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Special Issue
Rural Renewable Energy Utilization and Electrification II

Edited by
Prof. Dr. Javier Domínguez Bravo and Dr. Jorge M Islas-Samperio

MDPI

https://doi.org/10.3390/en16073143

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Energy Supply Systems Predicting Model for the Integration of Long-Term Energy Planning Variables with Sustainable Livelihoods Approach in Remote Communities

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Abstract: The Sustainable Development Goals (SDGs) of the United Nations Organization pursue the provision of affordable and quality energy for all human beings, which is why the correct planning of Energy Supply Systems (ESS) in communities that present levels of energy poverty, that is, the impossibility to satisfy their minimum needs for energy services. This work proposes a methodology to evaluate the contribution to development by the adequate provision of the demand of ESS in remote communities through the approach of Sustainable Livelihoods (SLs). The methodology starts from the initial evaluation of the sustainable livelihoods or capitals of the communities and the analysis of their interaction. Then, a capital improvement process is proposed by selecting the indicator values that optimize the model in each period, through an evolutionary algorithm that guarantees that the indicators evolve to a rich scenario as a result of planning to evolve the key variables based on a quantitative model with the indicators that empower evaluating the contribution of the ESS to them.

Keywords: sustainable livelihoods; energy management; renewable energy; energy systems optimization; evolutionary algorithm

Citation: Pereyra-Mariñez, C.; Andrickson-Mora, J.; Ocaña-Guevera, V.S.; Santos García, F.; Vallejo Diaz, A. Energy Supply Systems Predicting Model for the Integration of Long-Term Energy Planning Variables with Sustainable Livelihoods Approach in Remote Communities. *Energies* **2023**, *16*, 3143. https://doi.org/10.3390/en16073143

Academic Editors: Javier Domínguez Bravo and Jorge M Islas-Samperio

Received: 1 March 2023
Revised: 23 March 2023
Accepted: 28 March 2023
Published: 30 March 2023

1. Introduction

The sustainable development goals (SDGs) of the United Nations Organization have set as objective-7 (SDG 7), access to sustainable and quality energy for all. That is why correct long, medium, and short-term planning of energy supply systems in remote communities is necessary [1,2]. The gap between energy planning models and community development planning mechanisms justifies the need for models that integrate energy demand planning and the criteria of the Sustainable Livelihoods approach (SLA) to help in the decision-making in the development planning of remote communities in relation to the evolution of its energy demand [3].

The concept of Energy Poverty (EP), measures the possibility that a population has to satisfy their minimum needs for energy services [4]. This concept can be applied to monitoring studies of access to quality energy services in communities or regions [5], as presented by a study by the National Energy Commission (CNE) of the Dominican Republic that establishes the energy-poor provinces [6]. EP in communities must be reduced not only to achieve SDG 7, related to affordable energy but also as a way to promote greater economic development in remote communities [7]. In other words, the energy supply systems are very important to carry out the development in communities with EP [8].

The evaluation of EP in remote communities allows it to be articulated with Sustainable Livelihoods (SLs) [9]. This articulation allows evaluating not only how communities can meet their energy needs, but also the correct supply of energy demand in the long, medium, and short term, which contributes to the integral development of communities. In order for the SLs to be useful in contributing to the reduction of energy poverty in remote communities, a system of indicators must be established that allows correlating demand and community assets [10]. As part of the procedure for the development of the SLs, the indicators of the system will be selected by key actors, as a way of adapting it to the characteristics of the evaluated community, to contribute to the reduction of poverty under the specific conditions of each one.

Microgrids of Renewables energy sources and new energy business models through community cooperativism can help to improve communities' development and increase the interest of the electrical companies in the deployment of the electrical grid [11].

The sustainable livelihoods approach has been proposed by the Food and Agriculture Organization of the United Nations (FAO) as a tool for the implementation of rural development projects [12]. However, the research consulted, which focuses on the development of remote communities based on an adequate supply of energy, does not allow for evaluating the evolution of development over time, nor with the evolution of energy demand [3].

Pereyra-Mariñez et al. (2022), have shown the analysis of different models for energy planning and the evaluation of sustainable livelihoods in remote communities [3]. This research argues that the current energy planning models do not include elements that involve indicators to measure the development of the capitals that make up the SLs. Therefore, the objective of this article is to develop a model that considers the necessary elements to achieve the integration of long-term energy planning variables and SLs. On the other hand, A.Vallejo-Díaz et al. (2022) have presented research on small-scale wind energy to contribute to decarbonization in a decentralized grid [13]. This technology is suitable for harnessing kinetic energy in the wind in remote communities. In addition, that work introduced the approach of energy resilience for distributed energy systems against threats from atmospheric events. Recently, E. Garabitos Lara et al. (2023) presented an evaluation of the economic feasibility of the use of a photovoltaic system for distributed energy [14], however, the framework of the work shows how competitive benefits can be obtained, such as internal rate of return of 9% and payback time of 4.46 years, with scenarios in the cities, and even better in rural areas, where the levelized costs of energy are higher according to E. Mulenga et al. (2023) [15].

Considering the depth of the literature analysis on the integration of the SLA with Long-Term energy planning, this work proposes:

- A methodology that allows guiding decision-making for the development and evolution of the energy supply system in the long term for remote communities.
- A process of optimization of the indicators that make up the capitals of the community, taking them from a poor scenario to a rich one as a result and guaranteeing harmonious and sustainable growth between the capitals.
- The integration of long-term energy planning variables and SLs.

The organization of the article is as follows: Section 2 presents a systematic review of the literature about SLA, the assets pentagon calculation, and the methods for simulation algorithm and polynomial regression. Section 3 develops the methodology that was applied to integrate the SLA with lorn-term energy planning variables. Section 4 analyzes the results obtained from the simulation. Section 5. discusses the findings from the simulation model results. Finally, in Section 6 the conclusions and future work on the findings are shown.

2. Systematic Literature Review

Energy projects in remote communities that make it possible to achieve the SDGs require the development of methodologies for forecasting energy demand, the availability of renewable energy carriers, guaranteeing minimum costs of the energy served, achieving high levels of social acceptance, maximum use of renewable resources and a lower environmental cost [16].

2.1. Sustainable Livelihoods Approach

The Sustainable Livelihoods Approach (SLs) measures the capacities or assets that communities have for the development of their lives [17]. A livelihood is sustainable when it is resilient to sudden shocks and maintains its capabilities and assets both now and in the future without undermining its natural resource bases. The capacities or assets of livelihoods can be classified into five types of capital according to M. Barman et al. (2017) [18]. A review of the capital used by authors of development projects in remote communities has been carried out by Pereyra-Mariñez et al. (2022) [3]:

- Human Capital: characterized among others by the levels of health, nutrition, education, and knowledge.
- Social Capital: they are networks and connections between individuals with shared interests, forms of social participation, and relationships of trust and reciprocity.
- Natural Capital: these are the natural resources useful in terms of livelihood.
- Physical Capital: these are the infrastructures and equipment that respond to the basic and productive needs of the population.
- Financial Capital: These are the financial resources that populations use to achieve their livelihood objectives.

Chen et al. (2013), have presented four stages for the evaluation of the capitals of a community as follows: (1) Identify the attributes and key variables. (2) Select to set the weights of the selected indicators according to your experience. (3) Rate the options with reference to a scale of scores regarding their relative importance, in terms of different weights, such as 0–0.33, 0.34–0.66, and 0.67–1.00; deficient, medium, and well, respectively. (4) Calculate the weighted scores [19].

Fang et al. (2014), have developed a methodology combining the SLs capital and the questionnaire method. The main variables correlated are selected. To measure the contribution of different capitals in livelihood strategies, it is important to standardize each variable based on Equations (1) and (2) [20].

$$Z_i = \frac{x_i - \overline{x}}{S} \quad (1)$$

$$C_i = \sum W_i Z_i \quad (2)$$

where, C_i is the estimated value of livelihood capital ($i = 1, 2, 3, 4, 5$), W_i indicates the weight of the i^{th} observation and Z_i represents the normalized value, as well. Table 1 presents the indicators proposed according to the level of relationship with the energy demand. Where WB means World Bank, UNDP means United Nations Development Program and DFID means Department for International Development.

Table 1. Energy-related indicators, presented by Pereyra-Mariñez et al. (2022) [3].

Capitals and Indicators	Acronym	WB	DFID	UNDP	Total
Human capital	CH	1		3	4
The economically active population (%)	CHI1			1	1
Occupancy rate	CHI2	1			1
Scholarship	CHI3			1	1
Life expectancy	CHI4			1	1
Family size (According to Organization for Economic Cooperation and Development (OECD).)	CHI5				

Table 1. *Cont.*

Capitals and Indicators	Acronym	WB	DFID	UNDP	Total
Labor productivity (According to Organization for Economic Cooperation and Development (OECD).)	CHI6				
Social capital	CS		4	1	5
Community Participation Level	CSI1		1		1
Collective representation	CSI2		1		1
Leadership	CSI3		1		1
Participation in decision-making	CSI4		1		1
Climate information services	CSI5			1	1
Financial capital	CF	8	1		9
Local GDP/hab (is taken from the International Monetary Fund (IMF).)	CFI1				
Access to credit	CFI2	1			1
Household income	CFI3	1			1
Social help	CFI4		1		1
Arrival of tourists	CFI5	1			1
Grid electricity cost	CFI6	1			1
Spending on energy sources	CFI7	1			1
Remittances	CFI8	1			1
Investment Capital	CFI9	1			1
Savings	CFI10	1			1
Physical capital	CP	7	1	2	10
Access to information	CPI1		1		1
Access to energy	CPI2			1	1
Energy consumption per inhabitant	CPI3	1			1
Self-coverage of the Energy Demand	CPI4			1	1
Use of renewable energies	CPI5	1			1
Transport infrastructure	CPI6	1			1
Carrier penetration Renewable energy	CPI7	1			1
Grid reliability	CPI8	1			1
Proximity to the grid of the community interconnected system	CPI9	1			1
Access to water	CPI10	1			1
Natural capital	CN	1		7	8
Disponibility of Renewable Energy carriers	CNI1	1			1
Air quality	CNI2			1	1
Particles total	CNI3			1	1
Net absorption CO_2	CNI4				
Available Water	CNI5			1	1
Biodiversity	CNI6			1	1
Forest cover area	CNI7			1	1
Hydrographic basin management	CNI8			1	1
Availability of water and aquatic resources	CNI9			1	1
Total		17	6	13	36
Capitals and Indicators	Acronym	WB	DFID	UNDP	Total

Table 1. *Cont.*

Capitals and Indicators	Acronym	WB	DFID	UNDP	Total
Human capital	CH	1		3	4
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Occupancy rate	CHI2	1			1
Scholarship	CHI3			1	1
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Family size (According to Organization for Economic Cooperation and Development (OECD).)	CHI5				
Labor productivity (According to Organization for Economic Cooperation and Development (OECD).)	CHI6				
Social capital	CS		4	1	5
Community Participation Level	CSI1		1		1
Collective representation	CSI2		1		1
Leadership	CSI3		1		1
Participation in decision-making	CSI4		1		1
Climate information services	CSI5			1	1
Financial capital	CF	8	1		9
Local GDP/hab (is taken from the International Monetary Fund (IMF).)	CFI1				
Access to credit	CFI2	1			1
Household income	CFI3	1			1
Social help	CFI4		1		1
Arrival of tourists	CFI5	1			1
Grid electricity cost	CFI6	1			1
Spending on energy sources	CFI7	1			1
Remittances	CFI8	1			1
Investment Capital	CFI9	1			1
Savings	CFI10	1			1
Physical capital	CP	7	1	2	10
Access to information	CPI1		1		1
Access to energy	CPI2			1	1
Energy consumption per inhabitant	CPI3	1			1
Self-coverage of the Energy Demand	CPI4			1	1
Use of renewable energies	CPI5	1			1
Transport infrastructure	CPI6	1			1
Carrier penetration Renewable energy	CPI7	1			1
Grid reliability	CPI8	1			1
Proximity to the grid of the community interconnected system	CPI9	1			1
Access to water	CPI10	1			1
Natural capital	CN	1		7	8
Disponibility of Renewable Energy carriers	CNI1	1			1
Air quality	CNI2			1	1
Particles total	CNI3			1	1
Net absorption CO2	CNI4				

Table 1. *Cont.*

Capitals and Indicators	Acronym	WB	DFID	UNDP	Total
Available Water	CNI5			1	1
Biodiversity	CNI6			1	1
Forest cover area	CNI7			1	1
Hydrographic basin management	CNI8			1	1
Availability of water and aquatic resources	CNI9			1	1
Total		17	6	13	36

2.2. Assets Pentagon

The assets pentagon is used to graphically represent the value of each of the capitals [21]. Each capital can take on a value between 0 and 1. The capitals are independent, although there is an interrelation that occurs through the variables and parameters that the indicators that the capital shares. In the ideal case, a regular pentagon is obtained, however, the capitals evolve forming irregular pentagons in which the area shape of this allows for establishing the level of development reached by the study community.

In Figure 1 three assets pentagon scenarios are presented. In the poor scenario, a low total area is observed with a level of more than half of natural capital and social capital, while human, physical, and financial capital are much less than half. In the normal scenario, the community has an increase in its human capital and this in turn is transformed into an increase in financial and physical capital. In the wealth scenario, energy intervention projects have influenced the increase to optimal levels of human capital and this in turn evolves to the optimal level of other capitals, reaching the pentagon in a quasi-regular manner.

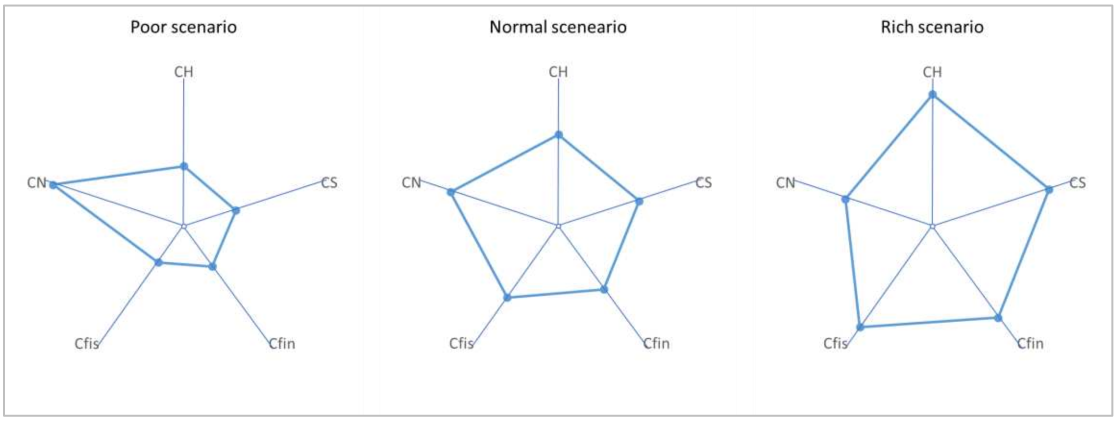

Figure 1. Assets Pentagon Scenarios, presented by [22].

The area of the pentagon that is formed with the results of the capitals can be calculated using Equation (3) which is called the Gaussian determinant [23]. The area of the pentagon that will result from the evaluation of the capitals in each scenario in the long term, will allow evaluation of the global gain or loss of the assets that make up the EMV [24]. Equation (4) represents Equation (3) expanded.

$$A = \frac{1}{2}\left|\sum_{i=1}^{n-1} x_i y_{i+1} + x_n y_1 + \sum_{i=1}^{n-1} x_i + 1 y_i - x_1 y_n\right| \quad (3)$$

$$A = \frac{1}{2}|x_1 y_2 + x_2 y_3 + \cdots + x_n - 1 y_n + x_n y_1 - x_2 y_1 - x_3 y_2 - \cdots - x_n y_{n+1} - x_1 y_n| \quad (4)$$

Although the total area of the pentagon allows us to assess the overall contribution of capital to community development, there are different irregular pentagons that can have the same area. To distinguish and compare the pentagons, the coefficient of variation on the capitals can be adopted [25]. Between two pentagons of equal areas, the one with the smaller coefficient of variation will be the more stable. In Equation (5) the coefficient of variation (CV) is presented.

$$CV = \frac{\sigma_{C_i}}{\overline{X}} \tag{5}$$

where σ_{C_i} is the standard deviation between the capitals, and $\overline{X}$ is the mean of the capitals.

2.3. Simulation Algorithm

An evolutionary algorithm is an artificial intelligence-based computer application that solves problems using mechanisms commonly associated with biological evolution, weaker solutions are eliminated, while stronger and more viable ones are retained and re-evaluated to the time limit of achieving the desired results [26,27].

The evolutionary method, similar to other genetic or evolutionary algorithms, finds a good solution to a reasonably well-scaled model. Because the evolutionary method is not based on derivative or gradient information, it cannot determine whether a given solution is optimal, so it never really knows when to stop [28].

Evolutionary methods are widely applied to optimize processes, being basic for the use of artificial intelligence [29]. The evolutionary method using the generalized reduced gradient solving method (GRG), never ensures that it has found the best solution or that an improvement could be found in the evolutionary algorithm were executed for a longer time [30]. When Solver has converged to the current solution this can mean that Solver has found an optimal solution; if so, new members of the solution will tend to "crowd" around this solution. When Solver cannot improve the current solution, it will continue to search for better solutions in the specified time.

2.4. Polynomial Regression

Modeling the factors makes it possible to evaluate how much the community develops as energy is provided, the capital will change with a trend toward the energy demand. A polynomial regression analysis using Microsoft Excel is useful to find this trend [31]. With this, we can have a path between an initial scenario and an optimum point in time and establish the goals at each stage of the horizon of development planning.

3. Methodology

The proposed methodology for modeling and simulating the behavior of capital initial with diagnosis in a study community is shown in Figure 2. This scenario evaluates each of the capitals based on the selected indicators applicable to the selected community. After the analysis of the interaction of capitals, the specific indicators of the study related to energy demand are defined. The ranges of variation of the indicators are defined and the optimization model is run until an optimal solution is found. In the case of not reaching an optimum, "*n*" runs of the model are carried out until reaching the best feasible solution during the "*n*" times. The following figure presents, divided into three stages, the structure of the proposed methodology. The first called endogenous potentialities development includes the evaluation of the potential of the community, its capital, and opportunities for intervention. The second called development of the quantitative model deals with the development of the quantitative model that models the indicators with their variables and parameters that contribute to the development of the community related to energy. The third stage is the model simulation and optimization which performs the simulation of the evaluation of the variables and parameters of these indicators in the energy planning horizon as a way of having a tool that allows evaluating the contribution to the development of the interventions carried out.

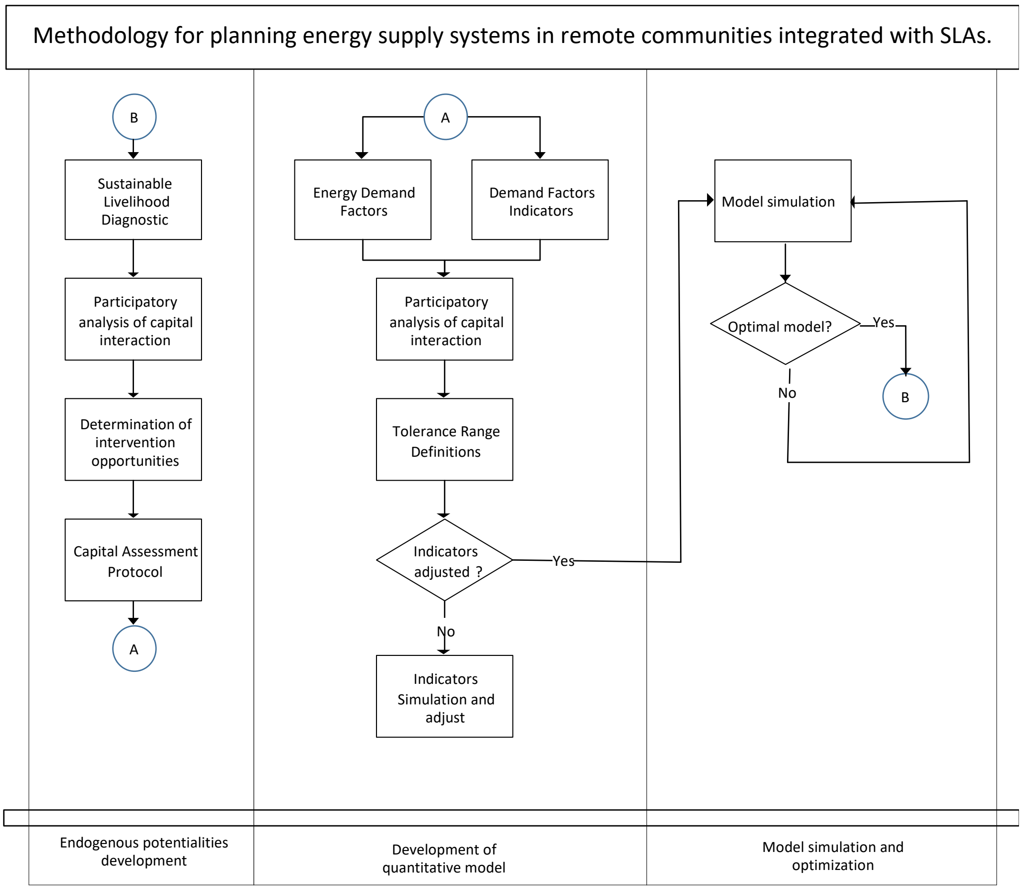

Figure 2. Proposed model for planning energy supply systems in remote communities based on SLs.

As has already been indicated, the area of the pentagon that is formed with the results of the capitals can be calculated employing the Gauss determinant. To establish a resolution method that allows the Gauss determinant to be applied, the ordinate axis has been set as human capital, then social capital is at 45°, financial capital at 135°, physical capital at 225°, and natural capital at 315°. All degrees are clockwise. This allows obtaining the Cartesian components in the plane of each capital by multiplying the value of the capital by $\sqrt{2/2}$. Table 2 presents the value of each component for the five capitals analyzed.

Table 2. Value of each component for the five capitals analyzed.

Variable	Description	Value
xC_h	Component x of Human Capital	0
xC_s	Component x of Social Capital	$C_s\sqrt{2/2}$
xC_{fin}	Component x of Financial Capital	$C_{fin}\sqrt{2/2}$
xC_{fis}	Component x of Physical Capital	$C_{fis}\sqrt{2/2}$
xC_n	Component x of Natural Capital	$C_n\sqrt{2/2}$
yC_h	Component *and* Human Capital	$C_s\sqrt{2/2}$
yC_s	Component of Social Capital	$C_s\sqrt{2/2}$
yC_{fin}	Component y of Financial Capital	$C_s\sqrt{2/2}$
yC_{fis}	Component y of Physical Capital	$C_s\sqrt{2/2}$
yC_n	Component y of Natural Capital	$C_s\sqrt{2/2}$

Therefore, the area of the pentagon will be determined by Equation (6).

$$A = \frac{1}{2}\left| xc_h yc_s + xc_s yc_{fin} + \cdots + xc_n - 1yc_n + xc_n yc_h - xc_s yc_h - xc_{fin} yc_s - \cdots - xc_n yc_{n+1} - xc_h yc_n \right| \quad (6)$$

where c_h is human capital, c_s is social capital, c_{fin} is financial capital, c_{fis} = physical capital, and c_n is natural capital.

3.1. Pentagon Area Shape Coefficient

The area shape coefficient (ASC) of the pentagon, obtained through Equation (7) allows us to evaluate the aspect ratio of the asset pentagons resulting from each proposed scenario. Equation (7) is the function objective to asset the evolution of areas, where A is the area of the pentagon of capitals. All capitals have values between 0 and 1.

$$Max\cdot \text{ ASC} = A\ (1 - CV) \quad (7)$$

Subject to:
$0 > c_h, c_h, c_s, c_{fin}, c_{fis}, c_n > 1$
Given the possibility of having the same total area of the pentagon with different arrangements of the capitals, it is necessary to establish a measure that allows evaluating the shape differences. The ASC penalizes the resulting area, subtracting a value proportional to the existing deviation (variation coefficient) [32–34]. The ASC of pentagons of equal area will be less while the more the capitals vary among themselves.

The goal of the proposed methodology is to obtain the maximum ASC according to the capital structure in the selected community. A maximum ASC guarantees the development of the community based on the growth of the ESS, as well as sustainability since this development will take place with a harmonious growth rate among the five capitals. After the first phase (evaluation of the capital), based on this potential, interventions are developed that modify the indicators and variables to promote development.

3.2. Capitals Modeling and Simulation Algorithm

Once the initial values of the capitals have been defined, the model is developed by performing macros, optimizing the areas, and calculating the capitals. A set of restrictions are developed for the variables so that the best response can be obtained for each case. For the evaluation of the three scenarios (poor, normal & rich) two cases were deemed. The first all evolve at the same rate and the second independently, however, the second was considered to have a better reference of the same condition of both.

Once the planning model was simulated, random variations were made for its simulation that allowed verifying its behavior and taking the average values. The average values are used as references to accurately determine the values of the three scenarios that define the three stages of evolution, from very low to rich resources. With the data from three scenarios, the behavior graphs are defined for the energy planning model integrated with the SLs. Furthermore, with them they are determined by adjustments of the most representative curves of each planning model run, to have the planning model represented through an equation and not of data. An equation allows us to determine the condition at each moment of the evolution between capitals. It is of great importance to establish that the analysis is conducted for limited conditions between 0 and 10 years.

With the modeling and simulation of the capitals and other variables, an analysis of the behavior of the systems can be developed at any moment. With the application of Equation (8), it has been possible to carry out a quantitative study from qualitative data.

$$Cap_{x(n)} = \sum_{n=0}^{n=10} Cap_{x(n-1)} \pm\ \delta * \frac{\Delta v}{\Delta t}\ ;\ 0 \le Cap_x \le 1 \quad (8)$$

where $Cap_{x(n-1)}$ is the capital under study x in the state n, δ is the discrete trigger function to define the addition or subtraction of the percentage factor, and $\frac{\Delta v}{\Delta t}$ is the percentage of 1% growth or decrease.

Figure 3 shows the capital simulation process. This flowchart expresses the logic of the simulation process of the variables and parameters for the calculation of the capital indicators. The prediction model starts from the generation of an initial scenario for the variables of the indicators defined from the review of the literature and is dimensioned using the community's survey, then it evolves to a rich scenario, optimized at each moment of the planning. the objective function. The optimization guarantees for each moment the highest value of each capital with the most regular shape possible of the asset pentagon.

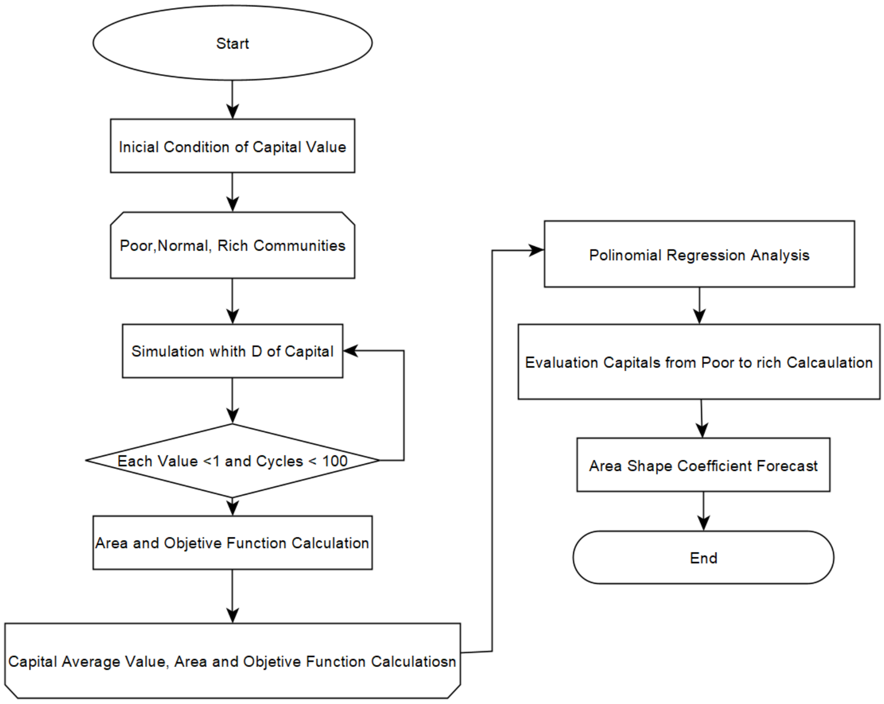

Figure 3. Capitals simulation flowchart.

Figure 4 shows the trend of the evolution of capital in the planning time horizon based on indicators related to energy demand. As can be seen, there is a linear increasing trend for four of the five capitals, except for natural capital, which decreases linearly because it is capital used by the community for its economic expansion. In any case, the proposed model limits the reduction of natural capital to 60% of the initial level and a harmonious regularity with the other capitals with the ASC.

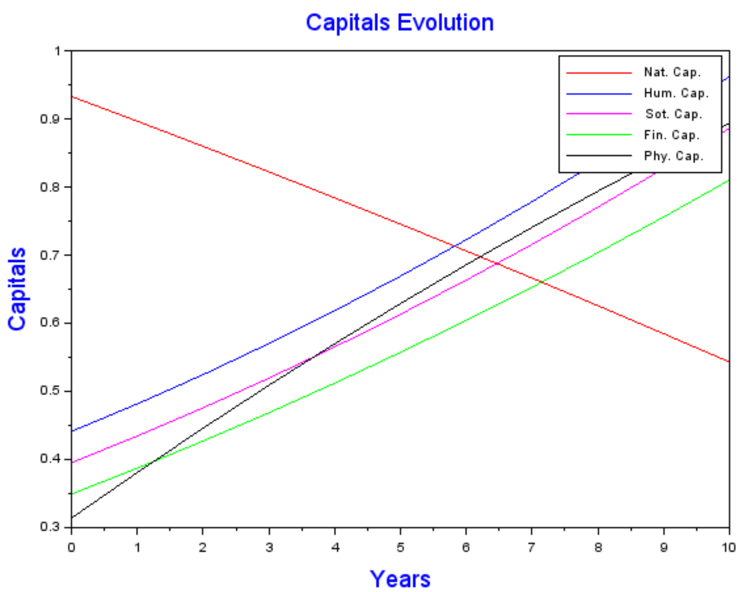

Figure 4. Capital evaluation equations.

4. Results

The results have been obtained through a simulation of the values of the variables established based on a survey carried out in Santana, a remote community of Los Cacaos, San Cristóbal Province in the Dominican Republic.

Figure 5 allows us to see graphically how the proposed methodology relates the variables of the key indicators for the delivery of livelihood opportunities to the communities so that their capitals improve over the time horizon. It is important to consider that the sustainable livelihoods approach carries out a process of participatory interaction between the indicators of the capital to guarantee the sustainable development of the community.

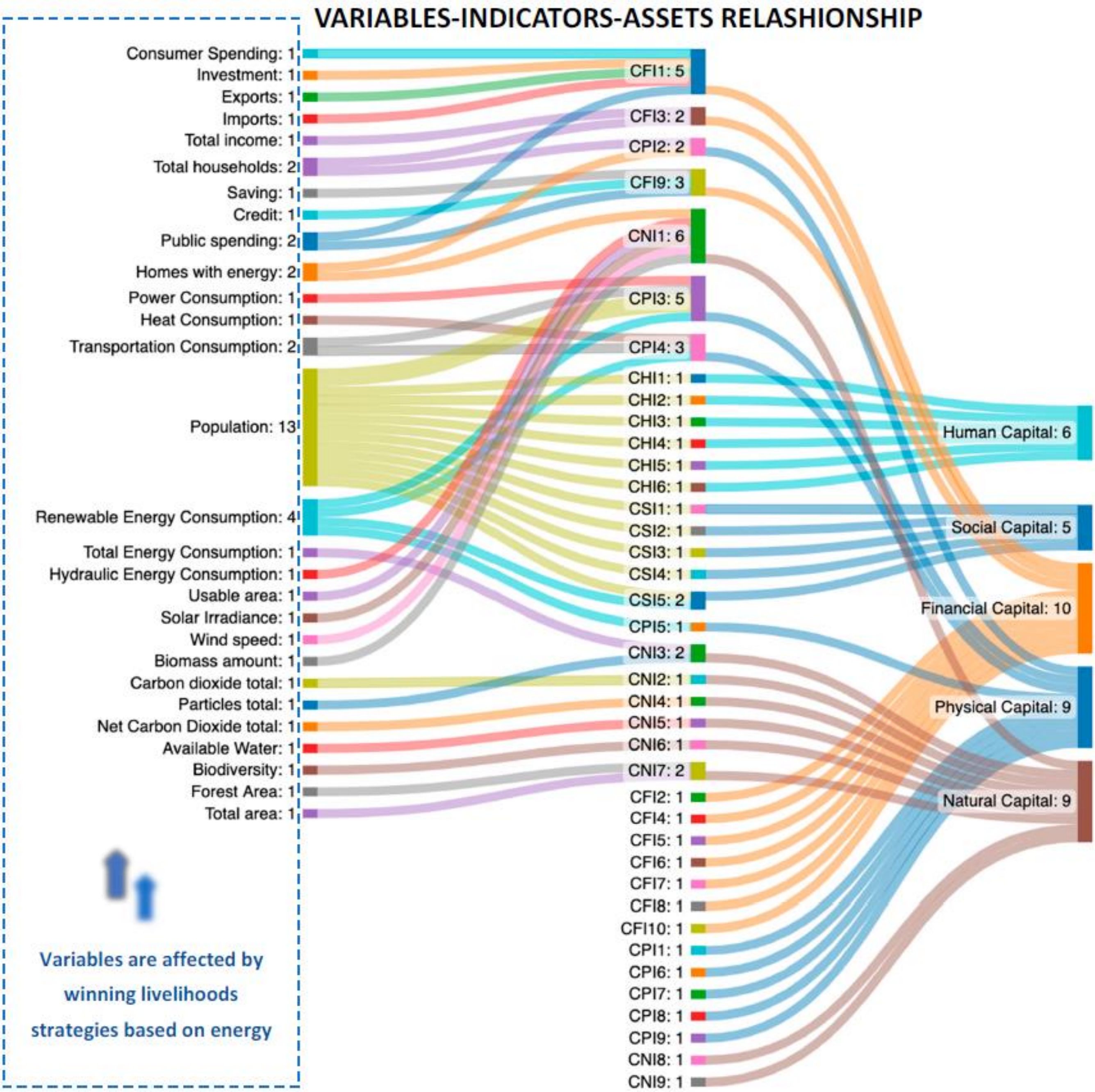

Figure 5. Variables indicators assets relationship diagram.

The analysis through the parameter's simulation of the community livelihood, shows the evolution from the poor to rich scenario, going through normal. With this, it is possible to establish the pathway that the community must follow in planning its development, at the same time that they control their development through monitoring capital variables.

A set of polynomial regressions equations were calculated based on the simulations performed, which allows seeing the behavior and analyzing its average value. This serves as the basis for establishing the initial and final value of the capital considering a normal evolution of the same. Table 3 shows the equations obtained through polynomial regression for each of the capitals.

Table 3. Regression equations for each capital.

Capitals	Equations
Human capital	$y = 0.0013x^2 + 0.0391x + 0.4412$
Social capital	$y = 0.0011x^2 + 0.0381x + 0.3952$
Financial capital	$y = 0.0009x^2 + 0.0371x + 0.3492$
physical capital	$y = -0.001x^2 - 0.068x + 0.3139$
natural capital	$y = -0.0003x^2 - 0.036x + 0.9933$

A polynomial regression analysis was performed for the objective function, taking the three scenarios: poor, normal, and rich. The resulting equation is described in Figure 6. The objective function represents the growth of the capital and the growth condition of the community, which is observed as a community whose growth objectives are outlined with a vision, allowing the capital to develop favorably, resulting in economic and social growth.

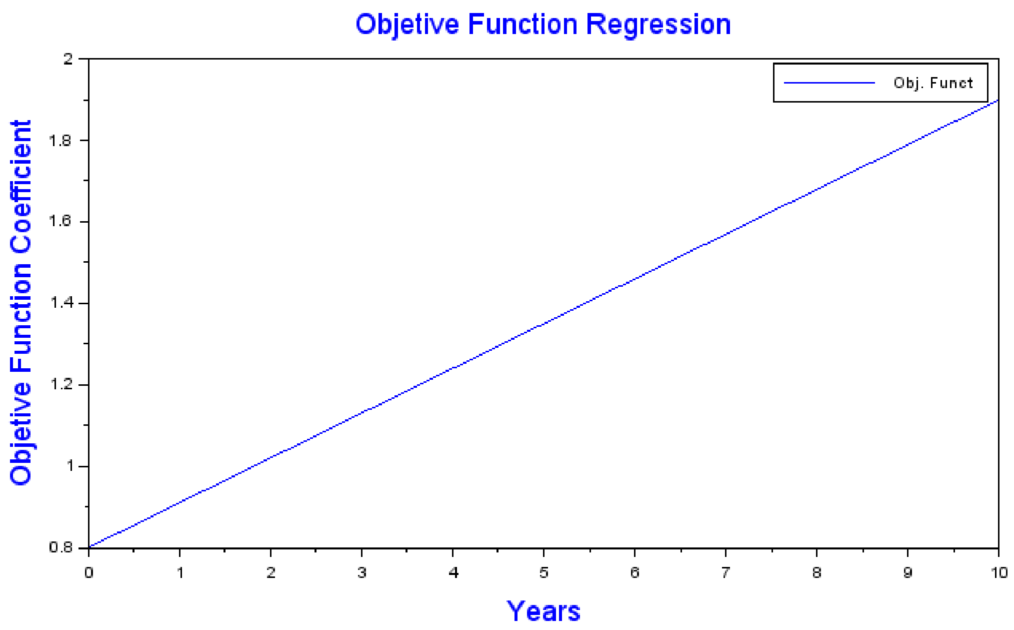

Figure 6. Regression of the objective function.

Table 4 presents the data that describes the behavior of the capitals and the objective function considering the polynomial regressions and evolution behavior between the different scenarios, as well. There is a growing trend in the data corresponding to human, social, financial, and physical capital, while natural capital decreases due to the use of resources made to promote community development.

This methodology allows evaluating the contribution to development by the adequate provision of the demand of the ESS in remote communities through the SLs approach by comparing the area of the pentagon with the optimum of the ASC with what is chosen for each possible scenario the solution that has the most regular shape for the largest possible area which translates into resilient and harmonious development among all capitals. For a case study, it will only be necessary to select the specific indicators and variables applicable to the community and substitute them in the validated model to obtain the long-term planning of community development based on its livelihoods.

Table 4. Capitals evolution behavior between the different scenarios.

Period	C_h	C_s	C_{fin}	C_{fis}	C_n	Objective Function
0	0.4412	0.3952	0.3492	0.3139	0.9933	0.80
1	0.4816	0.4344	0.3871	0.3809	0.9576	0.91
2	0.5246	0.4758	0.4268	0.4459	0.9225	1.02
3	0.5702	0.5194	0.4683	0.5089	0.8880	1.13
4	0.6184	0.5652	0.5116	0.5699	0.8541	1.24
5	0.6692	0.6132	0.5567	0.6289	0.8208	1.35
6	0.7226	0.6634	0.6036	0.6859	0.7881	1.46
7	0.7786	0.7158	0.6523	0.7409	0.7560	1.57
8	0.8372	0.7704	0.7028	0.7939	0.7245	1.68
9	0.8984	0.8272	0.7551	0.8449	0.6936	1.79
10	0.9622	0.8862	0.8092	0.8939	0.6633	1.90

5. Discussions

When evaluating the area–time curve with energy–time demand, there is a direct relationship between the area of the pentagon at each stage of the community planning horizon and energy demand. This allows corroborating that a correct provision of energy for intervention projects that allow taking advantage of the endogenous potential of the community will increase the capital of the community. However, this capital increase may not be sustainable if the growth of one capital is achieved at the expense of another capital, as has been seen in communities where financial capital grows and natural capital deteriorates significantly. Therefore, this research proposes that the Objective Function based on the ASC chooses for each possible scenario the solution that has the most regular shape, which will be the one that harmonizes the results among all the capitals.

There is a high correlation between the variations of the area and the ASC, which allows us to establish that as the capitals grow, there is a growth around the pentagon that they form and therefore a community development growth. This constitutes the fundamental utility of the methodology, being able to have a tool to evaluate within the temporal horizon how winning livelihood interventions help to improve community capital.

The variation of the energy demand expressed by the curve allows the evaluation of a trend highly correlated to the evolution of the area, which clearly states how the correct provision of energy to a community contributes not only to the decrease of PE but also to sustainable development, based on SLs indicators. As shown in Figure 7.

In the case studies, there will be a line of evolution that may go below at one time and at others above the trend line of the simulated planning. When this occurs, the variables that affect this change must be verified and the necessary interventions to control them according to future projections.

In certain cases where the rise or fall difference is too great at the beginning or end, or where shapes of the trend line are obtained that are far from the planned one, it is possibly intervention projects executed at very specific times within the time horizon. This is due to the certain availability of resources obtained by the particular social processes of the community. The differences produced must be adjusted with the initial planning model.

The sustainable livelihoods approach has a set of variables and parameters that in this work have been selected for their relationship with energy management, which can be considered as decision elements in future work that focuses on smart management in the short term.

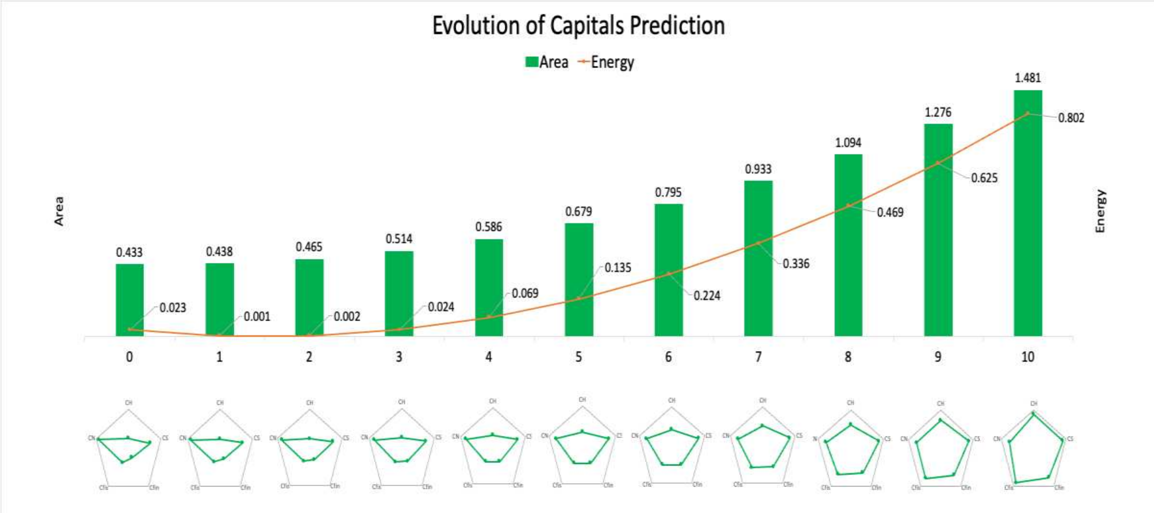

Figure 7. Forecast of the evolution of capitals.

Table 5 presents a model comparison with eighteen recent papers. In 2020, Mukisa et al. included the optimization of the model for a local case and develops his model for specific moment conditions [35]. The proposed model included the optimization and focuses on the long term with the annual evolution within a timeline only, the proposed work has included the projection of the evolution of capital through the temporal horizon.

Table 5. Proposed model comparison.

No.	References	SLA	Optimized Model	Capitals, Indicators and Variables Projected	Temporal Resolution	Spatial Resolution
1	Proposed Model	YES	YES	YES	Long Term	Local
2	Henao [36]	YES	NO	NO	Specific conditions	Local
3	Bhattarai and Thompson [37]	-	NO	NO	Specific conditions	Local
4	Martinkus [38]	YES	NO	NO	Specific conditions	Local
5	Huang et al. [28]	-	NO	NO	Long-term	Regional
6	Nadimi and Tokimatsu [39]	-	NO	NO	Long-term	Global
7	Yadav et al. [40]	-	NO	NO	Long-term	Global
8	Mahmud et al. [41]	-	NO	NO	Long-term	Global
9	Akinyele et al. [16]	-	NO	NO	Specific conditions	Local
10	Chinmoy et al. [42]	-	NO	NO	Long-term	Global
11	Khanna et al. [43]	-	NO	NO	Long-term	Regional
12	Søraa et al. [44]	-	NO	NO	Long-term	Global
13	Karthik et al. [45]	-	NO	NO	Specific conditions	Local
14	Viteri et al. [46]	-	NO	NO	Specific conditions	Regional
15	Mukisa et al. [35]	YES	YES	NO	Specific conditions	Local
16	Musonye et al. [47]	-	NO	NO	Long-term	Global
17	Lozano and Taboada [48]	-	NO	NO	Long-term	Global
18	Campos and Marín-González [49]	-	NO	NO	Long-term	Global
19	Ahmadi & Rezaei [50]	-	NO	NO	Specific conditions	Local

6. Conclusions and Recommendations

This paper studies the gap research between energy planning models and the Sustainable Livelihoods (SLs) approach. To contribute to decision-making in the development planning of remote communities in relation to the evolution of energy demand, work has been carried out to achieve sustainable development goals, especially objective-7. A model has been proposed that has the practical utility of guiding decision-making for the community's development and evolution of the energy supply system in the long term.

Due to the correlation between the area of the pentagon and energy demand, it can be concluded that the adequate energy supply system to remote communities will increase the community's sustainable livelihoods. In the case studies, the variables that affect the changes in the modeled trend line should be controlled. This must be carried out by comparing the real value with the projected one and taking actions that allow driving the study variable to the desired value.

A trend line from the case study will diverge from the modeled one, according to the execution of the interventions, based on the use of energy that affects the variables of the model. These interventions may be plans, actions, or microcredits that allow the installation of electro-energy equipment and machinery that help improve the efficiency of the products or services that the community offers.

Modeling of the energy supply system is necessary for the provision of the demand in long-term planning technologies. It brings the application of optimization of energy systems, especially with renewable energies to ensure an affordable and clean pathway. The proposed methodology is intended to be applied to communities classified with energy poverty. This will allow for having totally objective selection criteria in establishing an order of priority for the proper implementation of development projects.

Future works should study how an energy management system can control the dispatch demand in the short term the energy supply system according to the resources availability and its harnessing.

Author Contributions: Conceptualization, C.P.-M., F.S.G. and V.S.O.-G.; methodology, C.P.-M., J.A.-M. and V.S.O.-G.; investigation, C.P.-M., J.A.-M. and V.S.O.-G.; writing—original draft preparation, C.P.-M., J.A.-M., A.V.D. and V.S.O.-G.; writing—review and editing, C.P.-M. and A.V.D.; supervision, F.S.G.; project administration, C.P.-M.; supervision, F.S.G.; funding acquisition, C.P.-M. and F.S.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Ministerio de Educación Superior, Ciencia y Tecnología (MESCyT) grant number [2020-2021-3A9-054] and the APC was funded by Instituto Especializado de Estudios Superiores Loyola (IEESL).

Acknowledgments: The authors acknowledge the Instituto Especializado de Estudios Superiores Loyola (IEESL) for the contribution to the development of this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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