Energy Contribution to Sustainable Rural Livelihoods in Developing Countries: A System Dynamics Approach

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Abstract

Access to energy, particularly through clean and modern technology, can make substantial contributions to promote rural development particularly in poor areas of developing countries. However, the relationship between energy, poverty alleviation and sustainable development is still unclear. Also, while improving access to energy is necessary for development, the way that this has been undertaken has not always warranted a sustained livelihood in rural areas.

With the purpose of gaining a better understanding of the relation between energy and development, the current research project "Renewable Energy for Sustainable Livelihoods-RESURL", aims to evaluate and measure the factors that contribute or hinder the development of efficient, viable and appropriate access to energy provision in remote rural areas by using a multidisciplinary and participative perspective.

A System Dynamics model is constructed to evaluate the contribution of energy to rural livelihoods. SD modeling facilitates understanding feedback and control processes, as well as delays in decision making. Simulations show how isolated communities in conditions of poverty could attain a satisfactory level of human, social, physical and financial development by making sustainable use of their natural resources through energy technologies. The study draws on the sustainable livelihoods approach as a framework for assessing community assets and capacities.

1. Introduction

Large grid electricity infrastructure has been expanded to rural areas in the developing world in recent decades. Additionally, off-grid solutions have been brought to areas where the grid does not reach. However, billions of people particularly in poor rural areas still remain without access to clean and modern sources of energy. Energy provision, particularly through off-grid renewable energy systems, represents an important step for reducing the electricity gap in rural parts of the developing world (Takase, 1997). Yet successful service expansion to un-served rural areas has remained unclear and badly planned. Despite the fast acceptance of the technologies, particularly photovoltaic, and interest of governments and others in expanding off-grid solutions to rural areas (e.g., Byrne *et al.,* 1988; DEP, 2002), progress in planning and development of assessment methods remains slower than decision-making and actual expansion and implementation. Ghosh *et al.* (2002), making reference to India, believe that renewables were promoted as a panacea to the energy problems. They point out that doing ‘too much too soon’ resulted in unrealistic expectations leading to failures. In some cases, they argue, poor technology selection led to equipment malfunction (Ghosh *et al,* 2002). After more than twenty years of electricity expansion in rural areas it is now clear that un-intended discrepancies exist between the possibilities of the technology and the final outcomes in terms of positive and long-term effects on the communities.

Different forms of energy play an important role on human beings and have been considered symbols of development. Development agencies have shown that levels of wellbeing, progress and growth are associated with levels of consumption and energy demand (e.g., PNUD, 2003; World Bank, 2003a; World Bank, 2003c; Calleja 2003). Yet, despite that government and international aid organizations have made substantial investments in projects to provide energy to communities of isolated rural zones (IRZ). In practice, it has been observed that communities have not received the expected benefits (OPET, 2003; Calleja, 2003; Cherni, 2003).

Sustainable Livelihoods (SL) is a way of thinking about targets, possibilities and priorities of development in order to accelerate progress in the eradication of poverty (DFID, 1992, 2003; Scoones 1998; Ellis, 2000). SL is relevant for this study because it addresses the fundamental questions of what institutional mechanisms allow the poor to achieve a sustainable livelihood, while others fail, and what policies and strategies can serve as support for those people who live in poverty (FAO, 2003).

The added value of the SL concept is that it focuses on poverty reduction in a sustainable manner because it aspires to construct a link between macro-policies and micro-realities and vice versa. It starts from an integral approach to environmental, social and economical themes, with the aim of achieving sustainability on the medium and long term.

With the aim of reaching a better understanding of the relationship between energy provision and poverty reduction, through establishing a comparison between theory and practice, this paper presents a study of the effect that forms of efficient energy implementation can have in remote rural areas.

2. Energy provision and rural development

Drawing on definitions provided by the Sustainable Livelihoods approach, it is possible to establish that “livelihood” comprises possibilities, assets (which include both material as social resources) and the necessary activities to earn a living (Cherni and Hill, 2005). A livelihood is sustainable when it can take tensions and shocks and recover from them and, at the same time, maintain and improve possibilities both for the present and for the future without damaging the existing natural resource (DFID, 2003; FAO, 2003). Up to what point rural electrification has been seriously considered central to improve livelihoods, reduce poverty and achieve development is still debatable. Nevertheless, after substantial electrification programmes were completed in developing countries in the 1970s and 1980s, about 2 billion people —one third of the world’s population— continue to live without electricity (World Bank, 1996), which means that they depend entirely on traditional forms of energy and therefore, do not have the opportunities available through the new forms of energy (PNUD, 2003). The sources of traditional energy include biomass (wood, charcoal and manure) and human and animal energy, while modern sources of energy include sources such as kerosene, diesel and electricity (WEC, 1999).

In spite of the generalized use of traditional energy in rural areas, these patterns of consumption have serious implications for rural development (WEC, 1999).

The pressure for social development has increased the identification and implementation of strategies for rural energizing that may accelerate the transition from traditional energies to modern energies in rural areas. The search for these strategies is based in addressing particular dimensions:

• Realistically in the short term and probably in the medium term, the chances of eliminating the dependence of the majority of the rural population on traditional energy sources, particularly wood, are scarce. Given that the use of biomass in developing countries will continue for sometime, energy policies must encourage the more efficient and sustainable use of bio-combustibles, while at the same time the conditions are created to provide modern combustibles to those who lack them (Bames et al, 1997).

• The use of traditional sources of energy is not in itself undesirable but rather, it is their management that usually requires attention. It is more a problem of technologies rather than resources. Thus is the importance of the modern appliances that are capable of making more efficient and economical use of fuels than the traditional ones.

• Any transition from traditional sources of energy to modern must be gradual and consistent with structural changes in the rural economy. Many rural areas cease being so and therefore change their patterns of energy consumption.

The main use of energy in rural areas is domestic and at 85%, the most widely used energy continues to be traditional, in spite of its negative impact on sustainable livelihoods. Renewable energies are a good alternative to solve the problem of rural energizing because they satisfy the objectives of economic and social development with positive and tangible effects in regional development and on employment with additional benefits on the environment.

3. Local resources and energy provision

The paper draws on the concepts of SL and its associated notions - assets or capitals - in order to review the major impact of energy on livelihoods. Our main objective here is to be able to identify a baseline of the community endowments but first we turn to explain the five capitals associated to the SL concept.

Natural Capital. This refers to the portions of natural resources (land, forests, wild and marine resources, water, air quality) from which are derived the flows of resources and services (for example, cycles of nutrients, protection against erosion, assimilation of wastage, protection against storms, diversity degree) which are useful in terms of livelihood. Natural Capital is very important for those who obtain all or part of their livelihood from activities based on natural resources (cattle rising, fishing, wood cutting, mineral extraction, etc,) (DFID, 2003). Natural capital is usually one of the most abundant capitals in isolated zones. However, the poor frequently lives in deserts, arid or infertile areas. The main natural capital of poor people is biomass (wood, branches, leaves, crop residues, manure) which can be used as fuel. Peasants in rural zones assume wood as a free natural resource and use it for cooking and illumination with an impact both on the environment and on their health. However, the continuous consumption of biomass need not exhaust environmental resources if one takes into account the agro-silviculture and forestry management programs in which peasants themselves take part. (Barnes et al, 1997).

In some cases coal and peat are also natural resources of poor people. The access to these natural resources is affected by many factors (for example, land property, climate) and its sustainability is not only affected by its use as a combustible but by changes in the use of land (combustible is less available when land is used in the production of food) (Barnett, 2001). These changes can increase the exploitation of natural resources, such as forests, increasing the competition for land and resources (Barnett, 2001).

Another energy source related with natural capital includes water falls, wind and solar radiation. However, these sources require other forms of capital to convert them into useful energy.

Improving energy can help reduce emissions, protecting the local and global environment; the efficient use of energy sources and good management can help in the sustainable use of the natural resources and the reduction of deforestation (DFID, 2002b).

Social Capital. This refers to social resources in which populations support each other in the search of their objectives in terms of livelihood. These are developed through the following: a) Networks and connections, b) Participation in more formal groups and c) Confidence relations, reciprocity and interchanges which facilitate the cooperation, reduce costs of transactions and provide the base to create security networks between those less privileged. The networks and social relations frequently determine the access of individuals to natural resources (who can collect combustibles), the access to the technology of conversion of energy possessed by others (grain mills, cooking ovens, machines to prepare the soil, water irrigation pumps), the access to other people's skills (electricians, repairmen) and information regarding technical (and managerial) alternatives (Barnett, 2001). Political decisions are those that determine development and at the same time the expansion and coverage of rural energizing (Unión Temporal Icontec-AENE, 2003).

Researches who analyze development have shown that some countries and communities use all their productive resources (human, physical, and natural capital) in a more efficient way than others and, therefore, obtain better results. The difference between them lies in the way people interact, cooperate and solve their conflicts, that is in the Social capital of a community (World Bank, 2003a).

Local participation is essential for the success of rural energy policies. Cooperatives, NGOs, and communal organizations can be very efficient means to contribute to the provision of energy services and the management of energetic resources (Barnes et al., 1997; Gallo, 1995). Where it is not possible to establish a minimum level of lawfulness and order it is difficult to find and efficient performance of projects and programs. A good performance of projects is also associate with civic rural societies (organizations, networks, networks of civic participation and shared spaces) to create confidence between citizens and their institutions (Machado, 1998).

Human Capital. It represents aptitudes, knowledge, labor skills and good health which on the whole allow populations to take on different strategies and achieve objectives in terms of livelihood. Human capital can be increased investing in education, health care and training for work (World Bank, 2003a). Modern energy services improve the live of poor people in uncountable ways, reducing the time women and children spend in basic survival activities such as collecting wood and water, cooking, etc. (DFID, 2002b).

Electric light lengthens the day, providing hours for reading and working besides introducing the use of educational means of communication in schools (including information and communication technologies) (DFID, 2002b). The access to energy requires abilities in many aspects related with the provision of energy (for example, people with knowledge about electric installations), thus contributing to the generation of formal and informal employment in the construction, maintenance and provision of energy services.

The modern forms of cooking protect women from the daily exposition to smoke, refrigeration allow local hospitals to conserve basic medicines (IEA, 2002), sterilize equipments, which in turn reduces the mortality of infants and mothers and the occurrence of illnesses (DFID, 2002b). With energy, pumped access to drinkable water improves. Clean water and food, in turn reduce hunger (DFID, 2002b) and improves quality of life.

Interventions show that any change in the sources of energy used must take into account the needs of families, their acquired knowledge, the family size, and their preferences, activities and believes. Both men and women must be involved at all stages in the identification of requirements and, in general, in any decision related with the type of energy for their families (North, 2002). Some important points that must be taken into account in the planning of energizing are the following (North, 2002):

- Lack of knowledge regarding energy alternatives.
- Family size. It could be that the amount of food required for a large family for a large family cannot be cooked in available stoves.
- Food preferences. It includes the types of food preferred by families and the consequences in terms of stove size and necessary fuels.
- Attitudes and believes. The use of more efficient of sources energy will have a high social impact on families. The time spent by women collecting wood will also be reduced.

Physical Capital. This includes the basic infrastructure and production goods necessary to support livelihoods. Infrastructures consists in the changes in the physical surrounding that contribute to populations obtaining their basic needs and to become more productive, such as, accessible means of transport, adequate housing and buildings, provision of water and sanitation, clean and accessible energy and access to information (communications). Production goods are the tools and equipment that populations use to function in a more productive way. (DFID, 2003). The introduction of energy infrastructure and the provision of energy services, though they may seem to have a positive impact, do not automatically bring economic development. In the language of Sustainable Livelihoods, acquiring physical capital (in the form of energy), though it helps, does not necessarily leads towards building more Physical, Social or Human Capital and, specifically, does not lead directly towards building Financial Capital. That is, Physical Capital does not impact directly in the livelihood strategies, neither is there any guarantee of a significant impact on the reduction of the vulnerability context. (Wilkinson, 2002).

Isolated zones have many infrastructure problems. They lack water, energy, sewage, housing, roads, etc.

- Access to energy sources (electricity) and combustibles (fossils and biomass) (Barnett, 2001).
- The access to energy requires converting energy in useful forms, particularly in technologies of final use such as stoves, lamps, machines, radios, etc. (Barnett, 2001).
- Production technology allows substituting people's heavy work (Barnett, 2001).
- Transportation services depend on access to trustworthy and reasonable prices for combustibles (Barnett, 2001)
- The physical environment (rural or urban).

Financial Capital. It refers to the financial resources that populations uses to achieve their objectives in terms of livelihood. The two principle sources of financial capital are available funds or savings (cash, bank deposits or liquid assets such as cattle or jewelry) or loans and regular income (pensions and other payments by the state or money transfers). In developing countries the main sources of energy are wood, residues from crops, manure, animal and human energy. More intense contributions of energy are necessary to obtain greater productivity and income (Gallo, 1995), thus incrementing the Financial Capital.

The access to energy services facilitates economic development with the possibility of creating micro-firms, the development of maintenance activities beyond day light hours and local businesses which create employment (DFID, 2002b). Modern energy can contribute directly to the reduction of poverty incrementing poor countries' productivity and extending the quality and offer of products (IEA, 2002).

Cheaper and more convenient fuels (and the associate conversion technology) increase productive labors and diminish the costs of production and the prices of products (Barnett, 2001).

It is often the case that the poor does not have financial capital to make the transition from traditional sources of energy to modern sources, besides not being able to save considerable amounts of money for future purchases (North, 2002).

In developing countries, initial costs of access to modern sources of energy are often prohibitive for poor rural populations who, in general, cannot obtain credit either (Barnes et al., 1997)

Farmers spend considerable amounts of money on candles, kerosene and batteries to illuminate their houses (Barnes et al., 1997) and, besides, people are prepared to spend an important part of their income on superior energy in order to improve their quality of life and their productivity (Barnes et al., 1997).

If poor families in developing countries gradually increase their income, they could have more modern electrical appliances and would therefore demand more and better energy services (IEA, 2002). This situation is shown in the Energy Stairway (Figure 1) which represents the types of fuel that households could use in response to increments in their prosperity. A typical Energy Stairway for cooking is to go from traditional fuels, i.e., manure, crop residues, wood, charcoal and coal, to modern fuels, i.e., Kerosene, GPL and electricity. The order of fuels shown in the Energy Stairway responds to increase in technological efficiency, diminishing CO_2 and SO_2 emissions and particles and increases in capital costs (Meikle and Bannister, 2002).

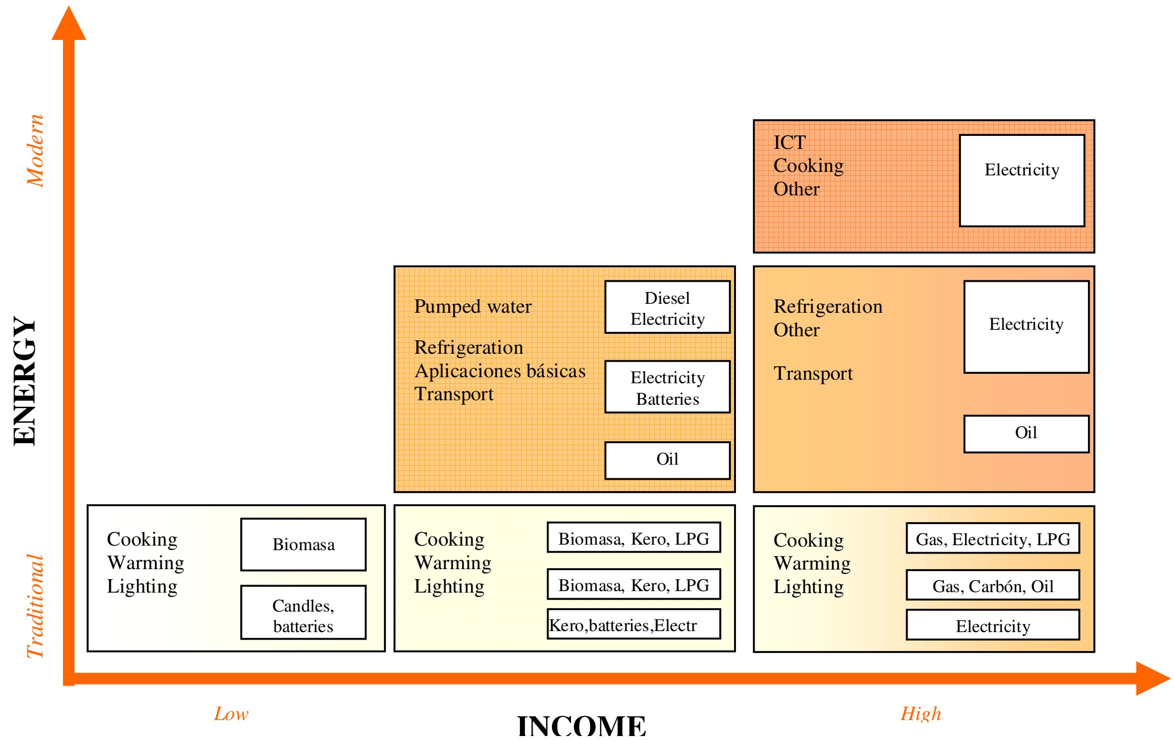

Figure 1. Energy Stairway, according to income. Source: IEA Energy-Income

[Cooking, Heating, Lighting, Water pumping, refrigeration, basic applications, other applications, transport]

Given the conditions of poverty and the poor level of quality of life in relation to health, education, drinkable water, and housing, there is a tendency to give greater priority to social programs rather than productive projects. With that, rural societies lag behind in the possibilities of conforming small centers of economic accumulation which will lead them within dynamical paths of growth (Machado, 1998).

The following sections discuss the systems dynamics modeling approach that seeks to establish the effects of applying energy technology options in poor and remotely located communities. This method can account for the evolution of community assets in the long term. Initial energy provision can unfold on positive effects on human and social development. More human and social development in a community may well lead to larger levels of electricity consumption, which, in turn may affect the physical, financial and natural capitals in the community. From a perspective of multiplicity of influences and feedbacks, the modeling based on System Dynamics seems a most appropriate approach to establish possible community evolution. In the following section, a System Dynamics model is constructed that can bring into account the most important aspects of these possible evolutions.

4. Application of a system dynamics approach to the problem of rural energy provision

We have established that poverty in rural communities can be a crucial factor that reduces substantially the extent of both, energy demand and supply. We argue that this situation cannot reduce poverty because it leads to vicious circles of poverty traps as represented in Figure 2 by the three positive cycles. If one manages that demand pulls off the supply, we would break these vicious circles and for this is required the determination and aspirations of the community.

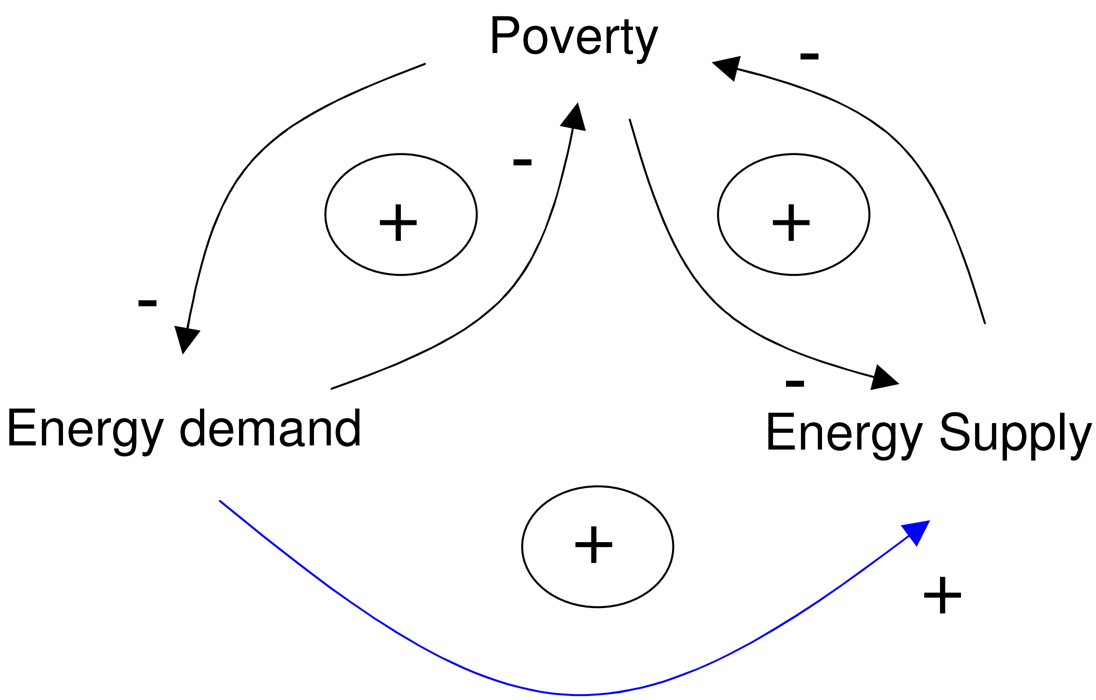

Figure 2. Vicious circle of poverty trap

[Energy demand — Energy supply — Poverty]

Nevertheless, development proposals, welcomed or promoted within communities such as those inspired in the previous analysis of sustainable livelihoods, contribute to reinforce the productive use of energy on the part of the community. Figure 3 illustrates this in a clear way.

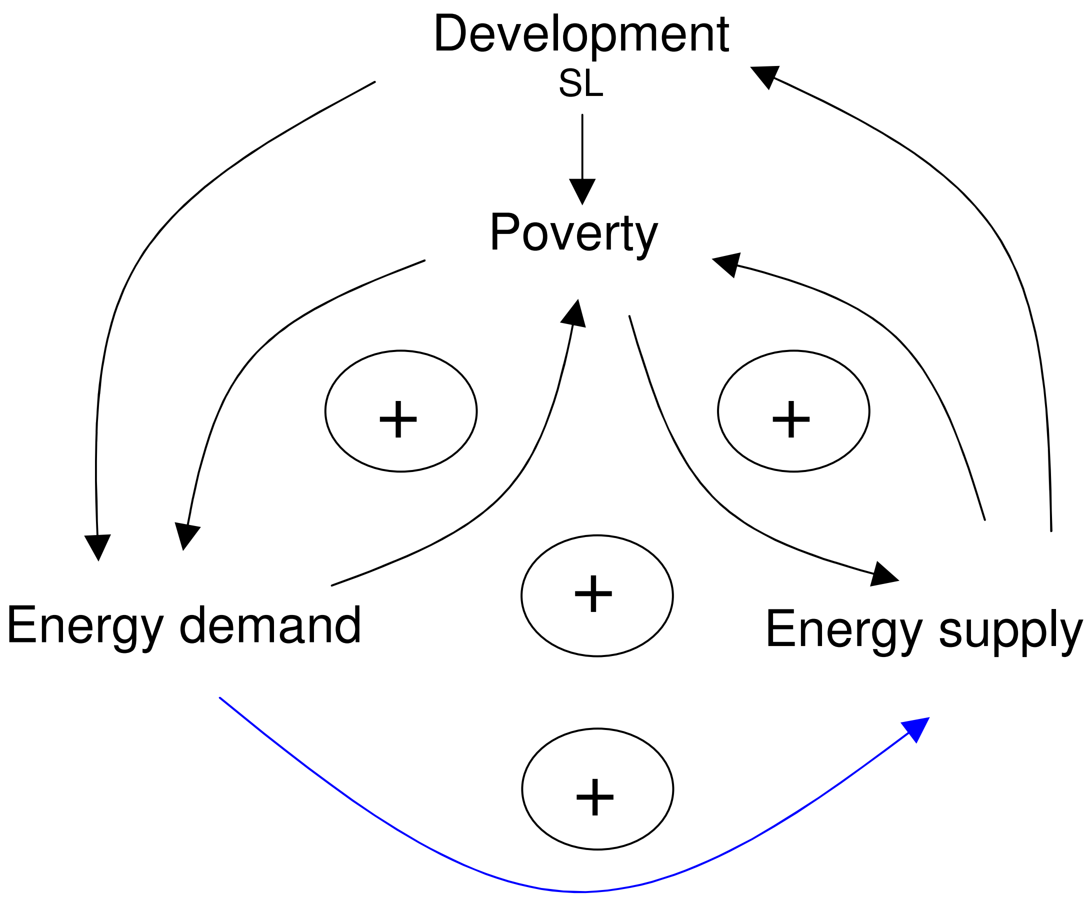

Figure 3. Sustainable Livelihoods as a means to reinforce development and energy use

Sustainable livelihoods imply that the requirements of energy for productive use on the part of communities arise as far as possible from renewable energy sources (due to the principle of ecological sustainability). Figure 4 illustrates this hypothetical dynamics.

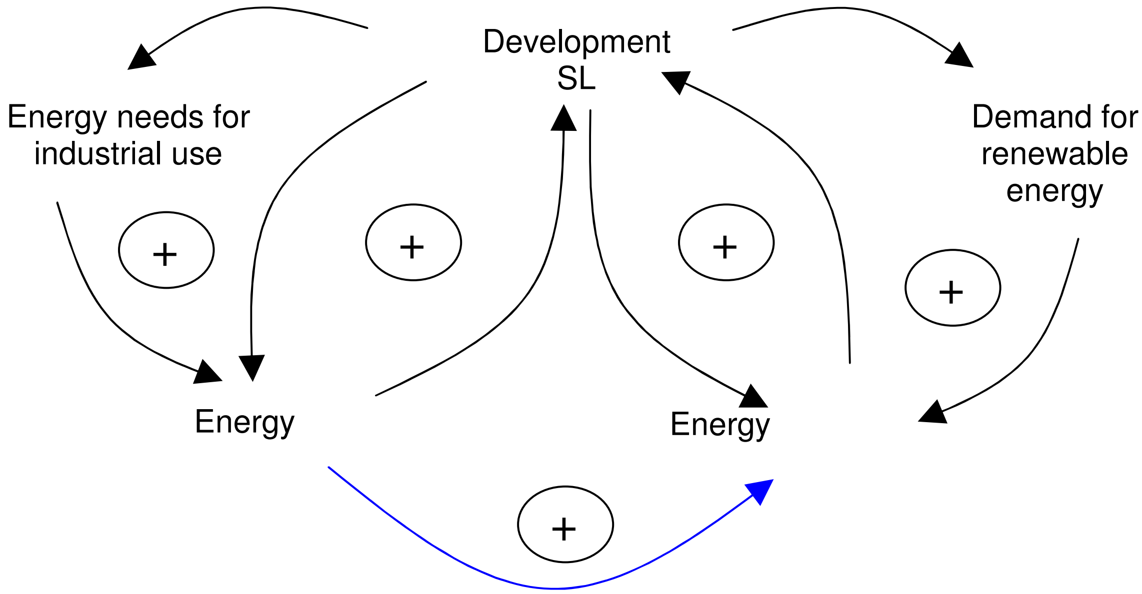

Figure 4. Sustainable Livelihoods reinforces development and the use of renewable sources

Numerous questions arise related with the form in which one can achieve the development of communities, in particular, on the role that energy can play to accelerate it. What forms of energy are required? In what quantities? How much of the energy is employed for human and social development? What amount of financial resources must be employed? And, what is the cost in terms of natural capital that must be employed to support the development of physical capital required?

In order to respond to this and other questions it was necessary to develop simulation models and carry out simulation exercises under public policy scenarios which can be directed towards supporting sustainable livelihoods of isolated communities.

5. SD Modeling and simulation results

In order to answer some of the questions proposed in the previous section, we turn to the formulation of the corresponding simulation models in Powersim

(RESURL, 2004). The most important models include: supply-demand, decision-making of energy technology and impact on capitals. Given the restrictions imposed on this paper, we briefly describe some of the most important modeling aspects.

Figure 5 shows the causal relationships between demand and supply of electricity. It is established that electricity supply depends on potential demand and the financial capital of the community which facilitates actual electricity consumption, encouraging population growth and increments in electricity demand.

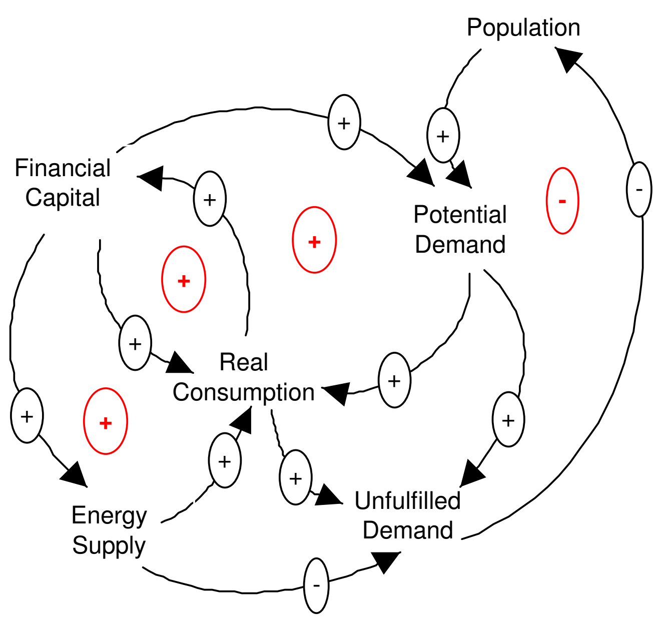

Figure 5 Principal aspects of the supply-demand module.

Figure 6 shows an example of how capitals are modeled. In this case Social Capital is increased by both human capital and electricity availability as communities can undertake more activities. However, social capital is eroded by the natural degradation rate and by increases in population (more probability of discontent).

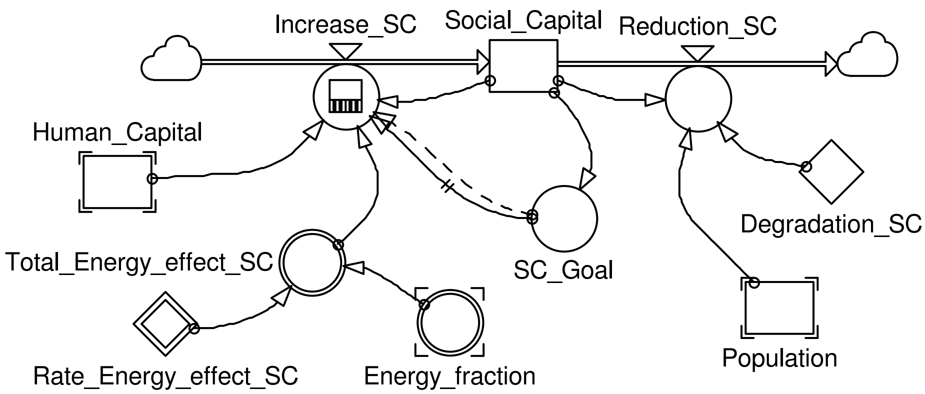

Figure 6. Aspects of the Social Capital module.

Figure 7 shows part of the decision-making rules with respect to new electricity supply for communities. Building solar facilities is considered first. Interconnection to the network is considered next. Other alternatives such as Hydro and wind technologies follow. Decisions depend on budget constraints, cost of solutions and technical feasibility.

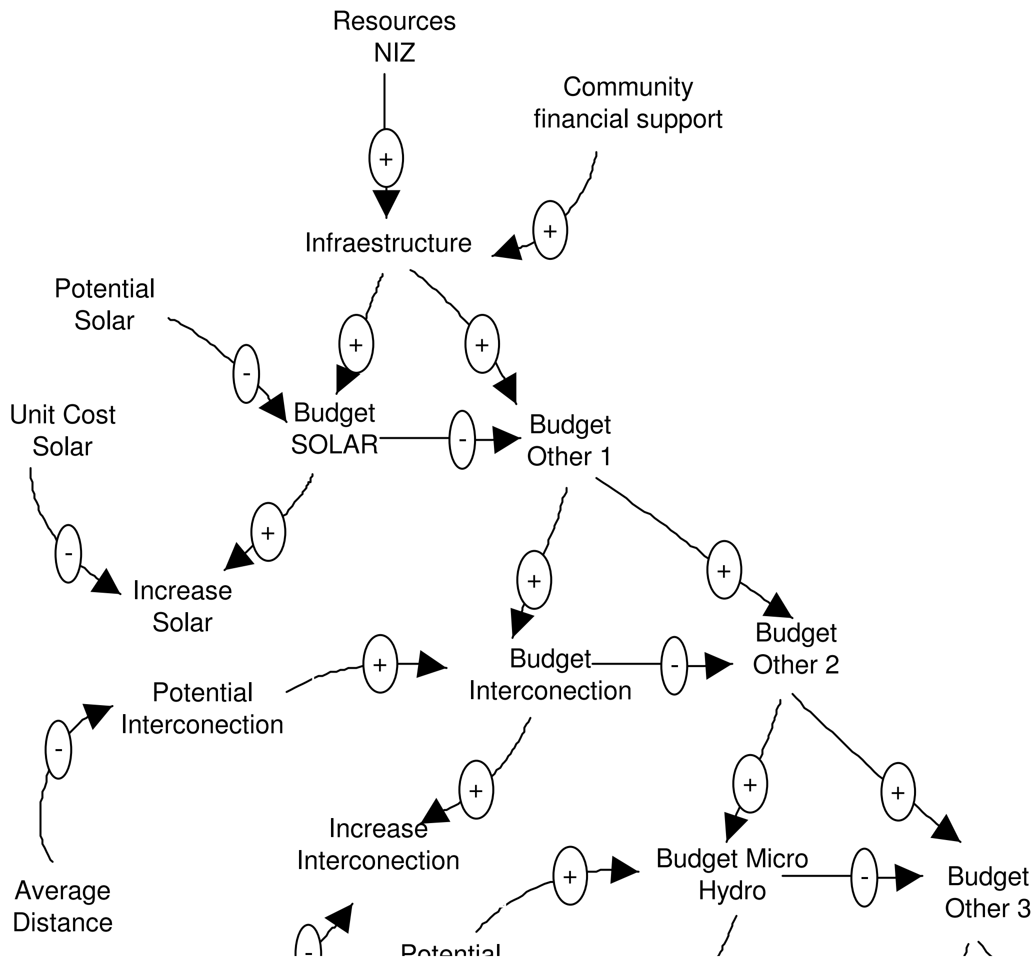

Figure 7. Extract of the decision-making module related to electricity supply.

The results that are presented here are preliminary and examples of possible scenarios that are built based on policies regarding the employment of resources (support for the financial capital of isolated communities) which seek to support the development of generation infrastructure (Physical Capital).

Figure 8 shows how under some policies, in less than 25 years it would be possible to satisfy electricity requirements of rural communities in Colombia. This assumes the effective employment of resources by government and financial community efforts (including human, social and financial).

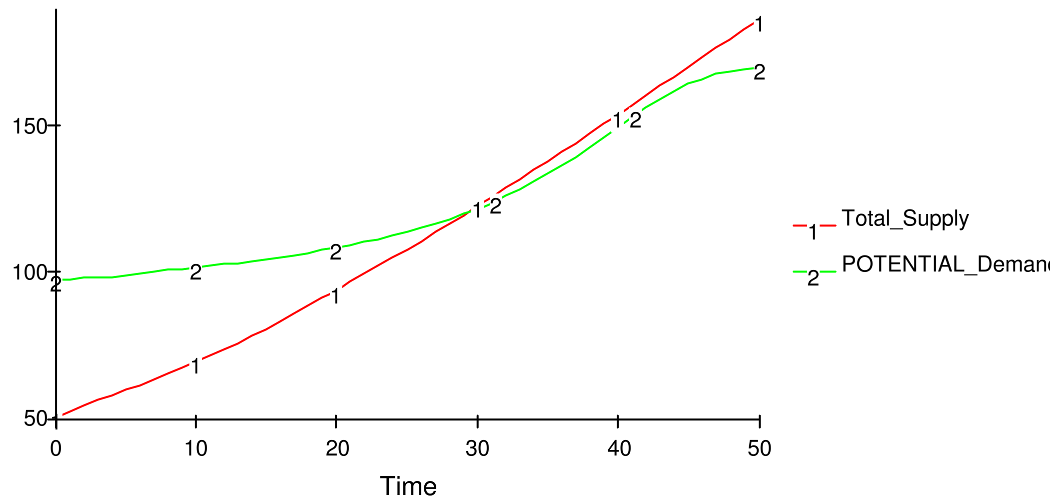

Figure 8. Possible evolution of the development of energy infrastructure for isolated communities in Colombia.

Under conditions of a similar (to the aforementioned) hypothetical scenario of employment of resources to support electrical infrastructure, Figure 9 shows the dynamics of the connection to the National Interconnection System and of the construction of wind, solar and hydro-energetic plants (micro). In this scenario, which is not the most desirable one, it is first consider the possibility of connecting the isolated zones to the transmission network before embarking on infrastructure works.

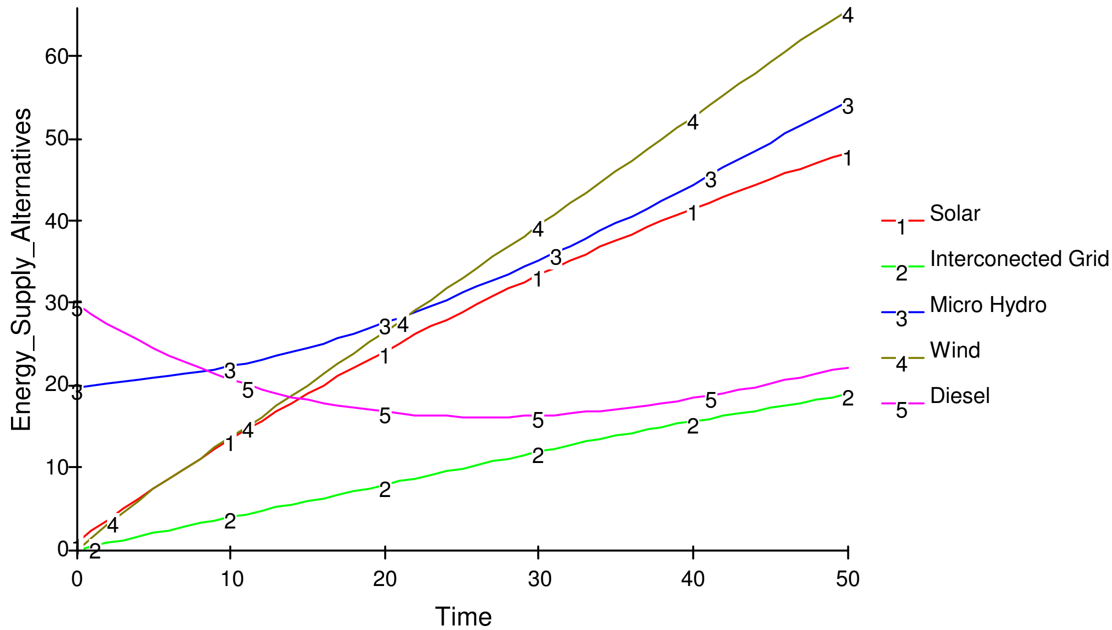

Figure 9. Evolution of the infrastructure for the electrification of isolated zones under a hypothetical preliminary scenario.

Figure 10 shows the evolution of the capitals of isolated communities under the scenario conditions mentioned above. As can be observed, in this hypothetical scenario, important levels of human, social, physical and financial development can be achieved at the cost of a relative sacrifice in the loss of natural capital, which is recovered almost totally.

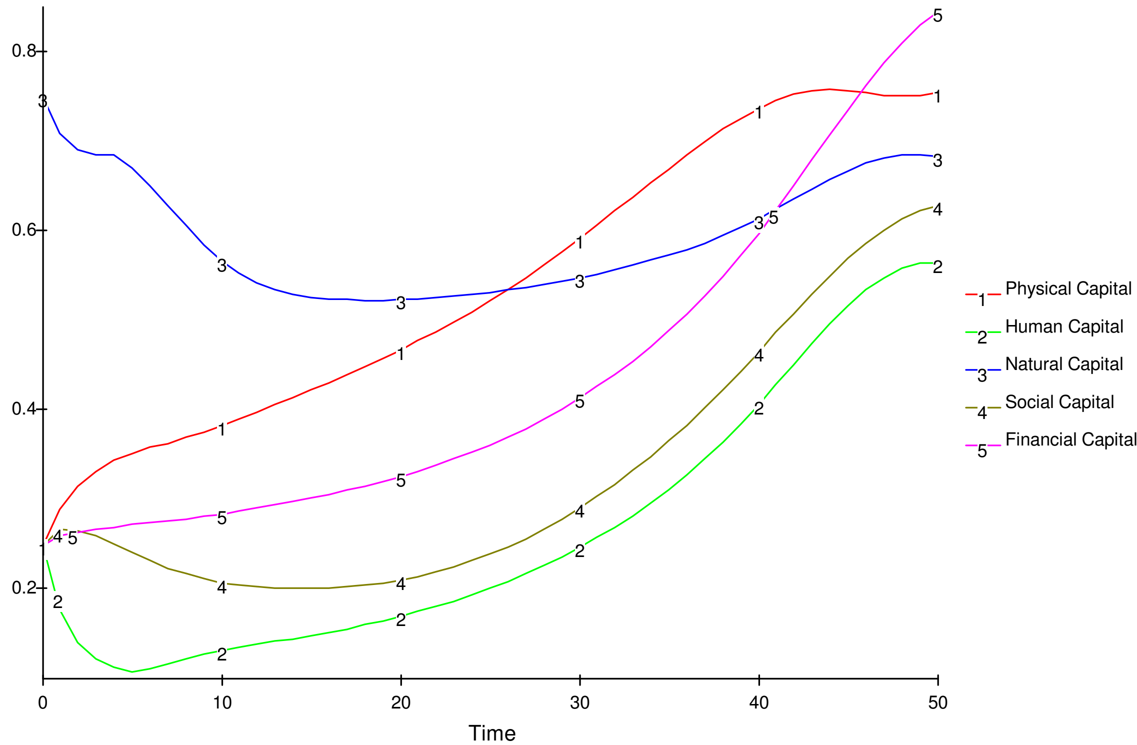

Figure 10. Evolution of capitals in is Colombian NIZ under very favorable conditions of a hypothetical scenario.

5. Conclusions

It has been shown how System Dynamics can be useful to evaluate development strategies of poor communities and the contribution that energy can have on rural sustainable livelihoods.

The conditions of poverty in which communities in isolated zones are trapped are shown and a way of breaking away from it is offered through sustainable livelihoods with the support of electrification solutions.

Preliminary results of simulations, under conditions of a hypothetical scenario, indicated how promising the methodological proposal is. This, in turn, shows ways to better understand the possibilities of development for isolated communities.

The results provided in this paper, an investigation in progress, are still preliminary.

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