and communication needs of the components. The PV modules are integrated as canopies to various houses of the settlements.

To recap, the case of the implementation of the microgrid on the island of Kyhtnos illustrates a model of distributed energy which has enabled a small, isolated community to become energy-autonomous in an ecologically-conscious and sustainable fashion.

## *Case study 2: Distributed energy infrastructures in Nepal based on the use of small-scale, hydropower technologies*

Small-scale hydropower, or micro-hydro, is one of the most cost-effective energy technologies to be considered for rural electrification. It makes use of a local energy resource, which can be usefully harnessed for rural energy demands from small rivers, where there is a gradient of a few meters and the flow rate is more than a few liters per second. It is a clean option based on locally available resources and can be reliable and affordable when appropriate technologies and approaches are used for its implementation, operation and management. It can be economically and socially viable, using local materials and capabilities for installation. Hydro is an option which can generate energy 24 hours a day continuously at its full capacity (if needed), the marginal costs are negligible, and it can thus promote job creation and the productive use of energy for income generation and social development of communities. There are a large number of successful small hydro projects in various developing countries, which show their adaptability to the local conditions, their sustainability and their positive contribution to local development.

Micro-hydro plants (from 5kW to 100kW) basically divert flowing river water, with no significant dams, and use the forces of gravity and falling water to spin turbines that generate power before churning the water back into the river downstream. In these 'run of the river' systems, water is channeled off through small canals and stored briefly in a settling tank to separate sediment, then dropped through a steep pipeline that delivers it into a turbine.

According to the experience of Practical Action (2014) (an NGO inspired by economist Schumacher’s [1973] Small is Beautiful) small hydropower technology is one of the small-scale renewable energy technologies that is most adaptable to local conditions, with great potential for sustainability. Introduced properly and within an appropriate policy framework, it can promote local technology and skills. Small-scale hydro energy schemes can be entirely operated and managed by the community itself, reducing costs and making an efficient use of human and natural resources.

Although companies that specialize in the implementation of energy projects and international consultants claim a relatively high investment cost for this technology, Practical Action (2014) states that projects based on the use of locally available resources and on the adoption of appropriate technologies and approaches, are characterized by a much lower cost. From implementations in Peru, Sri Lanka, Nepal and several other countries, Practical Action has found that for small hydropower systems the cost per kW installed ranges from US$ 1,500 to US$ 3,000 per Unit kW installed, which roughly means an investment cost of US$ 500 to US$ 1000 per connection. Technology research has reduced the cost of small hydro, and the free sharing of technology and know-how (encapsulated, for example, in the design manual for micro-hydro [Harvey 1993]) has created the capacity to manufacture locally much of the equipment. Alternative materials have been developed and skills transferred to local consultants to design and implement hydro systems. Local technicians (at community level) can operate and maintain these systems, and appropriate management and administrative models have been developed to suit local needs. As a result, there are now several countries with the capacity to manufacture and install equipment at very competitive costs. For the smaller hydropower schemes, major cost reductions have been achieved through the use of alternative materials and components, local capacity and skills: at present it is possible to find locally manufactured equipment for micro hydropower at one half, or even one third, of the cost of its imported equivalent. For pico-hydro (below 5 kW), it is possible to find components that cost one third to one fifth of the equivalent imported parts (e.g. synchronous generators, hydraulic governors and others) (Practical Action 2014).

The experience of Practical Action also shows that small hydro can create exceptionally low energy unit (kWh) costs compared to other options. With the appropriate technologies, implementation and management, the cost of a kWh for micro hydro can be as low as about one half of the cost of locally made wind energy systems and about one tenth of the unit energy cost of Solar Home Systems (for decentralized rural application) and finally about one half to one fourth of the unit cost of energy produced with diesel sets.

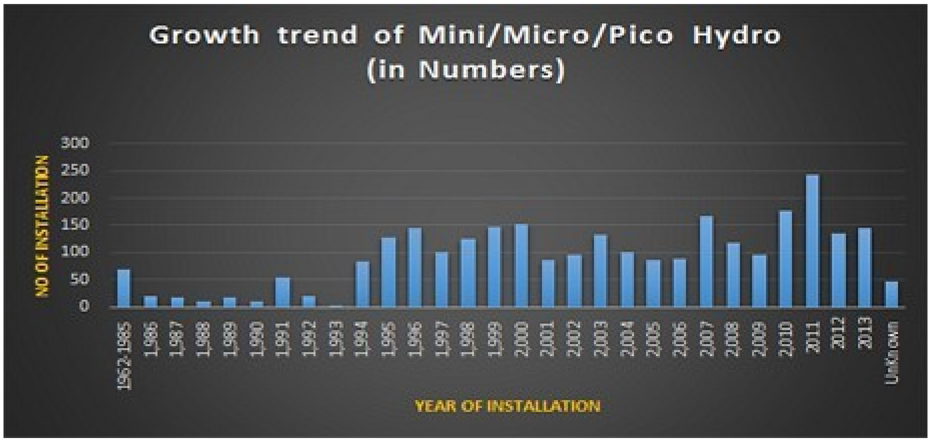

Fig. 2: Growth trend of Mini/Micro/Pico Hydro in Nepal (Source: Alternative Energy Promotion Centre, Government of Nepal Ministry of Science, Technology &

Environment. Retrieved from http://www.aepc.gov.np/?option=statistics&page=substatistics&mid=6&sub_id=50&id=1)

Fig. 3: Micro-Hydro installation in Nepal (left). Training in Nepal (right)

Specifically in Nepal where about 63% of the households do not have access to electricity (World Bank 2010), since the industry’s birth in the 1960s some 2,200 micro-hydro plants have been put into place, totaling around 20MW, which now provide electricity for some 200,000 households (Handwerk 2012). Around 65 private companies provide services related to the implementation of micro hydropower projects under the aegis of the umbrella organization called the Nepal Micro Hydropower Development Association.

The 323 operational RERL (Renewable Energy for Rural Livelihood program) facilities alone now create more than 600 full-time jobs and about 2,600 people have been technically trained on how to operate a facility. But micro-hydro's impact on employment goes further and includes specialized training to help spread electric access benefits throughout the community. Under the program more than 34,000 people, including 15,000 women, have been trained in larger efforts to develop capacity on renewable energy, manage local micro-hydro units and cooperatives, and initiate other environmentally related activities (Handwerk 2012). Similar efforts have been performed in Sri Lanka, Peru, Ecuador and other countries.[10]

In Ecuador a project by ESMAP (World Bank 2005) has undertaken the groundwork to establish the road map for picohydro development by initiating a market assessment for

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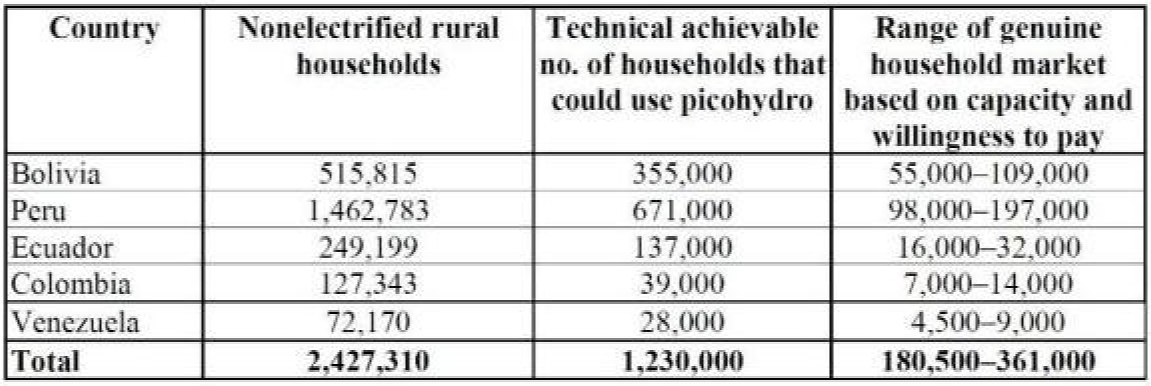
[10] Practical Action (undated) *Up-scaling Micro Hydro: a success story?* Retrieved from http://practicalaction.org/docs/energy/microhydro_scaling_up.pdf

picohydro in the Andean region, by developing technical capacity to install and maintain picohydro systems at demonstration sites, and by helping a small group of businesses see the commercial opportunities arising from the sale of picohydro systems in the country.



| 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** |

Table 2: Market Size for Picohydro in the Andean Region (Source: World Bank 2005)

In conclusion, the following characteristics and benefits of small-micro-pico hydro are supportive of the development of a social knowledge economy:

- Use of local resources and technologies
- Transfer of knowledge to local communities (the knowledge refers not only to operation and maintenance but also to reproducibility, manufacture and technology improvement)
- Local manufacture of several components and local assembly: use and development of appropriate technology
- Building with considerable participation by the beneficiary communities
- Supporting local economy through workshops, installer companies, etc.
- Community management of the infrastructure.

## *Case-study 3: Open source technologies for distributed energy infrastructures*

The Hugh Piggott (HP) small wind turbine (Piggott 2008) (see Fig. 4 below) has been used as the 'reference design' of the open-source small wind turbine developed by the rural electrification research group of the NTUA, since the majority of existing locally manufactured small wind turbines have been based on this design. To this date, three small wind turbines have been manufactured in practical student workshops, two for battery charging and two for grid connection, with rotor diameters of 1.8 m, 2.4 m and

4.3 m. The practical workshops are organized in the context of undergraduate dissertation projects and are open to all students of the NTUA. During these workshops, the small wind turbines are constructed from scratch by the participating students, a process which provides practical evidence of the ability of unqualified constructors to locally manufacture this small wind turbine technology. The educational aspect of these workshops is of significant value and provides a chance to experiment with a variation of learning processes.

Fig. 4 : A locally manufactured small wind turbine following the design manuals of Hugh Piggott (Source: www.rurerg.net)

The design manuals of Hugh Piggott have been a reference guide for locally manufactured small wind turbines worldwide and have proven to be valuable tools in spreading this knowledge, as they have been translated into more than ten languages. It has been estimated that more than one thousand locally manufactured small wind turbines are based on the Hugh Piggott design, many of which are in operation around the world. As rural electrification has been an obvious application of this technology, many NGOs and groups have used these design manuals to manufacture small wind turbines in developing countries,[11] while construction seminars for DIY (do-it-yourself) enthusiasts are organized by several groups around the world.[12] Since 2012, the Wind Empowerment association tries to network most of the organizations involved with locally manufactured small wind turbines around the world, with the aim of building the financial and human resources needed for the activities of these organizations, and performing joint technical research while sharing technical information.

## Open hardware research and development

One of the main advantages of open source hardware designs, and of the 'open design' philosophy in general, is the adaptability of the design. Open-source small wind turbine technology can be adapted to better suit different environments, such as coastal areas with high corrosion.

Another aspect of the adaptability of open hardware designs is the ability to use parts of the design in other open-source technologies and applications. This is the case of the open-source pico-hydro turbine developed in NTUA, which is a hybrid design between the locally manufactured axial flux permanent magnet generator (Piggott 2008) and the locally manufactured small hydro casing and turgo runner designs of Joseph Hartvigsen. The specific design is a grid connected 350W hydroelectric which has been driven with a pump in the labs of NTUA (see Fig. 5 below) with satisfactory results, while a battery charging prototype of the same design has been in operation for one year in a rural site in Greece.

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[11] Solar-Mad (www.solarmad-nrj.com) in Madagascar, Green Step (www.green-step.org) in Cameroon, Wind Aid (www.windaid.org) in Peru, the Clean Energy Initiative (www.tcei.info) in Mozambique, ÉolSénégal (www.eolsenegal.sn) in Senegal, COMET-ME (www.comet-me.org) in Palestine and I-Love-Windpower (www.i-love-windpower.com) in Mali and Tanzania.

[12] V3 (www.v3power.co.uk) in the UK, Otherpower (www.otherpower.com) in the US, Tripalium www.tripalium.org in France, Nea Guinea (www.neaguinea.org) in Greece and ESCANDA www.escanda.org in Spain.

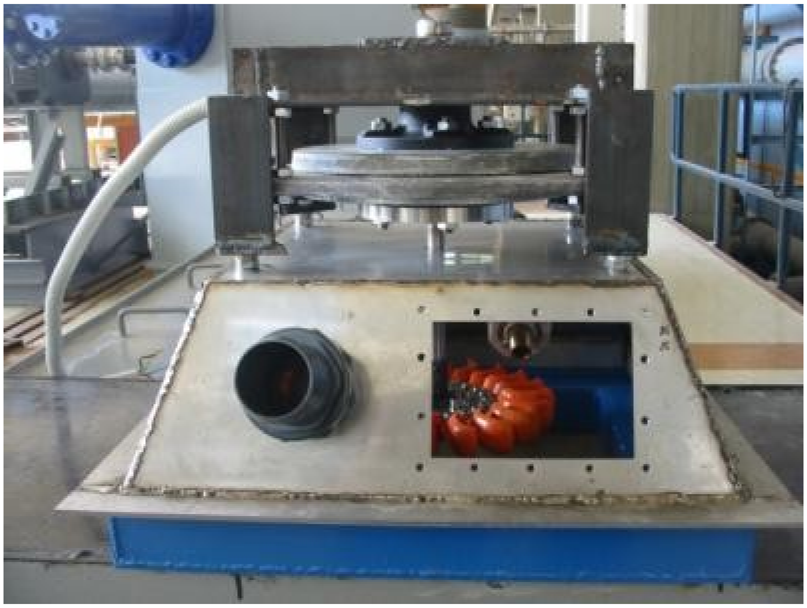


Fig. 5 : Open-source pico-hydroelectric developed in NTUA (Source: www.rurerg.net)

## Case-study 4: Low cost Biodigesters in Latin America

Organic waste from livestock can be turned from a problem of waste management for a small farmer into a means of local production of energy in the form of biogas and organic fertilizer for agriculture. This can be achieved through a process of anaerobic digestion. Biogas can be used as fuel for cooking, heating or lighting. In large installations biogas can also be used to power a motor that generates electricity. The organic fertilizer that is produced as a byproduct of the process can be used in agriculture to greatly increase crop yield.

Although many types of anaerobic digesters exist, this case study focuses on the low-cost polyethylene tube type (Fig. 6), as it is an appropriate technology for small farmers: it requires a low cost of investment, is simple to operate, requires little maintenance and is accessible to both small and large producers.

In rural areas, burning wood in open fires in order to cook, is a typical cause of illness for women and children, a cause for deforestation and for the expenditure of labor (during wood collection). By contrast, using biogas for cooking does not result in the emission of dangerous fumes. Also, the amount of work required for loading the digester with manure and water is significantly smaller. Furthermore, the use of organic fertilizer can increase crop yield and reduce farmers' dependency on chemical fertilizers and their farming expenses.

Fig. 6 : A locally manufactured biodigester with a low cost polyethylene tube in Costa Rica (source redbiolac.org)

Low cost digesters have been implemented in developing countries since the 1980s. They were first designed by Pound in Taiwan in 1981. Based on that design, the flexible tubular continuous flow digester, initially designed by Preston in Ethiopia, Botero in Colombia (1987) and Bui Xuan An in Vietnam (1994), adapted the digesters for tropical climates. In 2003 Martí-Herrero Botero's design adapted the digester to cold climates in the highlands of Bolivia, adding a greenhouse (Fig. 7) with adobe walls with high thermal inertia and insulation from the ground using local materials. This technology is accessible in countries such as Colombia, Ethiopia, Tanzania, Vietnam, Cambodia, China, Costa Rica, Bolivia, Peru, Ecuador, Argentina, Chile, Mexico, among others.

Fig. 7 A greenhouse to stabilize and/or increase temperature (Source: http://www.dswtwildernessjournal.com)

To produce enough organic fertilizer and biogas for a family, a biodigester requires roughly 20kgr of manure per day. This can be produced either from two or three cows, one or two dozens of sheep or less than ten pigs. Access to water is also necessary, though that does not have to be potable. For a small farmer with access to those resources, a biodigester could produce the following benefits:

- **Biogas:** Biogas can be used for cooking (Fig. 8), lighting and heating and is mostly methane gas, similar to butane or propane gas sold in cylindrical containers.
- **Fertilizer:** The organic fertilizer (which, as a byproduct of the process, is free) is a natural fertilizer that improves crop yield up to 30%. It can be used directly on the ground as a pretreatment for soil. It can be also used to increase the production of valuable grazing plants and enhance milk production.
- **Health:** When one is burning wood in open fires for cooking, the kitchen is covered with black soot. Combined with the fumes, this can cause respiratory diseases to women and children working in the kitchen. By contrast, such fumes are not emitted when burning biogas.
- **Pests:** When animal manure enters the digester, odors and flies – a frequent cause of infection – are eliminated. A decline in the population of flies in the farm is directly correlated with a reduction of mastitis in cows.
- **Deforestation:** When each small farm is generating its own fuel for cooking, then it is no longer necessary to cut firewood from nearby forests.
- **Workload and economics:** The number of working hours expended by family members for the collection of wood is significant and mostly shouldered by women and children. Also the amount of money spent on the procurement of gas can be a significant expense for a rural family, despite the fact that gas prices are subsidized by the state in many countries. On the other hand, twenty minutes per day are enough for loading the digester with fresh manure and water.
- **Sustainable appropriate technology:** This is a simple technology which can be accessible to anyone without prior (theoretical or practical) experience. All that is required is to install a digester with the help of a manual or a practitioner in order to understand the technology, its operation, maintenance and repair process. All materials can be sourced locally from the market,

without requiring any materials to be ordered from abroad.

- **Low investment:** The cost of a digester depends on family size and climate conditions. In cold climates, the cost of materials is about 250 US dollars, while in tropical climates it is about 150 US dollars. It takes two to three years to recover the investment, due to the savings in fuel costs, time and improved agricultural production.

Fig.8: Biogas for cooking (source redbiolac.org)

Such projects have been implemented in Asia, the SNV Netherlands Development organization has driven major national programs in Blangladesh, Camboia, Nepal, Vietnam, Indonesia, and other countries. China and India have their own national programs while in Africa, the SNV Netherlands Development Organization and German Society for International Cooperation (GIZ) are promoting programs mainly in Tanzania, Kenya and Rwanda. In the countries of Latin America and the Caribbean, where no national programs exist yet, many organizations and individuals have set up projects in Mexico, Honduras, Nicaragua, Costa Rica, Cuba, Colombia, Ecuador, Peru, Bolivia and Brazil. In Bolivia in particular, the EnDev-Bolivia project for "Access to Energy" run by the GIZ, is currently the largest project in Latin America on biodigesters. Aside from raising public awareness around the benefits of biogesters, the project, which has installed more than 400 of them in recent years, is running the 'Centro de Investigación en Biodigestores Biogas y Biól (CIB3)' research center and is offering training courses on designing digesters and social project management.

The 'Red de Biodigestores para Latinoamérica y el Caribe (REDBioLAC)' is another noteworthy project which brings together various institutions involved in the research, development, dissemination and implementation of low cost biodigesters in nine Latin American countries. Its members include manufacturers of digesters, NGOs, research centers and universities that share common goals such as:

- The sharing of information and experiences among the participating institutions in RedBioLAC.
- To identify and overcome technical, environmental, social and economic barriers.
- To suggest projects, mechanisms and ideas for spreading the low cost biodigester technology in other countries.
- To build partnerships that facilitate the adoption of biodigester technology.
- To systematize research and dissemination among partners (Health, Finance, Politics, Education, Industrialization and Commercialization).
- To promote the involvement of other organizations, institutions and researchers in the field of biodigesters.
- To encourage actions that influence policies related to biodigester technology.

REDBioLAC is operating a Spanish-language forum on its website as a platform of information sharing about the technology, with hundreds of members. Also, the network organizes an annual conference, with a view to sustaining the impetus of the knowledge sharing process.

# APPENDIX 2 – DEMO PROJECT

## *A Community Microgrid for Rural Electrification from Renewable Energy Sources*

The microgrid topology can be used either in off-grid or grid connected applications. In a typical off-grid application all the energy needed to power the consumer loads is provided from renewable energy sources while the battery bank is charged in order to store sufficient energy for periods when the consumed energy will be greater than that produced. In the grid connected case, the microgrid operates in a self-consumption mode where the energy transactions with the grid are minimized. In this case the microgrid power management system intends to minimize the amount of power taken from the grid, thus resulting in a high percentage of the power being provided from renewable energy sources, but not 100%. Consequently, the battery bank of the microgrid can be of less capacity since the grid itself acts as a means of energy storage.

Fig. 9: A rural microgrid (Source: www.sma.de)

### Electrification of rural household facilities

A microgrid can be used in a typical rural village of 20 households in the global South. The loads considered for each household are shown in Appendix 3 along with their daily hours of usage. Where possible, communal spaces for refrigeration and laundry can be used in order to reduce the total cost of individually purchased refrigeration and laundry equipment as well as their overall power and energy consumption. The same goes for multimedia equipment and communications, where communal home cinema and internet spaces will be more cost and energy effective. For the communal refrigeration, laundry, multimedia and communication loads, see Appendix 3.

## Electrification of manufacturing facilities for open source agricultural machines

In addition to providing electricity for households and refrigeration, laundry, multimedia and communication services, a microgrid based on renewable energy sources can provide the power and energy to operate workshop facilities for the local manufacturing of open-source agricultural machines, such as those prototyped by the Open Source Ecology project, which can assist in the everyday life of rural families. The loads considered for such a workshop are shown in Appendix 3 along with their daily hours of usage.

Fig. 10: Lifetrac from Open Source Ecology (Source: http://www.opensourceecology.org)

## Electrification of educational-training facilities

Educational facilities can assist in the wider dissemination of the microgrid electrification unit and in the production of open-source farm machines. Such educational facilities can also be used by the children of the local community. The loads considered for the educational facilities are shown in Appendix 1 along with their daily hours of usage.

## Dimensioning of the microgrid system

Depending on the available renewable energy sources, a hybrid system solution will be adopted, as analyzed in Appendix 3. A cost estimation of such a microgrid system based on a solar solution would amount up to 66,500 Euros, using a hybrid wind/solar solution up to 50,000 Euros and using a pico hydroelectric solution with a battery bank up to 34,500 Euros.

## Appendix 3

| Loads | Number | Power (W) | Hours | Energy (Wh) |
|---|---|---|---|---|
| Light | 3 | 20 | 5 | 300 |
| Radio | 1 | 70 | 3 | 210 |
| Mobile phone | 2 | 5 | 3 | 30 |
| Total | | 135 W | | 540 Wh |

Table 3: Consumer loads in a rural household

As shown in Table 3, a total of 2.7kW of instantaneous power will be required for 20 households, 85% of which will probably be needed in reality and a total of 10.8 kWh of electrical energy will be required for the consumer loads in all rural households on a daily basis.

| Loads | Number | Power (W) | Hours | Energy (Wh) |
|---|---|---|---|---|
| Freezer (300lt) | 4 | 200 | 5 (on and off) | 4000 |
| Refrigerator (200lt) | 3 | 200 | 5 (on and off) | 3000 |
| Washing machine (90lt) | 2 | 750 | 1 | 1500 |
| Home cinema with PC | 2 | 600 | 2 | 2400 |
| Satellite dish and router | 1 | 40 | 20 | 840 |
| Total | | 4140 W | | 11740 Wh |

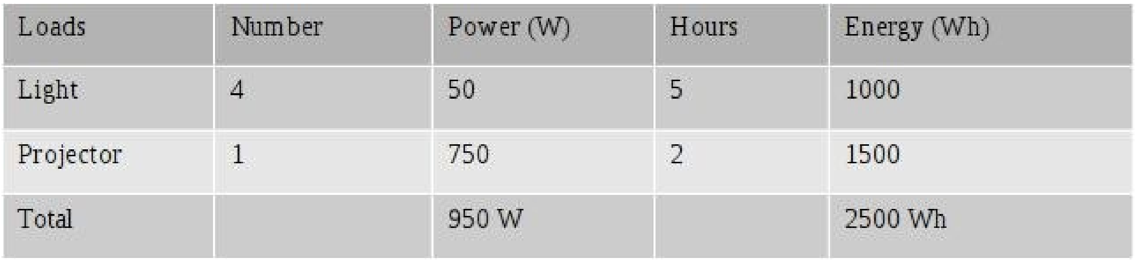
Table 4: Consumer loads in communal spaces

As shown in Table 4, a total of 4.1kW of instantaneous power will be required for communal spaces, 85% of which will probably be needed in reality, and a total of 11.7kWh of electrical energy will be required for the consumer loads in communal spaces on a daily basis. In total 5.9kW of instantaneous power will be needed and a total of 22.5kWh of electrical energy.

| Loads | Number | Power (W) | Hours | Energy (Wh) |
|---|---|---|---|---|
| Light | 4 | 50 | 5 | 1000 |
| Drill press | 2 | 750 | 2 | 3000 |
| Lathe | 2 | 1500 | 2 | 6000 |
| Arc-Welder | 2 | 2500 | 1 | 5000 |
| Band saw | 2 | 750 | 2 | 3000 |
| Milling machine | 1 | 750 | 2 | 1500 |
| Total | | 13750 W | | 19500 Wh |

Table 5: Loads for manufacturing facilities of open source agricultural machines

As shown in Table 5, a total of 13.8kW of instantaneous power will be required for the workshop, 85% of which will probably be needed in reality, and a total of 19.5kWh of electrical energy will be required for the workshop on a daily basis.



| Loads | Number | Power (W) | Hours | Energy (Wh) |
|---|---|---|---|---|
| Light | 4 | 50 | 5 | 1000 |
| Projector | 1 | 750 | 2 | 1500 |
| Total | | 950 W | | 2500 Wh |

Table 6: Loads for educational/training facilities

As shown in Table 6, a total of 0.95kW of instantaneous power will be required for the educational/training facility, 85% of which will probably be needed in reality, and a total of 2.5kWh of electrical energy will be required for the educational/training facility on a daily basis.

Depending on the available renewable energy sources, a hybrid system solution will be adopted. Considering the off-grid case and if only solar energy is used, then a total of 18kW of solar panels will have to be installed, possibly in three rooftops where on each roof 6kW of solar panel will be installed, and then each set will be connected through a 6kW inverter to the AC grid. In the case that running water is available throughout the year with an adequate head and flow, then a run-off-river pico hydroelectric plant could be installed with maximum power of 2kW. In the case of a good wind resource (at least 4-5m/s annual mean wind speed), a hybrid wind and solar system could be designed where the solar panels would be reduced to 9kW with two 5kW inverters to connect to the grid and two 4.2m diameter small wind turbines would be installed and connected to the AC bus with inverters and diversion loads.

In the case of an off-grid system based exclusively on solar energy, the flooded lead-acid battery bank will need to be able to store a usable capacity of 44.5 kWh, which will typically imply an overall capacity of 133kWh for a daily depth of discharge of 30%, thus resulting in a typical battery life of ten years. In a 48VDC system, this will imply 48 2V batteries in two parallel branches of 24 each and of 1350Ah capacity each. In the case of the off-grid hybrid solar and wind system, the battery capacity could be reduced by 20% because the wind turbines could be operating during nighttime. In the case of a pico hydroelectric system, the battery bank could be reduced by 50% or even not used at all.

In the case of a grid-connected system with self-consumption, the total installed capacity of renewable energy sources as well as the storage capacity of the battery bank can be reduced, since any excess energy will be sold to the grid and any energy required will be bought from the grid, thus reducing the total cost of the system significantly, though the dependency on fossil fuels will be increased.