

Sorting Algorithm Applied in Geographical Regions Using Residential Electricity Consumption Indicators

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Abstract— The electricity consumption per capita in Ecuador almost doubled between 1999 and 2017. Although electricity, gas and fuels are subsidized by the state, and thus generate savings for users, this often leads to inefficient use or bad energy consumption habits in the population. The current economic situation in the country has urged reconsidering the continuity of fuel subsidies, so prices have been adjusted. It is evident that the continued elimination of subsidies will negatively impact Ecuadorian low and middle-income families, becoming necessary to find alternatives and possible solutions regarding energy, while also familiarizing with the profile and habits of electricity consumption in residences. A sorting algorithm based on Theory of Decision in Uncertainty is implemented to rank 8 urban-marginal areas in Guayaquil City according to 14 indicators that significantly impact energy consumption. From 700 thousand users of urban-marginal areas of Ecuador, 200 thousand can be found in Guayaquil. The information of some indicators of electrical consumption collected in surveys applied in residences of the areas is used as an ordering criterion. Results will show the differences between those areas and will be useful for later studies or for decision-making processes of competent authorities in order to improve living conditions while maintaining rational indicators of electrical consumption. Los Esteros, Guasmo and Vergeles present the best consumption pattern, in comparison with Bastión Popular and Flor de Bastión, which show the worst results in regards to the consumption among the 8 areas studied.

Keywords— electricity consumption indicators; energy consumption; energy demand; ordering algorithm; theory of decision.

I. INTRODUCTION

The Ecuadorian population is constantly growing: according to official National Institute of Statistics and Census (INEC) information, in 1950 the population was 3,202,157 inhabitants and is currently close to 17 million [1]. This growth is correlated with the energy demand of the residential sector that, according to statistical reports [2], shows an increasing consumption trend.

It is worth noting that electricity, gas and fuels are subsidized by the state, which although represents economic savings for users, frequently leads to inefficient use and bad energy consumption habits [3]. The current national economic scenario has urged to reconsider the continuity of subsidies [4]. For instance, the 92-octane gasoline subsidy has been eliminated. However, elimination of subsidies may affect the average cost of other resources, such as energy. So, what would happen if the Ecuadorian State eliminated subsidies with direct residential implications? In general, it

is evident that there would be a negative economic impact on low and middle-income Ecuadorian families [5]. It is necessary to consider alternatives and possible solutions in the energy and residential field to face the aforementioned question.

In Ecuador, some feasibility studies of electricity production from renewable energy sources have been carried out [6]–[8]. The use of ecological materials in asphalt mortars and in energetically efficient housing construction has also been studied [9]. In the residential field, studies have been developed to take advantage of intelligent electrical systems to optimize the consumption of electrical energy [10]. To estimate energy consumption in households a questionnaire was applied in a marginal urban area of Guayaquil [11]. The incidence of adolescents on economic, sociodemographic and residential consumption habits indicators has also been assessed [12].

Mathematical models based on deterministic or statistical principles have always been used to solve the most varied

problems in natural sciences, both empirically and theoretically. Phenomena of an inorganic or inanimate nature governed by mechanics, physics, or chemistry laws, as well as phenomena of organic or animated nature to which biological principles and laws also bind, whether dynamic or static, have easily assimilated these mathematical models.

Fortunately, recent models and algorithms have gained ground to form the foundations of Numerical and non-Numerical Mathematics with uncertainty. Fuzzy logic has been used as a basis: a tool that allows to model eminently social phenomena with data that it is not reliable enough to assume statistical laws because of its poor structure. Models associated with relationship, grouping, ordering, etc. —some of which have been known for quite some time— can facilitate the path for those who take sides with one alternative over another [13], [14]. These models have been used successfully in recent years in economics and management. Broad treatment with these models can be reviewed in [15].

This study corresponds to the line of research expressed in the previous paragraph. The statistical information used was taken from the research project entitled: Simulation and Projection of the Behavior of the Electric Power Demand in Rural and Urban - Marginal Areas of Guayas – Ecuador, coded as FCI-037-2018, which corresponds to multi-stage works published in the form of preliminary results [6], [16], [17].

This paper aims to organize 8 urban-marginal areas of Guayaquil, based on criteria and indicators taken from a survey of electricity consumption applied to a sample of households in each study area [18], [19]. Given the data obtained includes objective and subjective information, an ordering algorithm based on fuzzy mathematics is used.

II. MATERIAL AND METHOD

To apply the ordering algorithm, groupings $E_1 = \{P_1, P_2, \dots, P_m\}$ of m elements, and $E_2 = \{C_1, C_2, \dots, C_n\}$ of n characteristics or qualities that form the criteria for ordering are needed. These techniques, based on fuzzy mathematics, are the result of the research carried out by Kaufmann & Gil for the approach and solution of economic, management and social problems. The ordering algorithm used in this study is developed in [15], [20]–[22]. In [23]–[25] this algorithm is applied in the solution of practical problems.

The following groupings are considered for this paper: $E_1 = \{P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8\}$

Where:

- $P_1 =$ Bastión Popular,
- $P_2 =$ Los Esteros,
- $P_3 =$ Flor de Bastión,
- $P_4 =$ Guasmo,
- $P_5 =$ Malvinas,
- $P_6 =$ Mapasingue,
- $P_7 =$ Monte Sinaí,
- $P_8 =$ Vergeles,

That is, E_1 is made up of 8 urban-marginal zones of the city of Guayaquil, cantonal capital of the province of Guayas in Ecuador.

On the other hand,

$$E_2 = \{C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{14}\}$$

Where:

- $C_1 =$ Average social stratification score,
- $C_2 =$ Average outlet 120 volts per region,
- $C_3 =$ Average of saving lights per region,
- $C_4 =$ Average of air conditioning equipment,
- $C_5 =$ Average of rooms in the home,
- $C_6 =$ Average years of use of the refrigerator,
- $C_7 =$ Average years of use of the blender,
- $C_8 =$ Average years of use of the washing machine,
- $C_9 =$ Average years of use of sound equipment,
- $C_{10} =$ Average number of years of radio-recorder use,
- $C_{11} =$ Average years of television use,
- $C_{12} =$ Average years of computer use,
- $C_{13} =$ Average years of use of the fan,
- $C_{14} =$ Average number of years of use of the electric iron.

That is, E_2 is made up of 14 characteristics or qualities that have been selected from the survey questionnaire. The following 4 matrix processes must be followed for the application of this ordering algorithm:

1) *Step one:* The $n \times m$ matrix that contains information on the characteristics or qualities of each of the study areas:

	C_1	C_2	C_3	.	.	.	C_n
P_1	μ_{11}	μ_{12}	μ_{13}	.	.	.	μ_{1n}
P_2	μ_{21}	μ_{22}	μ_{23}	.	.	.	μ_{2n}
P_3	μ_{31}	μ_{32}	μ_{33}	.	.	.	μ_{3n}
.
.
.
P_m	μ_{m1}	μ_{m2}	μ_{m3}	.	.	.	μ_{mn}

These values can be obtained from both measures and assessments. The μ_{ij} values located in each cell represent the degree at which each P_i element in E_1 meets the characteristic or quality C_j in E_2 .

The two following conditions must be met:

- Values should be normalized by converting them to an [0,1] interval, dividing, for each column $1 \leq j \leq n$, the value μ_{ij} by the maximum value of that column.
- Considering the goal is to order from best to worst, the matrix should be made in such a way that the highest values are the most appreciated. In case the higher values of a characteristic or quality are the worst appreciated, the complementary value is taken with respect to 1.

2) *Step two:* Once these conditions are met, the following matrix is formed:

	C_1	C_2	C_3	.	.	.	C_n
P_1	α_{11}	α_{12}	α_{13}	.	.	.	α_{1n}
P_2	α_{21}	α_{22}	α_{23}	.	.	.	α_{2n}
P_3	α_{31}	α_{32}	α_{33}	.	.	.	
.
.
.
P_m	α_{m1}	α_{m2}	α_{m3}	.	.	.	α_{mn}

Where α_{ij} , $1 \leq i \leq m$, $1 \leq j \leq n$ meet i) and ii).

3) *Step three*: Then, the following matrix is formed with C_1 characteristic or quality and its values:

	P_1	P_2	P_3	.	.	.	P_m
P_1	x	β_{12}	β_{13}	.	.	.	β_{m1}
P_2	β_{21}	x	β_{23}	.	.	.	β_{2m}
P_3	β_{31}	β_{32}	x	.	.	.	β_{3m}
.	.	.	.	x	.	.	.
.	.	.	.	.	x	.	.
.	.	.	.	.	.	x	.
P_m	β_{m1}	β_{m2}	β_{m3}	.	.	.	x

Where $\beta_{ij} = 0$, if $\alpha_{i1} < \alpha_{j1}$ and $\beta_{ij} = 1$, if $\alpha_{i1} \geq \alpha_{j1}$

This process is repeated with the remaining C_j for $j = 2, \dots, n$ and n matrices formed by zeros and ones are obtained. Note that the elements of the main diagonal are not considered because they do not tax the ordering decision.

4) *Step four*: The matrices obtained in the previous step only offer information on the degree of preference for E_1 pairs of elements for each E_2 characteristic or quality. The following matrix is formed, resulting from the average for each of the n corresponding cells.

	P_1	P_2	P_3	.	.	.	P_m
P_1	x	δ_{12}	δ_{13}	.	.	.	δ_{1m}
P_2	δ_{21}	x	δ_{23}	.	.	.	δ_{2m}
P_3	δ_{31}	δ_{32}	x	.	.	.	δ_{3m}
.
.
.
P_m	δ_{m1}	δ_{m2}	δ_{m3}	.	.	.	x

Where $0 \leq \delta_{ij} \leq 1$: A value $\delta_{ij} = 1$ means that P_i exceeds P_j for all the characteristics of the set E_2 and if $\delta_{ij} = 0$ means that P_i does not exceed P_j in any characteristic of E_2 . In general P_i exceeds P_j for some characteristics of E_2 and for others not, hence $0 \leq \delta_{ij} \leq 1$.

For groupings E_1 and E_2 formed by few elements, this algorithm can be illustrated by a sagittal graph considering threshold values. For groupings composed of many elements, the algorithm can be easily programmed if the following observations are considered:

- The first place in the order is the P_i for which the entire column of the last matrix is formed of zeros.
- The last place in the ordering is formed by the P_j for which the entire row of the last matrix is formed of zeros.

In this way, the first and last place of the order is obtained. The corresponding rows and columns are eliminated, and the process is repeated with the second and penultimate places, then the third and the third last, until all the elements are exhausted.

III. RESULTS AND DISCUSSION

Once the information collected in the socioeconomic surveys for energy consumption was processed, the μ values were obtained. Table 1 shows the starting values of the $n \times m$ matrix. Indicators from 1 to 5 with the highest values are the most appreciated, while 6 until 14 are the least appreciated, given the longer uses of household appliances, lower frequency of its renewal with better, more efficient and lower electrical consumption technology. After performing the 4 matrix processes specified, Table 2 was obtained, in which δ values within the interval $[0,1]$ are specified. With these values, the respective binary ordering arrays are established from a tuner or threshold as a discriminator. Thresholds of 0.7, 0.6 and 0.55 were considered. Table 3 shows the matrix obtained from the threshold 0.55.

Table 4 summarizes the order of the areas obtained for each threshold. It is evident that the 0.55 threshold has a better order. In the three proven thresholds, it is observed that the areas 2, 4 and 8—that is, Los Esteros, Guasmo and Vergeles, respectively—are marginal urban areas with better characteristics or qualities in terms of the 14 socioeconomic indicators considered in this study. Meanwhile, areas 1 and 3, Bastión Popular and Flor de Bastión, display the worst characteristics.

TABLE I
VALUES μ OF THE SOCIOECONOMIC INDICATORS OF EACH URBAN AREAS MARGINAL OF GUAYAQUIL

No	Socioeconomic Indicators	Urban Areas Marginal of Guayaquil							
		1. Bastión Popular	2. Los Esteros	3. Flor de Bastión	4. Guasmo	5. Malvinas	6. Mapasingu	7. Monte Sinai	8. Vergeles
1	Average social stratification score	551.2	636.3	500.04	579.07	542.9	568.8	410.3	561.8
2	Average outlet 120 volts per region	6.1	7.7	5	6.7	6.9	5.9	3.6	5.5
3	Average of saving lights per region	4.9	7.5	4.5	6.2	5	5.5	3.1	4.3
4	Average of air conditioning equipment	0.9	1	0.15	0.7	0.42	0.5	0.1	0.6
5	Average of rooms in the home	3.2	3.8	3.1	3.8	3.5	3.6	2.5	3.2
6	Average years of use of the refrigerator	6.58	4.89	6.86	6.03	7.26	6.94	5.64	6.25
7	Average years of use of the blender	4.46	4.32	4.3	3.99	4.2	4.24	4.41	3.9
8	Average years of use of the washing machine	4.72	4.86	4.84	4.81	4.89	4.98	3.41	5.09
9	Average years of use of sound equipment	5.35	3.82	4.64	4.62	4.22	4.87	4.3	4.17
10	Average number of years of radio-recorder use	6.67	6.55	5.4	5.42	9.4	6.9	5.3	4.45
11	Average years of television use	5.73	4.74	4.98	4.52	4.99	5.14	4.55	4.5
12	Average years of computer use	4.18	3.49	3.82	4.1	3.05	4.07	3.49	3.77
13	Average years of use of the fan	2.77	3.67	3.47	3.31	3.72	3.57	3.02	3.21
14	Average number of years of use of the electric iron	4.76	6.64	4.36	4.21	3.89	3.67	3.77	3.53

TABLE II
VALUES β OF THE SOCIOECONOMIC INDICATORS OF EACH URBAN AREAS MARGINAL OF GUAYAQUIL

	1. Bastión Popular	2. Los Esteros	3. Flor de Bastión	4. Guasmo	5. Malvinas	6. Mapasingue	7. Monte Sinai	8. Vergeles
1. Bastión Popular	x	0.21	0.57	0.21	0.43	0.43	0.36	0.43
2. Los Esteros	0.79	x	0.71	0.57	0.79	0.79	0.64	0.64
3. Flor de Bastión	0.43	0.29	x	0.07	0.36	0.50	0.43	0.07
4. Guasmo	0.79	0.43	0.93	x	0.64	0.86	0.50	0.57
5. Malvinas	0.57	0.21	0.64	0.36	x	0.50	0.57	0.36
6. Mapasingue	0.57	0.21	0.50	0.14	0.50	x	0.50	0.29
7. Monte Sinai	0.64	0.36	0.57	0.50	0.43	0.50	x	0.29
8. Vergeles	0.57	0.36	0.07	0.43	0.64	0.71	0.71	x

TABLE III
BINARY MATRIX OBTAINED FROM THE THRESHOLD 0.55

Threshold ≥ 0.55								
	1. Bastión Popular	2. Los Esteros	3. Flor de Bastión	4. Guasmo	5. Malvinas	6. Mapasingue	7. Monte Sinai	8. Vergeles
1. Bastión Popular	x	0	1	0	0	0	0	0
2. Esteros	1	x	1	1	1	1	1	1
3. Flor de Bastión	0	0	x	0	0	0	0	0
4. Guasmo	1	0	1	x	1	1	0	1
5. Malvinas	1	0	1	0	x	0	1	0
6. Mapasingue	1	0	0	0	0	x	0	0
7. Monte Sinai	1	0	1	0	0	0	x	0
8. Vergeles	1	0	0	0	1	1	1	x

TABLE IV
ORDINATIONS OBTAINED FROM THE THRESHOLDS APPLIED

Thresholds	Ordinations obtained
≥ 0.7	{2, 4, 8} > {5, 6, 7, 1, 3}
≥ 0.6	{2, 4} > {8} > {5, 7} > {6, 1, 3}
≥ 0.55	{2} > {4} > {8} > {5,6} > {7} > {1} > {3}

Figure 1 shows the graph diagram of the matrix obtained from the threshold 0.55; the respective ordering is sequentially evidenced, starting with the elimination of the nodes that only have arrow exits.

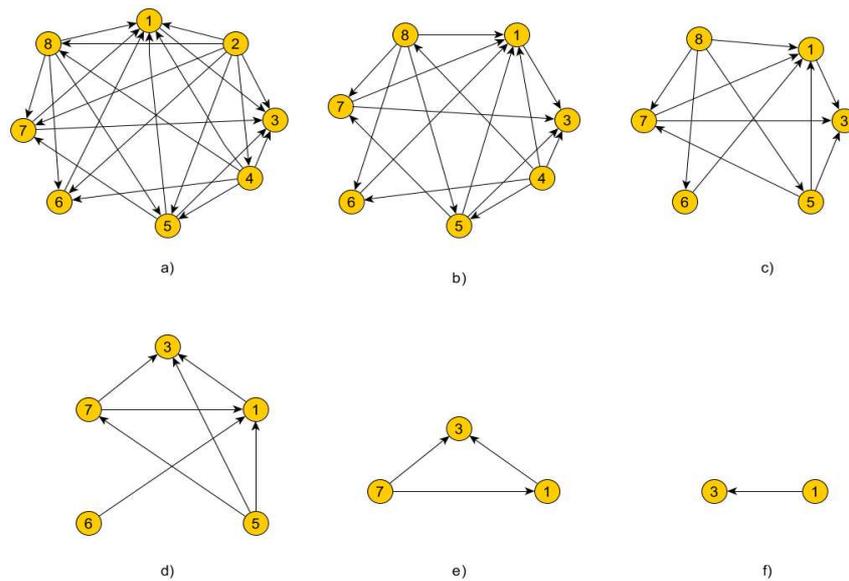


Fig. 1. Graph representation of the binary matrix for the threshold 0.55. a) Initial graph, b) Graph with node-2 removed, c) Graph with node-4 removed, d) Graph with node-8 removed, e) Graph with node-5 and 6 removed, f) Graph with node-7 removed.

IV. CONCLUSIONS

This study shows the application of a fuzzy mathematical algorithm for sorting geographical areas based on socioeconomic indicators of residential electricity consumption. Bearing in mind that indicators are directly related to electricity consumption and its efficiency, it is concluded that Los Esteros, Guasmo and Vergeles are the areas with optimal indicators, in comparison with Bastión Popular and Flor de Bastión, which show the worst results in regards to the consumption among the 8 areas studied.

These results could serve as a reference to promote energy efficiency policies at the residential level and apply this methodology in other areas of the country and the region. "Best" or "worst" results do not necessarily represent lower or higher consumption rates. The results were assessed indirectly to determine better levels and quality of life in the inhabitants. This is considered a strength of the study. Statistical tools were accepted for this study, but the fuzzy approach was preferred since it can operate better with information of joint objective or measurable and subjective data which, given household surveys do not always reflect the exact truth, if the case.

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REFERENCES

- [1] INEC, "Ecuador en cifras," 2017. [Online]. Available: <http://www.ecuadorencifras.gob.ec/guayaquil-en-cifras/>.
- [2] ARCONEL, "Estadística del Sector Eléctrico," 2019. [Online]. Available: <https://www.regulacionelectrica.gob.ec/estadistica-del-sector-electrico/>.
- [3] V. Orejuela, D. Arias, and A. Aguila, "Response of Residential Electricity Demand Against Price Signals in Ecuador," in *Proceedings of the 2015 IEEE Thirty Fifth Central American and Panama Convention (Concapan XXXV)*, 2015, pp. 1–6.
- [4] F. Schaffitzel, M. Jakob, R. Soria, A. Vogt-Schilb, and H. Ward, "Can government transfers make energy subsidy reform socially acceptable? A case study on Ecuador," *Energy Policy*, vol. In Press, 2019.
- [5] G. Poveda Burgos, M. Suraty Molestina, and R. Mackay Castron, "Trade policy in the framework of the ecuadorian international trade [Políticas comerciales en el marco del comercio internacional ecuatoriano]," *Espacios*, vol. 39, no. 47, 2018.
- [6] S. Coello Pisco, Y. González Cañizares, J. Hidalgo Crespo, J. Barzola Montesés, and L. M. Alonso Águila, "Desarrollo de habilidades Science, Technology, Engineering and Mathematics, en estudiantes universitarios de Física mediante proyectos I +D + i. Caso: estimación de la demanda de la energía eléctrica en zonas rurales y urbano-marginales," *Rev. Mex. Física E*, vol. 65, no. 1, pp. 44–51, 2019.
- [7] M. Mite-León and J. Barzola-Monteses, "Statistical Model for the Forecast of Hydropower Production in Ecuador," *Int. J. Renew. Energy Res.*, vol. 10, no. 2, pp. 1130–1137, 2018.
- [8] J. Barzola-Monteses, M. Mite-León, M. Espinoza-Andaluz, J. Gómez-Romero, and W. Fajardo, "Time Series Analysis for Predicting Hydroelectric Power Production: The Ecuador Case," *Sustain.*, vol. 11, no. 6539, pp. 1–19, 2019.
- [9] J. Barzola, F. Cabrera, and M. Espinoza, "On Parameters Testing of an Innovative Mortar Made of Rice Husk to be Used for Housing Walls," in *ISES Solar World Congress 2015*, 2015, no. November 2015, pp. 1–7.
- [10] J. Barzola and L. Rubini, "A Hypothetical Migration Analysis of the PLC based on IEEE 1901.2 Standard," in *Proceedings of the 21st World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2017)*, 2017, pp. 86–91.
- [11] J. Hidalgo, S. Coello, and Y. González, "The Determinants of Household Electricity Demand in Marginal Ecuador: 'A Case Study at Monte Sinai,'" in *16th LACCEI International Multi-Conference for Engineering, Education, and Technology: "Innovation in Education and Inclusion."*, 2018, pp. 1–6.
- [12] H. Wallis, M. Nachreiner, and E. Matthies, "Adolescents and electricity consumption; Investigating sociodemographic, economic, and behavioural influences on electricity consumption in households," *Energy Policy*, vol. 94, pp. 224–234, 2016.
- [13] A. A. Aliaga-Benavides, Y. Santana-Pacheco, A. Mustelie-Hechavarría, and Y. Guzmán-Bazán, "Computer algorithm for comparing and ordering models based on indicators and user value," *Rev. Fac. Ing.*, vol. 26, no. 46, pp. 61–69, 2017.
- [14] T. Nishijima, A. Honda, and M. Ohki, "Proposal of an efficient rank-ordering method based on subjectivity," *Communiation Pap. 2017 Fed. Conf. Comput. Sci. Inf. Syst.*, vol. 13, pp. 353–356, 2017.
- [15] J. Gil Aluja, *Elementos para una teoría de la decisión en la incertidumbre*. España: Editorial Milladoiro, 1999.
- [16] J. Hidalgo-Crespo, Y. González Cañizalez, S. Coello Pisco, J. Barzola-Monteses, L. M. Alonso Aguila, and T. Crespo-Vaca, "Household Electricity Demand in Marginal Ecuador: Estimation and impact of explanatory variables," *Rev. Ibérica Sist. e Tecnol. Informaçãõ*, 2019.
- [17] Y. González Cañizalez, J. Hidalgo-Crespo, S. Coello Pisco, J. Barzola-Monteses, and L. M. Alonso Águila, "Sorting urban-marginal areas in Ecuador by weighting energy consumption indicators," *Rev. Iber. Sist. e Tecnol. Inf.*, 2019.
- [18] C. Grottera *et al.*, "Linking electricity consumption of home appliances and standard of living: A comparison between Brazilian and French households," *Renew. Sustain. Energy Rev.*, vol. 94, pp. 877–888, 2018.
- [19] L. Maluf de Lima and M. R. Piedade Bacchi, "Assessing the impact of Brazilian economic growth on demand for electricity," *Energy*, vol. 172, pp. 861–873, 2019.
- [20] J. Gil-Aluja, "Entre la epistemología y la lógica. Decisión y algoritmo de ordenación," *Cuad. Gestión*, vol. 1, no. 1, pp. 151–159, 2001.
- [21] A. Kaufmann and J. Gil Aluja, *Grafos neuronales para la economía y la gestión de empresas*. España: Editorial Pirámide, 1995.
- [22] J. Gil Lafuente, *Marketing para el nuevo milenio: nuevas técnicas para la gestión comercial en la incertidumbre Descripción principal*. España: Ediciones Pirámide, 1997.
- [23] L. M. Alonso Águila, "La evaluación del aprendizaje desde una perspectiva de la subjetividad y la incertidumbre. Una propuesta de modelo de autoevaluación a partir de competencias," *Rev. Iberoam. Educ.*, vol. 40, no. 6, pp. 1–10, 2006.
- [24] E. R. Veitia Rodríguez, Y. Martínez-López, and A. Montalbán Estrada, "Aplicación de la lógica difusa en la toma de decisiones para la sostenibilidad del suelo," *Rev. Ciencias Técnicas Agropecu.*, vol. 23, no. 3, pp. 31–36, 2014.
- [25] A. C. Durán C. and R. C. Piedra, "Percepción de estudiantes y docentes sobre el curso de nivelación en matemáticas del ISFODOSU: una aplicación de la matemática difusa," *Rev. del Salomé*, vol. 1, no. 1, pp. 67–103, 2016.