International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 14, Number 3 (2021), pp. 213-218

System Dynamics Model for Sustainable Development in Isolated Rural Areas

Y.F. Ceballos[1*], V.H Mercado-Ramos[2], and C. Pérez-Palacios[3]

[1] Grupo Ing. y sociedad. Ingeniería Industrial, Universidad de Antioquia, Medellín, Colombia.

[2] Grupo ITOS. Ingeniería de sistemas, Universidad de Antioquia, Medellín, Colombia.

[3] Fundación universitaria María Cano, Medellín, Colombia.

**Corresponding Author (ORCID: 0000-0001-5787-8832)*

Abstract:

Community development is a topic that has been widely discussed in economic, technological, and academic environment. Normally, the sustainable development of rural communities is directly linked to the way in which people in the communities react to new conditions or fit the situation in a constructive altruism. In many studies, the power supply in rural communities is thought as a focus of development and growth in areas such as social, human, and financial. Tools to help decision-makers regarding which alternative is most appropriate for use in each community are based on an economic, physical, and social characterization. However, this branch of study had found a significant development, not considering the need to relate as a community focal point for rural development in the region, composed of all adjacent communities, which directly or indirectly affected by the positive and / or negative impacts of implementing energy technology in the community with the best physical characteristics for implementation. This document aims to highlight the lack of holistic analysis that involves the area in which the energy technology must be implemented.

Keywords: Sustainable livelihoods framework, non-interconnected zones, Sustainable Development, Rural Electrification, sustainable livelihoods, System dynamics.

I. INTRODUCTION

The way in which energy decisions evolve in isolated communities is directly related to economic relations and that these social enhance the community and neighboring communities [1]. The improvement of the social networks, the emergence of innovation and continuous improvement in energy technology will allow a perpetuation through time. However, without enough incentives or pressure from neighboring communities that have a deterioration of its environment can be removed or abandoned. This situation is compounded by the uncontrollable violence and natural disasters that can lead to unexpected situations in the simulation models. For the decision of energy technologies, exist some tools that involve information on the methodology of sustainable livelihoods [2] and it is implemented in a multicriteria decision models [3]. All these tools enable immediate decisions, without considering the time factor in the decision-making process through the simulation of policies and their impact over time. Other studies have shown the need to evaluate in a better way relevant development in energy technology over time [4] but make no reference to the need to engage in sustainable development impacts in the whole region but emphasize the development of a particular community.

II. THEORETICAL BACKGROUND

In the world there is inequality in income distribution. According to UNDP (United Nations Development Program) in the world are 850 million illiterate adults (14% of world's population), 960 million people without access to drinking water resources (16%) and 2 billion people without access to electricity (33%). This situation is unacceptable socially and environmentally unsustainable, constituting a major challenge for all nations of the world [5], [6].

Various studies have suggested that economic development is tied to energy development, which strongly improved the economic conditions of a regional or a community to a greater subsequent generation and energy consumption, applying transformation processes that create value. These studies also show that global energy demand may increase dramatically and much of this increase will occur in the developing countries [7], [8].

However, they are also known negative impacts of generation and power consumption. Most kinds of energy come from fossil fuels, with problems directly associated with the environment and the process will be given to waste resulting from energy generation. This is one reason that justifies the use of clean technologies for energy production, contributing simultaneously to the needs of rural communities and minimizing the impact that this technology makes in the environment [9].

Minimizing environmental impact is directly linked to understanding the dynamics of development of contemporary societies; this was evident in the complexity of reality and the enormous challenge of operationalizing the theoretical interpretation of society. This problem becomes bigger when it comes to incorporating new theories and new models of interpretation and intervention, especially when working with more extensive and complex, such as sustainable development, still under assembly theory [10]

Either way, the truth is always very complex and theoretical models, divided into various disciplines; they must necessarily travel analytical reduction ability to allow the seizure of all the dynamics and complexity. The combination of various disciplines to address a comprehensive and multifaceted reality from the perspective of sustainable development should articulate processes of the economy, ecology, the social, politics, technology, culture, an effort. Further reduction and analytical treatment of the relationships and interrelationships of the whole. In this way, the need to use a tool that allows integrating all these aspects of reality and for this use general systems theory.

Decisions are currently routed using conventional energy technologies including sites with potential for exploitation of various forms of power generation, guided by the economic reasons in management and the experiences that have been taken for implementation of this technology in past years. This situation affects the way of selecting technology to be brought to the target community and not consider the interests and needs of the region. In rural areas of developing countries, renewable energy can play a significant role in meeting basic energy needs, as well as enabling the emergence of productive activities that generate income for their habitants. It also can help alleviate poverty in urban areas, slowing the migration from the countryside into the city, changing the structure of growth in urban areas, contributing to the decentralization of electricity production, and reducing dependence on the external market energy.

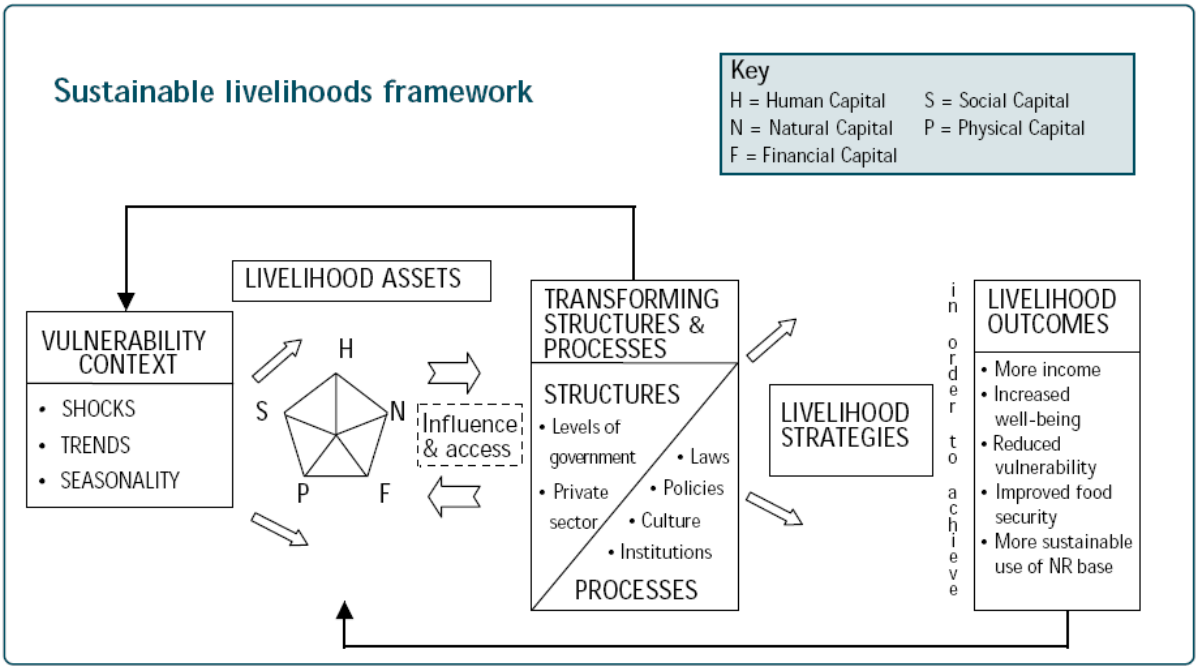

Figure 1. Sustainable livelihoods framework. [10]

The problem of sustainable development of rural communities with economic difficulties and energy has been the subject of numerous studies worldwide, both from the standpoint of development of various technologies, such as programs aimed at the replacement, use and development of energy alternatives sustainable. Several of these studies and programs have been encouraged by policies of the United Nations Environment Program -UNEP- and driven through initiatives financed by the same entity, such as The Global Network on Energy for Sustainable Development -GNESD -. Other initiatives have been developed in collaboration with governments, non-profit organizations, or private companies, such as The Global Village Energy Partnership, GVEP, "the European Union Initiative for Poverty Eradication and Sustainable Development" EU Energy Initiative and the UK Renewable Energy and Energy Efficiency Partnership, REEEP.

One such initiative is the International Renewable Energy Technology and Sustainable Livelihoods - RESURL, led by Imperial College in London, England, with the participation of researchers from Cuba, Peru and Colombia, and financial support from the Department for International Development.

The framework of the MVS (see Figure) can think about the goals, opportunities, and development priorities to accelerate progress on eradicating poverty. The MVS allows defining institutional arrangements for people who are present in a community to achieve a successful decision making and strategies that enable people who are in difficult living conditions have improved conditions. The theory of livelihoods focuses primarily and foremost in people [10]. Its aim is to achieve an accurate and realistic understanding of the strengths of peoples (assets or capital endowments) and his struggle to turn them into positive achievements in terms of livelihoods.

From the perspective of technology management, emphasizes the importance of the skills associated with mastering a particular energy technology for its successful introduction in a rural community composed of several groups of people, relationships, and strategies of exchange between them. In this sense, there is need to understand the dynamics of the relationship between the community and their livelihoods, their capabilities, technologies (both for power generation and for the productive use of it) and public policies that affecting the community and the region, which takes a systemic perspective that allows the integration in a holistic way.

Communication between communities and the way in which relevant information is exchanged to generate the necessary development in the region is a determinant of success in energy technology. However, the way information is exchanged by the communities is a process of co-creation, which involves complex and difficult parameters to determine, at any simplification of reality [11].

Normally, the criteria for evaluating the efficiency of energy technology are to employ a purely economic analysis, if set aside for administrative information, which are subject to rural communities, but which uses only the knowledge of an officer who knows just who the real social problems afflicting the rural community.

III. METHODOLOGY

Regarding methodology have found a process for the assessment of regional needs for the implementation of an energy technology based strictly on the application of geographic information systems if the verification of the efficiency of decision over time. On a methodology is necessary to include the following processes: Identification the target population and its characterization based on any theoretical framework that can be sustainable [12], [13].

Also identified studies to quantify the capital employed in the theoretical framework of MVS, which are based on the design of a detailed analysis of the conditions of a particular community and how is evolving over time, if you take into account the impacts that this decision in the present technological communities that belong to the environment, which limits the objective of the tool, because they know the side effects of the decision and behavior against intuitive of it, in view of sustainable development in the region.

To formulate criteria for the evaluation methodology will be identified as a useful tool to collate information from field work and experiences in rural areas. These studies used criteria such as sustainable livelihoods and Gini coefficient, which used information from the social and economic structure of the region, but not involving assessments over time [14], [15]. The Gini coefficient is usually used to measure income inequality but can be used to measure any form of uneven distribution. The Gini coefficient is a number between 0 and 1, where 0 corresponds to perfect equality (everyone has the same income) and 1 corresponds to perfect inequality (one person has all the income and the other none). From this clarification it is concluded that this ratio cannot be used to directly measure the efficiency and inequality of income distribution on the part of local authorities.

To exemplify this problem is used a Meta model, which uses the following variables: Economic growth: It is related to the way that the rural community uses the new technology, to make the income better, using in a different way the resources inside the community. Technology use: It is related to the way that people use energy, rational and controlled, making sustainability inside the whole area. Social investment: It is related to the way that the public institutions make an economic investment, to help the community to overcome different needs, particularly energy needs. Community growth: In this variable shown the way that the community develops, in a way specifically to economic y social growth. Energy efficiency: it's the right use of energy, rational and using different innovative process and Unsatisfied needs: Is the set of requirements that every rural community in the region has, like problems of access and unequal distribution of resources.

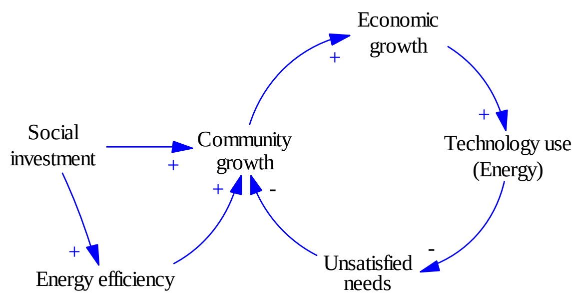

Fig. 2 Causal diagram. Source: Author

Presents a cycle of reinforcement, which comprises the effect of the appropriate and rational use of technology, along with the proper use of it on unsatisfied needs, which reduces these needs, improving quality of life community and allowing growth as a community, which was subsequently reflected in economic growth, accompanied by educational processes, which can improve energy use over time, reinforcing the virtuous cycle.

IV. SYSTEM DYNAMICS MODEL

System dynamics is used to make a simulation of the problem situation and the causal diagram is mapped in a simple diagram of flows and levels, which can perform trend analysis. Social development and local needs are counted as levels and they could be used as an indicator of the evolution of energy technology in influence. Impact in a rural community is analyzed, but the effect produced by the needs to be covered by technology towards other communities has a negative impact on the evolution of the coverage of local needs, which affects social development in early technology implementation, accompanied by the effect of economic problems in the community in management, prioritizing the needs at the base of Maslow's pyramid of needs, given the impossibility of deciding to employ the appropriate sustaining income energy, since there is no freedom to do it [16], [17].

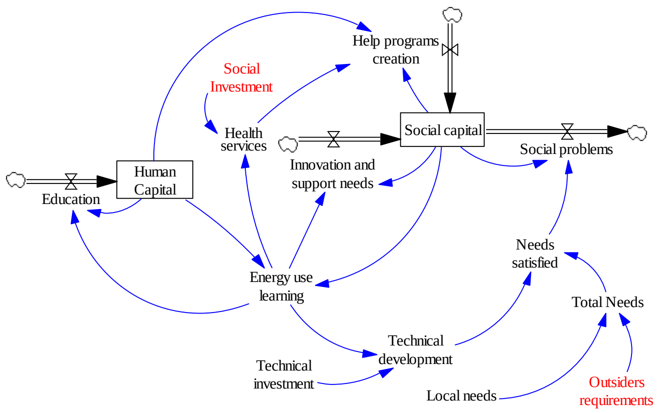

Fig. 4. Stock and flows diagram.

The surrounding communities are simulated with a constant energy demand. We use an easily identifiable behaviour to observe the impact of this demand in the community, Social investment is one of the variables that enables the creation of accompanying programs, since community usually does not have the resources necessary to perform a process of continuous learning, as noted above, due to its priorities [17].

Social capital is influenced by several factors, including support groups (technical and technological knowledge to use and exploitation of energy), which meets needs of sustainability and innovation in the rational use of energy in the first period of technology introduction, but we must bear in mind that as time goes on, these groups are replaced with ones made up of local people who have already acquired the skills needed to lead and / or participate in them.

Human capital is influenced in different ways, because learning and use of energy includes to employinformation technologies, to find a better way to work, and to access to different networks to help and teach. Another way to use energy is in health care sector because social capital includes the way of use energy for store vaccines and other medicaments. Figure 4 can show the relationships mentioned.

In conclusion, the expected behaviour of the community, in terms of coverage of local needs and social development, can be defined in the way inward investment and the learning process converge, allowing an adequate appropriation and assessment of benefits provided by energy technology in terms of meeting needs and creating new needs, and the possibility to choose the way in which these needs will be supplemented by technology.

The capitals of Sustainable Livelihoods (Department for International Development 2002) that are used in modelling are only social capital and human capital, as they represent the variables that directly influence social development area, given the hypothesis mentioned previously.

IV. RESULTS

As simulation results (Figure 5), it can be observed the need for support programs aimed at enabling the choices that people have in a human group, since their creation allows for a flow of information, generating new skills and knowledge and freedom to decide for options of use of energy more convenient, making sustainable development possible in such regions.

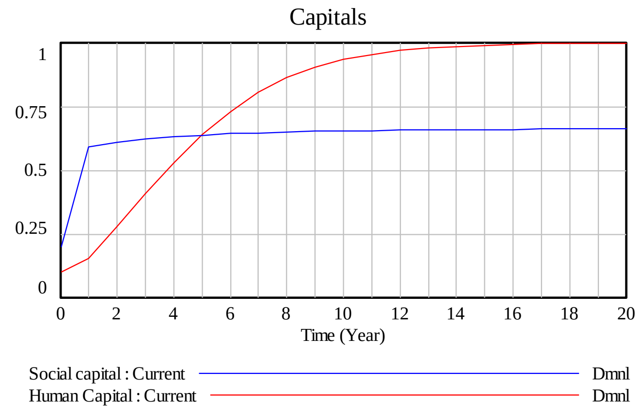

Fig 5. Comparative between capitals.

The creation of support groups is present at the beginning of the simulation, but as time goes on, given the capabilities of the community, these groups are converted into collective knowledge, allowing easy maintenance and operation of energy technology, which reduces the need for conducting on-going support programs.

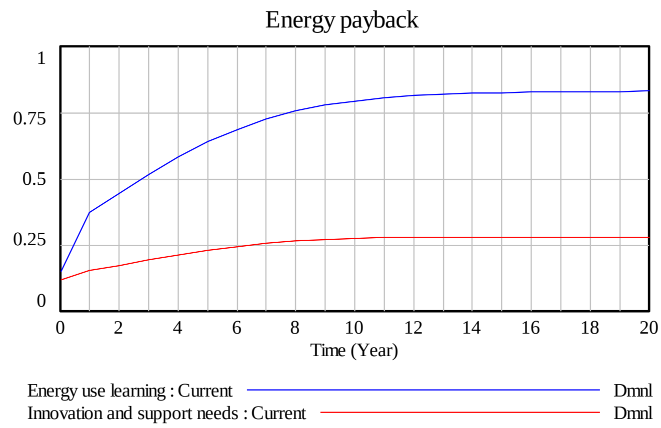

Fig 6. Learning.

In conclusion, the expected behaviour of an inclusion of energy technology must be accompanied by a comprehensive support program (see Figure 6), pending appropriation of knowledge and the creation of needs in communities, so that there is maintenance by local authorities interested in developing and meeting the needs of the community and other surrounding communities.

System dynamics is used to make a simulation of the problem situation and the causal diagram is mapped in a simple diagram of flows and levels, which can perform trend analysis. Social development and local needs are counted as levels and they could be used as an indicator of the evolution of energy technology in influence. Impact in a rural community is analyzed, but the effect produced by the needs to be covered by technology towards other communities has a negative impact on the evolution of the coverage of local needs, which affects social development in early technology implementation, accompanied by the effect of economic problems in the community in management, prioritizing the needs at the base of Maslow's pyramid of needs (Maslow 1943), given the impossibility of deciding to employ the appropriate sustaining income energy, since there is no freedom to do it (Sen 1999).

IV. CONCLUSIONS

The capacity assessment methodologies and building performance energy technology in a rural region has shown significant progress, apart from those related to a single community, since all the analysis refer to isolated situations, whether a follow-up social impacts that these decisions are in the middle.

Poverty, which has been discussed by various authorities, from a scholarly and social point of view, is directly linked to quality of life that allows full development in terms of basic needs and proper social relationships. In the model, poverty is classified as a cluster of factors that are discussed from a global perspective, linking the evolution of capital. Since they all have a tendency of growth, they can ensure that energy, based on the previous model, contributes to better development.

The conceptualization of the problem from both external and internal components, necessarily imply that communities need to develop knowledge through their own means, if you have complex technological capabilities as a source of resources to sustainable development.

Management of technological capabilities supposed to accumulate knowledge through learning that includes the sharing of internal and external sources to include synergy between the parties. Hence the complex technological capacity building is positively related to technological success.

REFERENCES

[1] R. Siemons, “Identifying a role for biomass gasification in rural electrification in developing countries: the economic perspective,” *Biomass and Bioenergy*, vol. 20, no. 4, pp. 271–285, Apr. 2001, doi: 10.1016/S0961-9534(00)00085-4.

[2] DFID, “Eliminating World Poverty: A Challenge for the 21st Century,” *Challenge*, no. November, 1997, Accessed: Sep. 23, 2010. [Online]. Available: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Eliminating+World+Poverty+:+A+Challenge+for+the+21st+Century#0.

[3] F. Henao, J. a. Cherni, P. Jaramillo, and I. Dyner, “A multicriteria approach to sustainable energy supply for the rural poor,” *Eur. J. Oper. Res.*, vol. 218, no. 3, pp. 801–809, May 2012, doi: 10.1016/j.ejor.2011.11.033.

[4] L. Goldemberg, “ACHIEVING THE MILLENNIUM DEVELOPMENT GOALS by Enabling the Rural Poor to Overcome their Poverty,” Rome, Italy, 2003. [Online]. Available: http://www.ifad.org/.

[5] A. Brew-Hammond and A. Crole-Rees, *Reducing rural poverty through increased access to energy services: A review of the multifunctional platform project in Mali*. United Nations Development Programme, UNDP Mali Office, 2004.

[6] United Nations Development Programme (UNDP), “Human Development Report 2011, Sustainability and Equity, A Better Future for All,” New York City, 2011. [Online]. Available: http://www.undp.org/content/dam/undp/library/corporate/HDR/2011 Global HDR/English/HDR_2011_EN_Complete.pdf.

[7] S. Fincher *et al.*, “Perspectives on HCI patterns,” in *CHI ’03 extended abstracts on Human factors in computing systems - CHI ’03*, 2003, p. 1044, doi: 10.1145/765891.766140.

[8] N. Tsolakis and J. S. Srai, “A System Dynamics approach to food security through smallholder farming in the UK,” *Chem. Eng. Trans.*, vol. 57, pp. 2023–2028, 2017, doi: 10.3303/CET1757338.

[9] Y. Xie, A. Ma, and H. Wang, “Lanzhou urban growth prediction based on Cellular Automata,” in *2010 18th International Conference on Geoinformatics*, 2010, no. 2009, pp. 1–5, doi: 10.1109/GEOINFORMATICS.2010.5567556.

[10] DFID, “Guías Sobre Medios de Vida Sostenibles MVS,” 2002. [Online]. Available: http://www.livelihoods.org/info/info_guidancesheets.html.

[11] J. McIntyre and M. Pradhan, “A systemic approach to addressing the complexity of energy problems,” *Syst. Pract. action Res.*, vol. 16, no. 3, pp. 213–223, 2003, Accessed: Jun. 24, 2010. [Online]. Available: http://www.springerlink.com/index/j843071m11l56122.pdf.

[12] D. Roy, M. H. Lees, B. Palavalli, K. Pfeffer, and M. A. P. Sloot, “The emergence of slums: A contemporary view on simulation models,” *Environ. Model. Softw.*, vol. 59, pp. 76–90, 2014, doi: http://dx.doi.org/10.1016/j.envsoft.2014.05.004.

[13] J. Amador and J. Dominguez, “Application of geographical information systems to rural electrification with renewable energy sources,” *Renew. Energy*, vol. 30, no. 12, pp. 1897–1912, Oct. 2005, doi: 10.1016/j.renene.2004.12.007.

[14] R. Davidson, “Reliable inference for the Gini index,” *J. Econom.*, vol. 150, no. 1, pp. 30–40, 2009, Accessed: Aug. 05, 2010. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0304407609000323.

[15] M. Top, M. Konca, and B. Sapaz, “Technical efficiency of healthcare systems in African countries: An

application based on data envelopment analysis," *Heal. Policy Technol.*, vol. 9, no. 1, pp. 62–68, 2020, doi: 10.1016/j.hlpt.2019.11.010.

[16] A. H. Maslow, "A theory of human motivation," *Psychol. Rev.*, vol. 50, no. 4, pp. 370–396, 1943, Accessed: Aug. 05, 2010. [Online]. Available: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:A+Theory+of+Human+Motivation#0.

[17] A. Sen, *Development as freedom*, 2nd ed. Cambridge, England: Alfred A. Knopf, New York, 1999.