A robust ranking model for analysing marginality of regions of Mexico

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Abstract: Marginality still is a significant problem around the world. It generates poverty, social marginalisation and low quality of life. In that sense, the understanding of the systemic contributors to poverty and exclusion can help find better strategies to improve the population's quality of life. The present work studies the spatial dimensions of the marginality in Mexico as its geography and location. A robust ranking model is proposed to find robust parameters of *ELimination Et Choix Traduisant la REalité* (ELECTRE) III method, analyse the marginality of regions and find extreme marginality in geographical areas. The main finding is a map of marginality in Mexico, showing regions with extreme marginality. The study regards marginality dimensions based on education, housing (services access) and incomes in the population.

Keywords: marginality; geographical marginality; regions of Mexico; robust ranking; ELECTRE III.

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1 Introduction

The developing countries require a continuous process of measurement of the current population condition. The implementation of innovation and sustainability are important strategies to be considered in the process of developing countries. Innovation is a strategy that has been tried to apply in developing countries to stimulate development and improve the quality of life of the poor (Yap and Devlin, 2015). However, the lack of adequate services and poverty remains around the world, not only in developing countries or regions limited in services and incomes.

Sustainability metrics are of interest to study the development of regions. The well-being is essential for researches, Musa et al. (2020) study community well-being measurement to justify the inclusion of different sustainability metrics to optimise outcomes for national happiness and urban sustainability. Arbolino et al. (2018) developed an analysis of Italian and German marginalised areas for solid biomass production planning. It is stated that this kind of process is a very complex process to implement more in marginal areas, where socioeconomic weaknesses are critical obstacles to the sustainable development of these territories.

The study of marginality is a crucial topic to investigate. Its study can help to understand the systemic contributors of poverty and exclusion that can overlap with the lack of resources and opportunities needed to achieve the desired conditions in life (von Braun and Gatzweiler, 2014). Marginality is a social phenomenon, but the term marginal also has an important use in the economy. Economic factors are also very important in the process of the marginalisation of certain individuals and social groups besides the marginalisation of areas or regions as spatial units (Pelc and Nel, 2020).

Marginality can be expressed as people with limited access to resources and opportunities, development of personal capabilities and choices (von Braun and Gatzweiler, 2014). It seems that population in marginality conditions could presents indicators of poverty, as von Braun et al. (2009) asserted, in many cases marginality is a root cause of poverty.

However, another definition of marginality is described by Gatzweiler et al. (2011). For authors, marginalisation is an involuntary position and condition of an individual or group on the margins of the social, political, economic, ecological, and physical system that prevents them from accessing resources, goods, and services. It limits their freedom of selection, reduces capacities, and eventually causes extreme poverty. It is identifiable that marginality meets a kind of situation of poverty.

For a broader understanding of the marginality, the phenomenon should be studied in an interdisciplinary approach; it will help to understand the interaction between the social system and geography of the population. Apart from being inclusive and interdisciplinary, the concept of marginality offers an integrated and systematic basis for understanding the interactions between social and ecological systems (von Braun and Gatzweiler, 2014).

In urban and rural areas is presented the marginality, Peña (2005) studies the marginalisation in urban areas in Mexico. In Mexico, marginality condition is expanded in the whole territory, some studies developed in some areas of Mexico are presented in (Collins and Ley García, 2019; Peña, 2005; Roldán et al., 2017). Moreover, it expresses how people are in societal positions and where they are and what services they have. In Mexico, marginalised people are disabled to traditional access and rights to use essential resources.

It is expressed by von Braun and Gatzweiler (2014) that only economic growth may contribute less to poverty reduction at societal margins, both at the bottom end of the income distribution and in geographically remote areas. The assert is reasonable due; some investments require a certain development level in the region and trained human resources, both limited and some cases non-existent in marginality areas. Concerning the above description (Collier, 2007) asserts that the bottom billion has shifted and no longer only lives in the poorest and often fragile states. In this sense, marginality remains not only in underdeveloped countries.

Marginality can be studied from the spatial dimensions as its geography and location too. Ferretti and Gandino (2018) is stated that the presence of marginalised communities that are at risk due to the strong trend towards the abandonment of rural areas for big cities. It is a current issue that impacts the community negatively because of the abandonment of rural heritage. Authors assert it is due to the critical weakness of the territorial system and exciting opportunity for rural regeneration in a region of Italy.

Due to the marginality problem's characteristics and the number of attributes considered, it seems necessary to analyse the problem from a multidimensional approach. In this sense, it is appropriate for the implementation of a multicriteria methodology. In this case, the Multi-criteria decision aid (MCDA) provides various methods to analyse marginality as a multicriteria problem. The MCDA methods help analyst or policy decision-makers evaluate many actions (or situations) accurately considering various criteria. Something very difficult for the limitation of the human capacity to handle that many information. In the MCDA methods, some approaches based on multiattribute utility, reference level, or outranking are presented. The present work's applied method is the *ELimination Et Choix Traduisant la REalité* (ELECTRE) III. It is adequate for this kind of problem. It presents a useful adaptation for different values in the attribute and the flexibility to adapt the decision-maker preference.

The present study analysed the marginality with the ELECTRE III method as a part of the MCDA methodology. A strategy to accomplish this process, a model is proposed to infer the robust parameters of the ELECTRE III method. The optimisation of the model finds robust parameters to helps the analyst in the parameter definition. It supports the evaluation of regions of Mexico for the marginality problem. The aim is to map extreme marginality regions in Mexico, regarding marginality dimensions based on education, housing (services access), and population incomes. In this sense, the marginality extreme corresponds to the regions with the lowest level of education, service access and income. The map is highlighted with the region performance evaluation and ranking generation from indicators of the population census.

The paper is structured as follows. In Section 2 is described the work developed about social analysis with multicriteria decision-making. The robust ranking model is described in Section 3. Section 4 presents the data used to characterise the population condition, and the robust ranking of regions based on their marginality levels. Section 5 includes an overview and discussion of the findings. Finally, concluding remarks are provided in Section 6.

2 Social analysis from a decision-making perspective

Social sustainability is related to social capital, social inclusion, social exclusion and social cohesion in rural economies, terms that are measured by relevant social sustainability indicators (Chatzinikolaou et al., 2013). Authors measure indicators of Social sustainability. Some of the considered indicators related lack of service or opportunities are education level, early school leavers, male employees, female employees. They applied the multicriteria method *Preference Ranking Organization METHod for Enrichment of Evaluations* (PROMETHEE) II to compare and rank 11 case study areas based on the social sustainability indicators (Chatzinikolaou et al., 2013).

Regarding the role that social enterprises play in the integration of socially excluded people into the labour market, it is analysed within the existing theoretical and political discourses on exclusion (Džunić et al., 2018). Considering the difficulties in measuring this social impact of social enterprises, the authors estimate this exclusion over marginalised groups' jobs. *The Technique for Order Preference by Similarity to Ideal Solution* method is applied for the ranking of the types of social enterprises according to the employment of socially excluded categories. Resulting in the problem that disabled or marginalised people can present in certain regions, where the research was carried out.

A study of competitiveness of regions of Mexico considers a dimension related to an inclusive, prepared and healthy society as a measure of the quality of life of the inhabitants (Muñoz-Palma et al., 2021). It includes academic performance indicators, medical offer and health services, socioeconomic conditions, poverty and inequality. The study was carried out by a multicriteria analysis model based on composed indexes using ELECTRE III.

Respecting, the health sector, *Cost-Effectiveness Analysis* is used to inform investment decisions in healthcare, in the form of cost-utility analysis of a marginal intervention per unit of a measure of health-related utility, such as disability. However, they do not address the important factor that concerns health distribution (Jit, 2018). For this, the authors implemented multi-criteria decision analysis methods and another economic evaluation method called benefit–cost analysis, where the benefits of health and not related to health are considered, which can be: health in populations with worse health, less access to medical care impoverishment related to medicine, among others. Phelps and Madhavan (2017) use standard approaches to evaluate the use of cost-utility analysis health interventions, most common with a social perspective. They are making a balance between providers, patients, payers, producers and planners in matters of public health.

On the other hand, it is stated that the mixed system of crops and livestock is a primary livelihood source in developing countries. Erratic climate changes are severely affecting the livelihoods of people who depend on diverse crop and livestock production (Ahmad and Ma, 2020). Therefore, the authors use the *Livelihood Vulnerability Index*, the *Intergovernmental Panel on Climate Change* and the Livelihood Effect Index to assess the livelihoods of the region and thus reduce their vulnerability.

The approaches to measure the accessibility of a market facility are rigid and complex in nature and impractical for decision-makers since it requires a large amount of information from them (Zafri et al., 2020). Therefore, these authors propose a multi-criteria decision-making approach that helps improve policy formulation to identify accessible poor rural areas.

3 A robust ranking model

In this section is proposed a robust ranking model. It is applied in the marginality problem for Mexican regions. The robust ranking model consists of two stages. The first stage corresponds to the optimisation model to find at least one compatible vector. The compatible vector(s) will be used as parameters for the ELECTRE III method. The second stage corresponds to a descriptive analysis in the set of parameters found in the first stage. Both are explained below.

3.1 The optimisation model

In order to use an ELECTRE III model, one must specify the following parameters:

i The weight vector $W = (w_1, w_2, \ldots, w_n)$, $w_j \geq 0$, $\sum_{j=1}^{n} w_j = 1$.

ii The vector of indifference thresholds $q = (q_1, q_2, \ldots, q_n)$, $q_j \geq 0$ j=1,2,…,n .

iii The vector of preference thresholds $p = (p_1, p_2, \ldots, p_n)$, $p_j \geq 0$ j=1,2,…,n

iv The vector of veto thresholds $V = (v_1, v_2, \ldots, v_n)$, $v_j \geq 0$ j=1,2,…,n .

In a preference disaggregation context, these parameters can be inferred from some adjacent preference information from the expert. In the proposed model, the input is the holistic information about the criteria comparison with a n-tuple G^* computed with some examples chosen as references. Let $\sigma \in S_n$ be the permutation of indices {*1,2, ..., n*} such that the criterion $g_{\sigma(i)}$ is ranked in the ith place of the ordering in such a way $g_{\sigma(j)}$ is preferred to $g_{\sigma(k)}$ provided $j > k$. In this sense, the expert is willing to rank the reference criteria of G^* in ascending order, from the least important to the most important.

Given this input, the objective is to find the more number of sets of inferred parameters that meet expert's preference. The model will find value variations between the sets of parameters.

A solution is encoded as a set of parameters in an m-ary string of two real values for each criterion. Each decision criterion corresponds to the parameters weights (w_j) and veto threshold (v_j) from a set of n decision criteria. The solution is represented as the parameter information $w_1, w_2, \ldots, w_n, v_1, v_2, \ldots, v_n$. The parameters q and p are expected to be defined by the expert in a deterministic way.

The cardinality of the set $|(W, V, T)|$ need to be maximised to find at least one compatible vector with decision-maker's preference and constrains related to the parameters of the ELECTRE III method. Here, W and V are the set of the parameters w_j and v_j, respectively of n decision criteria. T is the set of elements t_j indicating if the criterion j needs to use the parameter v_j ($t_j = 1$) or not ($t_j = 0$).

The optimisation needs to maximise the cardinality of set $|(W, V, T)|$ satisfying the following constraints. The sum of weight vector needs to be equal to one, $w_1 + w_2 + \cdots + w_n = 1$. Any element of the weight vector (w_k) needs to be less or equal to the sum of the rest of the weights $w_k \leq \sum_{j=1}^{n} w_j,\ j \neq k,\ i = 1,2,\ldots,n$. The pair of elements (w_k, w_j) must correspond with the preference of the pair $g_{\sigma(k)}$, $g_{\sigma(j)}$ given by the expert, $w_k \geq w_j$ *if* $g_{\sigma(k)} \succ g_{\sigma(j)}$. Any element v_k of V is equal or greater than the corresponding parameter p_k, $v_k \geq p_k$. Each coordinate of the set *W, V, T* is a positive real number $(w_j, v_j, t_j, \geq 0)$.

Each set of parameters found by the set $|(W, V, T)|$ corresponds to a solution (a ranking of regions). The model aims to find at least one compatible sets of parameters that satisfy restriction and the expert's preference. It is expected that those solutions will present value variations in the parameters. Those variations need to be analysed to find a robust set of parameter to ensure the final ranking solution is a robust solution. It means that a sufficiently small modification in the value of the parameters is not modifying the ranking of regions. In mathematical terms, the mapping sending parameters to solution of the optimisation program is discrete and continuous, hence locally constant.

Different studies have been proposed to help decision-maker on the parameter definition. Some models based on metaheuristic approaches can be found on Alvarez (2020) and Alvarez et al. (2018).

4 Marginality of regions of Mexico

4.1 Characteristic of the population condition

Marginality in Mexico can be measured by the population census carried out by (INEGI, 2015). Marginality is studied in Mexico by the National Council of Population in Mexico (CONAPO). The marginality situation of the population can be analysed by four dimensions with the currently available information. The education, housing, population dispersion and monetary are the dimension included in the survey of INEGI (2015).

4.2 Education dimension

One considered dimension in the census is the education. In Mexico, education is considered in the Mexican Constitution. It establishes the compulsory nature of primary education in kindergarten, elementary school, middle school and high school. There is consensus that access to knowledge is crucial for people to acquire the conditions and capacities to carry out their life project by associating themselves with freedom, autonomy, innovation and social mobility. The lack of those conditions and capacities impact the population negatively in terms of social and economic development. As it is asserted by CONAPO (2016), the backwardness and desertion intensify marginalisation.

Regarding the implication of education in the population, the education dimension includes the following two indicators:

- percentage of the illiterate population aged 15 years or over
- percentage of the population without complete primary education aged 15 years or over.

4.3 Housing dimension

Till (2007) express that there is a consensual definition; it is derived based on the statistical relationship between objective conditions and subjective perceptions. The housing is considered a human right. It is enshrined in the fourth paper of the Mexican Constitution; it states that "every family has the right to enjoy adequate and decent housing". The paper indicates that "the Law will establish the necessary instruments and supports in order to achieve this objective". CONAPO (2016) identify as it metric that decent housing should at least have essential services like electricity, water, drainage and toilet. In relation to the structure, it must be built with quality, durable materials that do not affect health, and also have enough space for individual activities and relatives of its inhabitants (CONAPO, 2016).

For CONAPO (2016), the lack of essential services is considered an expression of socio-spatial exclusion, inequity and inequality. Poor housing conditions, together with educational disadvantages, create disadvantageous scenarios and sociodemographic vulnerability. The housing dimension includes the following five indicators to measure the marginality:

- percentage of occupants in private homes without drainage or sanitary service
- percentage of occupants in private homes without electricity
- percentage of occupants in private homes without piped water
- percentage of private homes with some level of overcrowding
- percentage of occupants in private dwellings with dirt floors.

4.4 Population distribution dimension

In Mexico, there are around 190,000 settlements with less than 5000 inhabitants that suppose population dispersion and in some cases, inaccessibility. It is considered a negative impact affecting the available opportunities, due economies of scale, urbanisation and location are reduced (CONAPO, 2016). The population dispersion must be considered in the design of comprehensive strategies to promote production, access to goods and services, and social inclusion, at the same time as inequality is reduced. The population dispersion can be affected due to the geographical area. It means the spatial location already have areas limiting the development. For the population distribution dimension, the following indicator is considered:

- percentage of the population residing in towns with less than 5000 inhabitants.

4.5 Monetary dimension

In a particular approach, the marginality is very related with poverty condition. However, poverty extends far beyond the monetary dimension and is more than just deprivation in income or ability to consume (Sen and Anand, 1997). On the other hand, the monetary dimension should be considered in the marginality measurement. It is part of a multidimensional approach.

The population should have the opportunity to access decent work as a part of a human right and a fair wage. The concept of minimum wage is the main measure of remuneration. However, it is debatable whether it guarantees the coverage of the basic needs of food, education, health, housing, clothing and recreation of a worker (CONAPO, 2016). In Mexico, 2 minimum wages are considered as the income that constitutes the lower limit for people to have access to basic papers related to the state's social spending, as well as the possibilities of achieving competitive participation in labour markets (CONAPO, 2016). For the current dimension, the following indicator is evaluated:

- percentage of the employed population with incomes of up to two times the minimum wage.

For the evaluation of marginality of regions of Mexico, the above indicators are used as criteria decision with the methods described in Section 3. The term *indicator* and *criterion* will be used in the rest of the document indistinctly. They are summarised in shorter terms at Table 1. Table 2 shows the regions of Mexico that shall be evaluated to find the levels of marginality in the population.

The analysis of marginality in regions of Mexico is developed with data generated by INEGI (2010, 2015) in a survey throughout the population census carried out every five years in Mexico. The data was recollected from January to December of 2015.

Table 1 Decision criteria for evaluation of marginality

Label	*Shorter-term criterion*	*Indicator*
g1	Illiterate population	Percentage of the illiterate population aged 15 years or over
g2	Incomplete primary education	Percentage of the population without complete primary education aged 15 years or over
g3	Drainage or sanitary service	Percentage of occupants in private homes without drainage or sanitary service
g4	Without electricity	Percentage of occupants in private homes without electricity
g5	Without piped water	Percentage of occupants in private homes without piped water
g6	Overcrowding	Percentage of private homes with some level of overcrowding
g7	Dirt floors	Percentage of occupants in private dwellings with dirt floors
g8	Population dispersion	Percentage of the population residing in towns with less than 5000 inhabitants
g9	Employed population with low-income	Percentage of the employed population with incomes of up to two times the minimum wage

Table 2 The political division of the regions of Mexico

Label	*Region*	*Label*	*Region*
A1	Aguascalientes	A17	Morelos
A2	Baja California	A18	Nayarit
A3	Baja California Sur	A19	Nuevo León
A4	Campeche	A20	Oaxaca
A5	Chiapas	A21	Puebla
A6	Chihuahua	A22	Querétaro
A7	Coahuila de Zaragoza	A23	Quintana Roo
A8	Colima	A24	San Luis Potosí
A9	Distrito Federal	A25	Sinaloa
A10	Durango	A26	Sonora
A11	Guanajuato	A27	Tabasco
A12	Guerrero	A28	Tamaulipas
A13	Hidalgo	A29	Tlaxcala
A14	Jalisco	A30	Veracruz de Ignacio de la Llave
A15	México	A31	Yucatán
A16	Michoacán de Ocampo	A32	Zacatecas

Most of the indicators are obtained from the basic questionnaire tabulations, and income information is obtained from the expanded questionnaire (census sample). Table 3 lists the regions and the performance on each criterion (see Table 1 for the criteria definition).

Table 3 Evaluation of population indicators of Mexico

Region	*g1*	*g2*	*g3*	*g4*	*g5*	*g6*	*g7*	*g8*	*g9*
A1	5.53	16.5	2.14	0.95	5.36	28.39	3.82	28.85	37.41
A2	2.6	11.89	0.67	0.3	0.81	21.86	0.75	25.16	34.6
A3	1.96	10.46	0.26	0.47	2.82	23.03	1.15	10.35	22.85
A4	2.51	11.59	0.38	1.14	7.15	26.23	4.08	15.62	22.37
A5	6.68	18.56	4.08	1.59	6.49	37.93	2.95	30.88	40.69
A6	1.99	9.56	0.62	0.29	1.67	23.62	0.66	12.15	27.94
A7	3.9	15.24	0.38	0.38	0.96	25.65	2.45	14.47	31.18
A8	14.98	31.71	2.9	2.49	13.45	44.46	11.78	57.86	62.46
A9	2.67	12.65	1.4	1.81	2.39	22.16	1.76	17.05	34.77
A10	1.49	6.62	0.04	0.04	1.1	19.19	0.47	0.67	28.26
A11	3.17	14.5	3.68	2.63	3.26	24.58	4.33	36.19	39.16
A12	6.39	19.12	3.31	0.68	4.13	25.36	2	34.67	37.41
A13	13.73	27.25	13.03	2.4	15.64	42.11	14.86	49.68	53.29
A14	8.26	18.13	3.09	1.12	5.83	28.17	3.19	58.71	46.22
A15	3.55	14.9	0.86	0.34	1.84	22.12	1.59	17.5	29.4
A16	3.37	11.77	1.68	0.38	4.03	28.53	1.92	19.11	35.28
A17	8.35	25.35	2.32	0.81	4.26	28.05	5.9	40.58	44.88
A18	4.99	15.09	1.03	0.44	5.81	27.04	3.88	24.65	42.08
A19	5.07	17.56	4.66	2.54	4.36	27.63	3.92	39.14	37.96
A20	1.64	8.38	0.16	0.12	1.36	23.09	0.8	6.7	16.15
A21	13.65	29.22	2.44	2.87	13.05	38.33	13.44	61.51	49.46
A22	8.39	21.32	1.58	0.88	6.94	35.27	5.69	38.5	52.16
A23	4.57	13.01	2.93	0.67	3.23	24.21	1.52	39.07	25.92
A24	3.9	13.32	2.19	1.11	2.7	36.31	2.41	14.36	28.32
A25	6.33	18.87	2.34	2.29	10.68	25.21	5.56	40.08	43.64
A26	4.18	16.82	2.57	0.52	2.99	30.37	2.85	32.85	32.7
A27	2.19	11.15	1.05	1.05	2.52	26.63	2.61	17.39	29.93
A28	5.4	17.25	1.81	0.43	10.1	32.5	3.69	53.65	36.96
A29	3.03	13.35	0.37	0.73	2.51	28.69	1.52	13.92	37.39
A30	3.98	12.6	1.36	0.47	1.14	32	2	36.4	51.47
A31	9.51	25.04	1.53	1.62	13.39	32.03	6.84	46.2	49.68
A32	7.47	21.17	10.1	1.08	1.64	36.42	1.67	26.27	47.6

*Data published by INEGI (2015).

4.6 Application of the robust ranking model

The model explained in Section 3 was applied to rank the regions of Mexico using the data information for Table 3. The expert expresses his preference; a genetic algorithm is applied to optimise the model of Section 3.1. The descriptive analysis is carried out on the solutions from the genetic algorithm.

Step 1: Expert preference information

The expert defined his preference ordering the criteria from the least important to the most important. The expert defined the criterion *g3* as the least important, and the criterion *g1* as the most important. The complete ordered criteria are the follow:

$$g3 \prec g4 \prec g5 \prec g7 \prec g6 \prec g8 \prec g9 \prec g2 \prec g1.$$

Another information needed from the expert is the indifference (q) and preference (p) thresholds for each criterion.

Step 2: Optimising the model

A genetic algorithm (GA) was applied to optimise the model. A size population of 80 individuals was defined. The number of generations defined is 2000. The crossover index is 0.9, and the mutation index is 0.9. The mutation was defined with high probability to find the possible variation on feasible solutions. The previous test to GA shows better performance with high mutation index. In the application of the GA, 157970 solutions (sets of parameters) were found in 55.6 seconds. The GA is running in a macOS Mojave system, 10.14 version, 2.3 GHz Intel Core i5 processor and 16 GB of memory.

Step 3: Descriptive analysis of the sets of parameters

Once the 157970 sets of rankings were obtained, a descriptive analysis based on the SMAA method was carried out. The analysis provides a more general understanding of the data and helps to find a robust ranking.

4.7 Acceptability indices

The stochastic multiobjective acceptability analysis (SMAA) is a family of MCDA methods that considers the imprecision and vagueness of the information in the problem where it is being analysed (Durbach and Calder, 2016). This method considers a probability density fW over the space of all weights W and a probability density f_x over the space $x \subseteq \mathbb{R}^{m\times n}$ of the evaluations of the alternatives $g_j(a_i)$ with $g_j \in G$ and $a_i \in A = \{a_1, a_2, \ldots, a_m\}$ (see Lahdelma et al., 1998, 2003).

SMAA generates parameters based on simulation. Then it makes a sampling of both, weights and performance space. For the outranking approach the SMAA is implemented to make a descriptive analysis of weight, veto threshold and performance space.

Similar to the proposed outranking model by Tervonen et al. (2009), the data and other parameters of ELECTRE-III are represented by the set $T = \{M, q, p\}$. These components are considered to have deterministic values. Let us define the ranking function in equation (1) that gives the position order r to which an alternative a_i is assigned by ELECTRE III.

$$r = K(i, w, T, v) \tag{1}$$

Based on the weights and veto thresholds derived by the model in Section 3.1, SMAA calculates the acceptability index as a descriptive measure. As a part of the SMAA process, it describes the number of times that a certain alternative a_i is in the position r in the final ranking. Therefore, it is understood that the best alternatives will be those that present a *ranking acceptability index* (RAI) greater than zero for the first positions. The alternatives with a RAI close to zero, will be in lower positions in the final ranking.

The acceptability index is shown in Table 4, identifying the entities (alternatives), expressed in percentage. It shows the probability of a region appears in a certain position of the ranking. In the bottom of the ranking, Guerrero (A12) would be the most marginalised state in the Mexican Republic with a percentage of 75% of appearances in the last position. On the other hand, the Distrito Federal region (A9) obtained a frequency of 66% in the first position. It is the region with the lowest marginalisation. The acceptability index identifies the position of the region, giving a robust ranking or regions.

On the other hand, the descriptive analysis helps to identify the central weights vector (CWV) and central vetoes vector (CVV). They are robust parameters that are not affecting the final ranking with any small value variations in the parameter. Table 5 shows the defined parameters for the ELECTRE III method. The w and v are parameters defined with the robust ranking model. The w and v values correspond to CWV and CVV, respectively.

Table 4 Acceptability index in percentages

Position	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*A10*	*A11*	*A12*	*A13*	*A14*	*A15*	*A16*	*A17*	*A18*	*A19*	*A20*	*A21*	*A22*	*A23*	*A24*	*A25*	*A26*	*A27*	*A28*	*A29*	*A30*	*A31*	*A32*
1	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	5	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	70	0	0	25	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	25	0	0	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	24	0	6	0	0	11	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0
6	10	0	3	0	0	39	0	1	0	0	0	0	0	35	0	0	0	0	0	0	0	1	0	0	0	1	0	9	0	0	0	0
7	14	0	1	0	0	29	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	1	0	0	0	10	0	30	0	0	0	0
8	16	0	0	0	0	11	0	3	0	0	0	0	0	1	3	0	0	0	0	0	0	1	0	0	0	37	0	28	0	0	0	0
9	16	0	0	0	0	5	0	15	0	0	0	0	0	0	22	0	0	0	0	0	0	0	1	0	0	25	0	15	0	0	0	0
10	8	0	5	0	0	3	0	24	0	0	0	0	0	0	32	0	0	0	0	0	0	3	3	0	0	19	0	5	0	0	0	0
11	9	0	8	0	0	1	0	5	0	0	0	0	0	0	24	0	1	0	0	0	0	10	23	0	0	6	0	3	10	0	0	0
12	1	0	14	0	0	0	0	9	0	0	0	0	0	0	18	0	4	0	0	0	0	9	35	0	3	1	0	0	6	0	0	0
13	1	0	16	0	0	0	0	0	0	0	0	0	0	0	1	0	13	0	0	0	0	14	29	0	10	0	0	1	14	0	0	0
14	0	0	15	0	0	0	0	4	0	0	0	0	0	0	1	0	19	0	0	0	0	22	6	0	22	0	0	0	11	0	0	0
15	0	0	10	0	0	0	0	5	0	0	4	0	0	0	0	0	13	0	0	0	0	18	3	0	25	0	0	0	14	0	0	9
16	0	0	5	0	0	0	0	8	0	3	14	0	0	0	0	0	20	0	0	0	0	13	0	0	27	0	1	0	9	0	0	1

Table 4 Acceptability index in percentages (continued)

Position	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*A10*	*A11*	*A12*	*A13*	*A14*	*A15*	*A16*	*A17*	*A18*	*A19*	*A20*	*A21*	*A22*	*A23*	*A24*	*A25*	*A26*	*A27*	*A28*	*A29*	*A30*	*A31*	*A32*
17	0	0	5	0	0	0	0	14	0	1	13	0	0	0	0	0	18	0	0	0	0	9	0	0	13	0	3	0	19	0	1	5
18	0	0	5	0	0	0	0	5	0	3	61	0	0	0	0	0	8	0	0	0	0	0	0	0	1	0	4	0	8	0	5	1
19	0	0	3	0	0	0	0	4	0	15	9	0	0	0	0	3	1	3	0	0	8	0	0	1	0	0	14	0	5	0	19	16
20	0	0	3	6	0	0	0	3	0	5	0	0	0	0	0	11	4	3	0	0	8	0	0	4	0	0	9	0	1	0	10	34
21	0	0	0	18	0	0	0	1	0	10	0	0	11	0	0	14	0	0	0	0	20	0	0	0	0	0	9	0	3	0	8	6
22	0	0	1	18	0	0	0	0	0	11	0	0	6	0	0	16	0	5	0	0	10	0	0	5	0	0	13	0	0	0	5	9
23	0	0	0	16	0	0	0	0	0	13	0	0	8	0	0	16	0	8	0	0	15	0	0	3	0	0	6	0	0	1	6	8
24	0	0	0	9	0	0	0	0	0	24	0	0	6	0	0	19	0	3	0	0	8	0	0	5	0	0	10	0	0	9	6	1
25	0	0	0	13	0	0	0	0	0	9	0	0	8	0	0	8	0	8	0	0	5	0	0	15	0	0	14	0	0	3	15	4
26	0	0	0	5	0	0	0	0	0	6	0	0	9	0	0	10	0	13	0	0	11	0	0	13	0	0	13	0	0	11	8	1
27	0	0	0	6	0	0	0	0	0	0	0	0	16	0	0	3	0	23	0	0	13	0	0	14	0	0	5	0	0	9	9	3
28	0	0	0	8	0	0	0	0	0	0	0	0	18	0	0	0	0	11	0	0	3	0	0	41	0	0	0	0	0	16	3	1
29	0	0	0	1	0	0	0	0	0	0	0	0	18	0	0	0	0	25	0	3	0	0	0	0	0	0	0	0	0	51	3	0
30	0	0	0	0	0	0	25	0	0	0	0	11	0	0	0	0	0	0	0	61	0	0	0	0	0	0	0	0	0	0	3	0
31	0	0	0	0	0	0	53	0	0	0	0	14	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	22	0	0	0	0	75	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0

Table 5 The parameters of the ELECTRE III method

	g1	*g2*	*g3*	*g4*	*g5*	*g6*	*g7*	*g8*	*g9*
w	0.1746	0.1584	0.0480	0.0635	0.0797	0.1112	0.0952	0.1269	0.1425
q	1	3	0.5	0.3	1.5	5	0.5	5	4
p	3	6	1	0.6	2.5	10	1.5	8	8
v	4.8847	–	–	–	3.8207	–	2.2158	–	–

w and *v* are the central weight vector and central veto vector, respectively.

5 Overview and discussion

5.1 Ranking of marginality

The marginality condition should be explained concerning the particular situation of each region. The aggregation process explained in Section 3 was performed for modelling the experts' preferences. It compares the regions based on the marginality registers. The result is a ranking of the region based on their marginalisation level. It is shown in Table 6.

The ranking is the regions with the lowest level of marginality on the top and the highest level of marginality in the bottom. The regions with the lowest level of marginality are Distrito Federal (A9) and Nuevo León (A19). Baja California (A2), Coahuila de Zaragoza (A5), Jalisco (A14), Sonora (A26) and Aguascalientes (A1) are regions slightly down in the ranking. Regions with the highest level of marginality are Chiapas (A7), Oaxaca (A20), Guerrero (A12).

The regions with the lowest level of marginality present well performance. If we focus on the most critical criteria illiterate population (g1), population without complete primary education (g2), employed population with low-income (g9). The Distrito Federal (A9) and Nuevo León (A19) regions are with the best performance. Distrito Federal is having values of 1.49% in g1, 6.62% in g2 and 28.26% in g3. Nuevo León is having values of 1.64% in g1, 8.38% in g2 and 16.15% in g9.

The highest level of marginality corresponds to the regions with low indicator's performance. Guerrero (A12) is the most marginalised region, the illiterate population (g1) is 13.73%, the population without complete primary education (g2) is 27.25%, and the employed population with low-income (g9) is 53.29%. Oaxaca (A20) is one position up from Guerrero (A12). Oaxaca is with 13.65% in g1, 29.22% in g2, and 49.46% in g9. Chiapas (A7) is one position up from Oaxaca (A20). Chiapas is having 19.98% in g1, 31.71% in g2, and 62.46% in g9.

Even Chiapas has worse performance in g1 and g2 compared with Oaxaca and Guerrero, Chiapas has better performance in g7. The criterion g7 applies the veto factor because differences are more important in g7 regarding the expert's preferences (see Table 3). (e.g.) In g3, a difference less than 3 is not meaningful, and difference greater than 6 implies strict preference. In g7, a difference less than 0.5 is not meaningful, but a difference equal or higher to 1.5 implies strict preference. It means g7 is more sensitive to value variations than g1.

Table 6 Marginality ranking of Mexican regions

No.	*Position*	*Label*	*Region*
1	1	A9	Distrito Federal
2	1	A19	Nuevo León
3	2	A2	Baja California
4	2	A5	Coahuila de Zaragoza
5	3	A14	Jalisco
6	4	A26	Sonora
7	5	A1	Aguascalientes
8	6	A6	Colima
9	7	A28	Tamaulipas
10	8	A8	Chihuahua
11	9	A15	México
12	10	A22	Querétaro
13	11	A23	Quintana Roo
14	12	A3	Baja California Sur
15	13	A25	Sinaloa
16	14	A29	Tlaxcala
17	15	A17	Morelos
18	16	A11	Guanajuato
19	17	A10	Durango
20	18	A32	Zacatecas

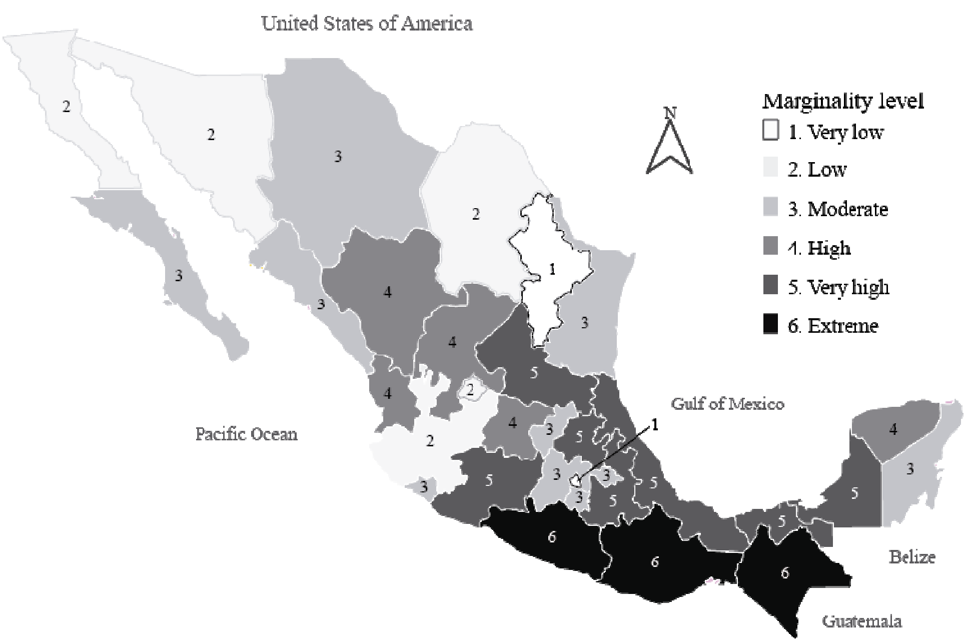
Table 6 Marginality ranking of Mexican regions (continued)

No.	*Position*	*Label*	*Region*
21	19	A31	Yucatán
22	20	A18	Nayarit
23	21	A4	Campeche
24	22	A16	Michoacán de Ocampo
25	23	A27	Tabasco
26	24	A24	San Luis Potosí
27	25	A13	Hidalgo
28	26	A21	Puebla
29	27	A30	Veracruz de Ignacio de la Llave
30	28	A7	Chiapas
31	29	A20	Oaxaca
32	30	A12	Guerrero

The map of marginality of Mexico helps to the identification of how the marginality is characterised in geographical areas. The level of marginality was divided into six categories. It will help to identify geographical marginality. The categories are very low, low, moderate, high, very high and extreme marginality level.

Figure 1 shows a geographical mapping of marginality in the regions of Mexico. The geographical mapping identifies extreme marginality based on the selected sets of indicators. The most marginalised regions are located in the south of the country. Chiapas, Oaxaca and Guerrero correspond to the extreme level of marginality.

Figure 1 Map of marginality level of regions in Mexico



The following level of marginality is at a very high level. In the current level, Campeche, Michoacán de Ocampo, Tabasco, San Luis Potosí, Hidalgo, Puebla, and Veracruz de Ignacio de la Llave regions present similar performance on the criteria decision. The regions belonging to the very high level of marginality are mostly located in the east of the country. The high and moderate levels are located more in the centre, corner areas and the northwest of the country. The low level of marginality includes regions on the north border with USA.

Moreover, Jalisco, a region in the centre sharing coast with the Pacific Ocean, is at the same level. The very low level of marginality includes Nuevo Leon and Distrito Federal. The former is located in the north sharing border with the USA. The latter is in the very centre of the country.

5.2 Discussion

Guatemala and Belize are adjacent countries with Mexico. They are in the south border of Mexico with Chiapas, Tabasco, Campeche and Quinta Roo. In this case, Chiapas belongs to the extreme level of marginality and share most of the southern border. It easy to find in the map of marginality on Mexico, that a major level of marginality is more ingrained in the south of Mexico. In the northern border, the regions present some level of marginality but less than regions on the south of Mexico.

It is stated that marginality exists around the world, even in developed countries. Nevertheless, marginality seems to be more ingrained in developing countries. Still, inclusion policies need to be developed to improve the situation of the marginalised population in Mexico. The political decision-making needs better actions in specific geographical areas of the population, regard cultural condition, and develop some innovative and sustainable strategies.

Decision-making or optimisation methods can be implemented to address the problem of developing marginal areas to finding sustainable solutions, as investment or development projects. The implementation of such a method will help to assess the feasibility of solution implementation.

The factors influencing the rate of diffusion need to be better understood since all development interventions seek to introduce innovations and unless innovation is widely adopted its contribution to economic or social development is minimal (Yap and Devlin, 2015).

6 Conclusions

The present research aims to analyse Mexico's marginality regions with a Multiple-Criteria Decision-Analysis method, the ELECTRE III. The inferring parameters model supported the ELECTRE III application. It helps the analyst to define the parameters of the method. The analysis of marginality with the proposed methodology helps to map the extreme marginality regions in Mexico. It should help understand how marginalised the regions of Mexico are, finding some region in extreme marginality.

The marginalised people in Mexico are affected by their bottom societal position, in some cases are isolated geographical areas, and their access to education and services to increase their development. The marginalised people present the lowest income of the population. Further research about marginalisation and poverty should be conducted.

The marginality implies a broader concept, not only the measurement and comparison of well-being, service access and incomes. However, the current research uncovers regions with extreme marginalisation and point out the attention for inclusive policies and action.

The research's main contributions are the model to infer parameters and discover the most marginalised regions of Mexico. First, the proposed model was optimised by a genetic algorithm that finds many set of parameters. A descriptive analysis was made to find the ELECTRE III method's robust parameters for the marginality problem. On the other hand, the evaluation of indicators of the population uncovers marginalised regions of Mexico. The new proposed model generates a robust ranking of regions regarding the marginality conditions. The resulted robust ranking is not affected by small variations in the values of the parameters.

The analysis showed the regions with an extreme level of marginality in Mexico, which should be the most attended and studied. They need critical attention to improve the quality of life of the population, at least as expected as a human right.

The marginalisation can be seen as being positioned at the margin of one or more societal or spatial systems, and having few assets and/or capabilities that would allow the actor to move away from or change that marginal situation (Gatzweiler and Baumüller, 2014). It requires better understanding of the marginal situation for the actors that describe its position. Further studies should be carried out, finding actions to be evaluated in the relation of the geographical situations of the regions. On the other hand, more models are needed to support the analyst of policy decision-maker for the analysis of social problems. It is important to consider different situation of expert's wiliness to express his or her preferences (Alvarez et al., 2020; Corrente et al., 2014; Greco et al., 2017).

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