Multiple criteria hierarchy approach for analyzing the competitiveness of regions in Mexico

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Abstract

The present paper has the main aim to evaluate the competitive level of the regions of Mexico based on their performance on 10 main factors from 100 indicators. The methodology is based on the Multiple Criteria Hierarchy Process (MCHP) capable of analyzing the performance of a subset and the comprehensive indicators, and how they impact the competitiveness of the region. An important aspect of the MCHP implemented is that it considers the interaction between criteria (indicators) and measure the performance of a large number of criteria. The main contribution to the research is with the identification of region with the worst level of competitiveness, and the factors are requiring more attention by the decision-makers.

Keywords: Multicriteria, hierarchy approach, competitiveness

JEL Codes: C69, C81, D81

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Enfoque multicriterio jerárquico para el análisis de la competitividad de las regiones en México

Resumen

El objetivo principal de este trabajo es el de evaluar el nivel de competitividad de las regiones de México basado en el desempeño de 10 principales factores provenientes de 100 indicadores. La metodología está basada en el Proceso Jerárquico Multicriterio con la capacidad de analizar el desempeño de un subconjunto de indicadores y el conjunto completo de indicadores, y como impactan en la competitividad de la región. Un aspecto importante de Proceso Jerárquico Multicriterio implementado es que considera la interacción entre criterios (indicadores) y mide el desempeño de un gran número de criterios. La principal contribución de la investigación es la identificación del nivel peor de competitividad de la región, y los factores que requieren más atención por el tomador de decisiones.

Palabras clave: Análisis multicriterio, enfoque jerárquico, competitividad.

Códigos JEL: C69, C81, D81

1. INTRODUCTION

Territorial competitiveness is a significant variable to attract domestic and foreign private investment. It forces organizations to give more attention to continuous improvement processes. The World Economic Forum (WEF) defines competitiveness as the set of institutions, policies and factors that determine the level of productivity of a country (WEF, 2016). The prosperity of a nation, says Porter (1990) depends on its competitiveness, which is determined by productivity. Also, Porter (1998) mentions the enduring competitive advantages in a global economy lie increasingly in local things–knowledge, relationships, and motivation that distant rivals cannot match. Charles and Zegarra (2014) say competitiveness have a positive effect on long-term economic growth, with the creation and maintain an environment that sustains more value for enterprises and more prosperity for people.

It is remarkable, that the economic growth is influenced by created clusters on regions. Ketels (2013) highlight the importance of clusters in regional economic performance and evolution. Delgado, Porter and Stern (2010) find that clusters contribute to the level of employment in young start-ups in regional industries, suggesting that a strong cluster environment in a region enhances the performance of start-ups. It seems the strength of related clusters in the region as well as the strength of the cluster in geographically adjacent regions impact positively in the growth of the industry employment Delgado, Porter and Stern (2012).

Multiple Criteria Decision Aid (MCDA) is a relevant approach to address decision making problematics. The MCDA significantly improves the quality of the decision-making process by introducing transparency, analytical rigor, auditability and conflict resolution for Multidimensional decision problems (Kabir et al., 2013).

For the present paper, the competitiveness of regions is addressed by a Multiple Criteria Decision Aid (MCDA). A specific approach is used to attend some properties of data of the Mexican regions. In order to take into account, the hierarchical structure of the competitiveness of Mexican regions, the study uses a new MCDA approach that is based on the extended ELECTRE III to a hierarchy of interacting criteria by (Corrente, Doumpos, Grego, Słowiński & Zopounidis, 2017). It is a new development of Multiple Criteria Hierarchy Process (MCHP) recently proposed by (Corrente, Grego & Słowiński, 2012). To the best of our knowledge, there is not any MCHP implemented to deal with the problem of competitiveness of regions. This innovative application allows us to estimate a new index of competitiveness of Mexican regions and analyze how subcriteria from a specific macrocriterion impact in the competitiveness of regions. For the above, it would be able to estimate the inequality and opportunities to access foreign and national investment of the 32 Mexican regions and illustrate it on a geographical map.

The work aims to analyze the performance of the regions of Mexico to establish their competitiveness level, regarding 100 decision criteria with different weighting. The main finding is that regions need to diversify the performance, not only focused on innovation and human resources to be competitive. This application can contribute to the design of policy and decision-making to develop regions' performance. The study of the interaction of criteria allows analyzing how some specific criteria are increasing the overall performance of the region to establish a competitiveness level.

The article presents the following structure. In Section 2, the literature review is presented. The data analyzed to establish the competitiveness of the regions are described in Section 3. The MCHP to address the competitiveness of regions is described in Section 4. Section 5 analyzes the competitiveness of regions and results. Contributions of this research are described in Section 6.

2. COMPETITIVENESS AND ITS MEASUREMENT

2.1 General perspective of competitiveness

Competitiveness is understood as the capacity of the company to offer products and services that meet specific quality standards of local and global markets at competitive prices and that provide an adequate return for the resources used in the production of these (Oyarce, 2013). In the case of private capital organizations that are oriented to markets with global competition, managers and workers can innovate and improve processes to offer quality products to a market every time more dynamic and changing. In the case of public institutions, such as state governments, the challenges are greater. There is a divergence in budgetary allocations, generating a competitive disadvantage among the states and, as a result, reorganization and concentration of national and foreign investment in a few regions. In this regard, Ginevičius and Podvezko (2009) say multidimensional character, diversity of criteria, and the interaction between them to describe the divergence in regional development.

Porter (1990) suggests that competitiveness is measured by productivity. Krugman (1994) mentions this as a synonym

of productivity. Accordingly, the increase in productivity allows sustain and increase participation in international markets, with a parallel rise in the standard of living of the population. Mercantilism conceived foreign trade as a zero-sum game. Smith (1776) mentioned that nature and cause of the wealth of a country are given by the trade deficit of another country. Therefore, the value that is consumed abroad annually must be higher than the domestic consumption of the country. The contribution that Smith (1776) has made in the field of production, and exports and imports, as these necessarily regulate that state "the wealth of the nations". The economic growth of countries in the long term is a consequence, mainly of the increase in productivity (Krugman, Obstfeld & Melitz, 2012). Porter (1990) defines that firms belong to the nations, those that compete for the markets and not the country or region (Suñol, 2006).

The competitiveness is given in the industrial environment and then at the national level (Kao et al., 2008). The environments with high uncertainties have a positive influence on the relationship between organizational structures and organizational competitiveness. Technology and innovation have an effect correlated with the competitiveness of the regions, and the ability to innovate is generally accepted as a critical success factor to the growth and future performance of firms (Khayyat & Lee, 2014). The performance of regional economies varies markedly in terms of wage, wage growth, employment growth and patenting rate. It also is strongly influenced by the strength of local clusters and the vitality and plurality of innovation (Porter, 2003).

Meanwhile, it is assumed that territorial competition is a concept that covers areas and mechanisms of economic, social, and even political dispute, under which different processes can be analyzed at a territorial level Clusters represent a new way of thinking about national, state, and local economies, and they necessitate new roles for companies, governments, and other institutions in enhancing competitiveness. The prevalence of clusters reveals essential insights about the microeconomics of competition and the role of location in competitive advantage (Porter, 2000). It is essential to look at all elements affecting the context for productivity and innovation in individual firms and clusters to improve the location of competitiveness (Ketels, 2003). Cluster policies are largely focused on strengthening existing agglomerations, not creating new ones (Ketels, 2013)

Botti and Peypoch (2013) shown that ELECTRE-I and Weighted-Sum Method MCDA applied approach results differ. Santiesteban and Lopez (2017) applied ELECTRE-III method to construct a valued outranking relation and a multi-objective evolutionary algorithm for exploiting relations and generate the ranking for the multicriteria ranking problem. Carayannis et al. (2018) say that cognitive mapping allows the cause and effect relationships between the determinants of competitiveness. Goncalves, Ferreira, Ferreira, and Farinha (2019) emphasize the importance of innovation and the human dimension to gaining competitive advantages based on the cognitive mapping and categorical-based evaluation technique (MACBETH). In the Fuzzy Rasch model by Huang and Peng (2012), it provides an effective means of applying the MCDM method to study

competitiveness. Huang, Huang, and Tzeng (2016) competency models can identify the range of capabilities at a company's disposal, and this information can be used to develop internal or external education training policies for sustainable development. Ko, Fujita, and Tzeng (2013) propose a fuzzy integral combined to induce features and reveal the decomposed information empirically, illustrating the dominance benchmark and the fusion effect for approximations. Lee, Mogi, Kim, and Gim (2008) fuzzy analytic hierarchy process uses interval values to reflect the vagueness of human thought. Yeo, Song, Dinwoodie, and Roe (2010) incorporate Dempster-Shafer theory for eliminating uncertainty in the evaluation and leveling process in the multiple decision-making group. Yeo, Wang, and Chou (2013) use an integrated fuzzy MCDM methodology to quantifies the weight of the criteria and rating of each alternative owing to the uncertainties and imprecision in the real world. Zangoueinezhad, Azar, and Kazazi (2011) proposed a Fuzzy Multiple Criteria Decision Making (FMCDM) as a useful and effective tool for competitiveness positioning. Zhang, Gu, Gu, and Zhang (2011) proposed Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) as a multiple criteria decision making (MCDM) method, which identifies solutions from a finite set of alternatives.

On the other hand, Blanco-Mesa and Gil-Lafuente (2014) evaluate competitiveness in the regions of Colombia to the generation of clusters with the aim of establishing similarity relationships between regions through the application of Pichat Algorithm, which allows identifying groups with homogeneous characteristics. Authors applied Hamming distance as a fuzzy technique to establish relations of similarity between each of the branches of economic activity in the regions. In the same context, Blanco-Mesa and Gil-Lafuente (2014) studied the economic activities analysis focusing on the crucial role of the location to be further competitive. They establish the relation of affinities using families of Moore and rectangular relationship. It is a fuzzy subset of thresholds that enables a fuzzy relation $[\tilde{R}]$ to be converted into its Boolean matrix $[B]$. Both studies are approached with fuzzy methods; a complete study of fuzzy decision-making review is found on Blanco-Mesa, Merigó, Gil-Lafuente, (2017).

2.2 Measurement of competitiveness in Mexico

The analysis of the competitiveness for the Mexican States is conducted using data collected from the Mexican Institute for Competitiveness (IMCO). A competitiveness index is generated by (IMCO, 2016b) reporting the federal entities in Mexico, showing existing capacities for the talent attraction and investment. The data generated by IMCO regards 10 dimensions used to evaluate the competitiveness of Mexican regions. Each dimension is conformed with a subgroup of different indicators; in total, there are 100 indicators for evaluating the competitiveness of 32 Mexican regions (IMCO, 2016a).

The data from IMCO are used in this work with a new approach, the Multiple Criteria Hierarchy Process (MCHP), to analyze the competitiveness, but regarding the interaction of subgroups of criteria in different levels on a hierarchy through ranking the Mexican regions. Table 1 shows the 32 Mexican regions and a brief

description of each dimension is explained below.

There are some subgroups of criteria that are evaluating the following dimensions.

g1 Legal system (LS): measures the environment of public and legal security in regions. It intricately linked to the quality of life of citizens through the prevention and elimination of what puts liberties, order, and public peace at risk, safeguarding the physical integrity and the rights of people. A functional State of Law generates favorable conditions for the attraction and retention of investments in regions.

g2 Sustainable environmental management (SEM): measures the ability of regions to relate sustainably and responsibly to natural resources and their environment. It provides information on the availability and management of water, air and solid waste. It also outlines certain risks that could be incurred by companies that want to invest in the state. Both elements directly affect the quality of life of the inhabitants.

TABLE 1. MEXICAN REGIONS

Label	Region	Label	Region
A1	Aguascalientes	A17	Morelos
A2	BCS	A18	Nayarit
A3	BC	A19	NL
A4	Campeche	A20	Oaxaca
A5	Chiapas	A21	Puebla
A6	Chihuahua	A22	Querétaro
A7	Coahuila	A23	Quinta Roo
A8	Colima	A24	SLP
A9	CDMX	A25	Sinaloa
A10	Durango	A26	Sonora
A11	Estado de México	A27	Tabasco
A12	Guanajuato	A28	Tamaulipas
A13	Guerrero	A29	Tlaxcala
A14	Hidalgo	A30	Veracruz
A15	Jalisco	A31	Yucatán
A16	Michoacán	A32	Zacatecas

Source: IMCO (2016a)

g3 Inclusive, prepared and healthy society (HIS): measures the quality of life of the inhabitants through three areas: inclusion, education and health. These give an indication of the opportunities that exist in a state to form, attract and take advantage of human capital. It includes indicators of academic performance, medical offer and health services, socio-economic conditions, poverty and inequality. A state that offers high levels of quality of life for its entire population is much more attractive for talent and investments.

g4 Stable and functional political system (SPS): measures the potential of state political systems to be stable and functional. The good quality of the political system can encourage investment by creating an environment of healthy competition that leads to greater accountability. Indicators that give information on corruption, citizen participation in the political life of the state and civil liberties are incorporated. The good quality of the political system can encourage investment through the creation of a stable environment and public management accustomed to rendering accounts.

g5 Efficient and effective governments (EEG): measure how governments can positively influence the competitiveness of their states. Among the actions necessary to achieve this objective are public policies aimed at promoting local economic development. Therefore, this sub-index includes indicators related to the promotion of economic development and the formality of the economy. In addition, it includes indicators on the capacity to generate their own revenues, the quality of the information of its public finances and the approach with citizenship by electronic means.

g6 Factor market (FM): measures the productivity of workers and other essential characteristics of employment since this human capital represents the most important production factor for the competitiveness of each federative entity. Those entities where workers are qualified and salaries are higher become more attractive for talent and, therefore, attract investment.

g7 Stable economy (SE): It measures the main characteristics of state economies, as well as the credit situation for companies and families. It includes indicators that describe the distribution of GDP, the dynamism of the economy, the level of debt, as well as economic dependence and diversification. The states that present a stable economy as well as large credit markets attract more talent and investment and are, therefore, prone to a greater generation of employment and wealth.

g8 Precursors (P): measure the financial, telecommunications and transport sectors. These sectors are of great importance because they are considered as necessary conditions to boost economic growth, investment and employment generation by directly affecting many other sectors of the economy. Therefore, its development is fundamental to improve the competitiveness of the states. This sub-index considers indicators related to access to and use of the Internet, physical means of communication, whether aerial or terrestrial and the use and access to financial services.

g9 Exploitation of international relations (EIR): measure the degree to which the states capitalize their relationship with the outside to increase their competitiveness. Therefore, the sub-index considers indicators related to international tourism and the flow of capital. In an environment of globalization, the competitiveness of regions depends even more on their ability to exploit links they have with the outside world.

g10 Innovation in sectors of the economy (ISE): measures the capacity of the states to compete successfully in the economy, particularly in sectors of high added value, intensive in knowledge and cutting-edge technology. The ability to generate and apply new knowledge is considered, which includes indicators related to the characteristics of the companies, the research context and the generation of patents. A state that has more innovative economic sectors is able to attract and retain more investment and talent.

3. METHODOLOGY FOR THE COMPETITIVENESS OF REGIONS

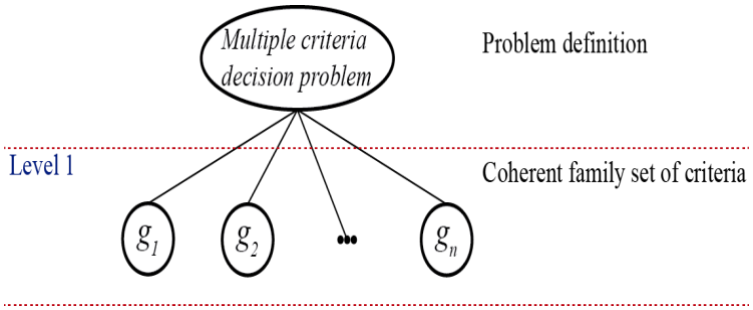
3.1. The multiple criteria decision aid process (MCDA)

The methodological approach of the multiple criteria decision aid (MCDA) concerns some stage to deal with the definition of the problem, find a possible solution and analyze the recommendations. The general framework introduced by (Roy, 1985) describes and underlines the operation of the methodology of MCDA. In stage 1, the proposal of recommendations is dealt with, stage 2 analyzes consequences and develops criteria, stage 3, comprehensive modeling of preference, and stage 4 investigates and develops the recommendation. In that sense, as a part of the MCDA process, the definition of the problem is developed in stage 1, the definition of a set of alternatives $A = \{a_1, a_2, ..., a_m\}$ and coherent family of criteria $G = \{g_1, g_2, ..., g_n\}$ is carried out in

stage 2, the processes of bout stages consider a classical process to approach MCDA problems. The figure 1 illustrates how the MCDA problems are dealt with by assessing the complete set of criteria at the same time and the same level; it is a flat structure.

When the comprehensive modeling of preference is carried out in stage 3, it is performed with aggregation procedures. In the outranking aggregation approaches, the recommendation of the possible solution is showed in two steps the aggregation preference and exploitation of the preference model. The aggregation procedure results in a preferential model where a relation between alternatives is represented with a membership value (0, 1). The exploitation process generates a recommendation in a ranking format of alternatives in descending order from de best to the worst.

FIGURE 1. MULTIPLE CRITERIA DECISION PROBLEM ASSESSED AT THE SAME CRITERIA LEVEL



Source: Own elaboration

3.2. Aggregation and exploitation procedures

The ELECTRE III (EIII) is a well-known outranking method that in the family of ELECTRE methods. EIII version uses distillation process to rank alternatives to complete or partial preorder. For a pair of alternatives $(a_i, a_l) \in A \times A$, the credibility of the assertion "action a_i is at least as good as action a_l" is assessed and denoted as $a_i S a_l$s, in general form, it can be said a_i outranks a_l. The EIII method constructs a comprehensive index based on a partial concordance index $C_j(a_i, a_l)$. EIII also generates the discordance index (d_j) to check in g_j the discordant level with the assertion "a_i outranks a_i" considered when veto threshold is used. Finally, the fuzzy outranking relation denoted as $\sigma(a_i, a_l); (0 \leq \sigma(a_i, a_l) \leq 1)$ is constructed (Roy, 1990). The fuzzy relation $\sigma(a_i, a_l)$ that means "a_i is at least as good as a_l" is validated.

The credibility matrix (fuzzy outranking relation) corresponds to the DM's preferential model that is latter exploited to construct a partial or complete ranking. The included procedure in EIII method is the distillation procedure. Two distillations are generated regarding some cut levels of the credibility matrix to define some preferential properties of the relation (a_i, a_l). The qualification of the alternatives is considered to set the preorders. In (Marzouk, 2011), a brief description of the distillation procedure is explained in five simple steps.

The previous aggregation and exploitation procedure are commonly applied in flat problems, where just one level of criteria is defined to solve it at a comprehensive level. The next section concerns structured problems in a hierarchy of criteria, where any

node in the tree is a subproblem of the comprehensive problem.

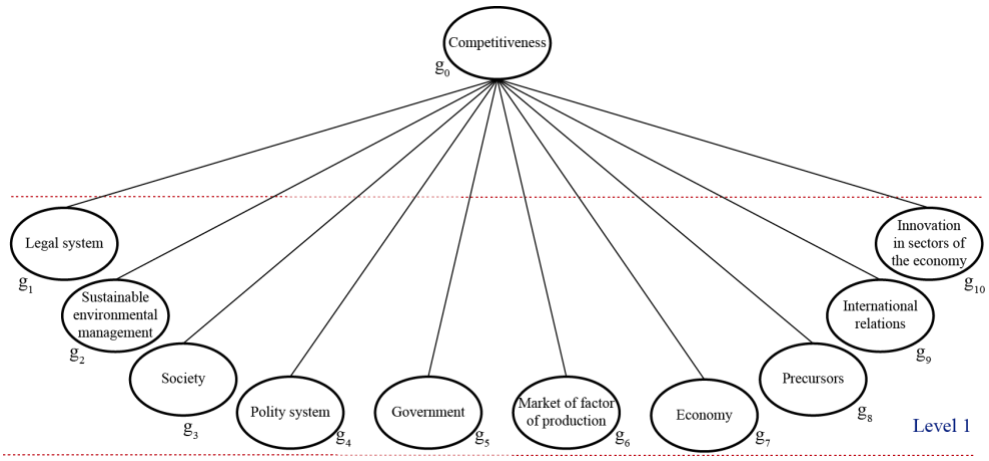
3.3. The multiple criteria hierarchy process (MCHP)

The MCHP structures the decision criteria of a problem in a hierarchy of subcriteria. It is different compared with the flat structure of the multiple criteria decision aid problem (MCDA) when the problem is solved only in a comprehensive way. For example, the MCDA will analyze the competitiveness of the regions in Mexico at the same level, assessing all the criteria at the same time (see Fig. 2). In this way, it is able to find which regions are the best and which are the worst, but it cannot understand how some subcriteria interact to evaluate a macrocriteria (e.g., legal system, economy, precursors) that impact in the competitiveness of regions.

In the competitiveness of regions problem is found a large number of criteria; in fact, assess competitiveness requires diver's kind of information approached commonly from composite indices (IMCO, 2016). However, from a different approach, the analysis of that complex problem could be decomposed in subproblems to make it easier and more in-depth analysis. Thus, it is often the case that a practical application is imposing a hierarchical structure of criteria (Corrente et al., 2012).

The MCHP was introduced first in (Corrente et al., 2012) to deal with problems where criteria do no correspond to the same level. Instead, a hierarchy structure is used to organize them in a subpart of the problem. The idea is considering the preference relation on subset of criteria in a hierarchy. In this case, it is needed the preference information elicitation and final recommendation analyzes (Corrente et al., 2012).

FIGURE 2. ASSESSMENT CRITERIA O THEN SAME LEVEL FOR THE COMPETITIVENESS PROBLEM



Source: Own elaboration based on ten factors of competitiveness

A hierarchical structure of criteria can be seen as a tree of criteria. The structure of the tree takes some particular interest by the expert or decision-maker and agglomerates the subset of criteria in leaves (macrocriteria). The leaves are decomposing the problem in smaller problems to understand the interaction on elementary criteria (subcriteria of the lowest level of the hierarchy). Fig. 2 deals with a multiple

criteria decision aid problem assessing criteria at the same level. However, the same problem can be analyzed in smaller problems as a hierarchy of problems. The Fig. 3 illustrates a tree structure of criteria, some leaves contain branches with more leaves, making a tree of subproblems.

Corrente et al. (2017) integrates the MCHP with ELECTRE III method, for simplicity it will be called it ELECTRE III-H as (Del Vasto-Terrientes, Valls, Slowinski, & Zielniewicz, 2015). The notation by (Angilella et al., 2018) is used to explain the hierarchy EIII.

G is comprehensive set of all criteria at all considered levels in the hierarchy.

G_0 is the root of the criterion.

l_G is the set of indices of the criteria in G.

$E_G \subseteq l_G$ is the set of indices of elementary criteria.

g_r is the generic non-root criterion (where r is a vector with length equal to the level of the criterion).

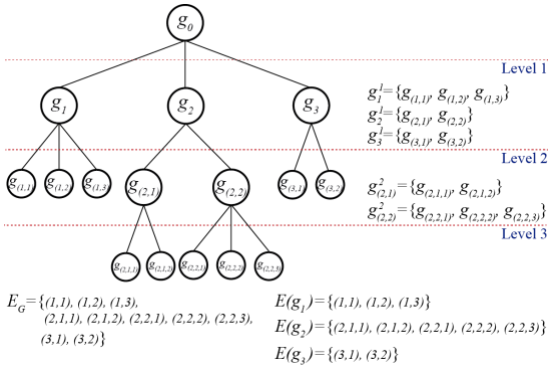
$g_{(r,1)}, \dots g_{(r,n(r))}$ are the immediately subcriteria of criterion g_r (located at the level below g_r). $E(g_r)$ is the set of indices of all the elementary criteria descending from g_r.

$E(F)$ is the set of indices of the elementary criteria descending from at least one criterion in the subfamily $F \subseteq G$ (that is, $E(F) = U_{g_r \in F} E(g_r)$).

G_r^l is the set of subcriteria of g_r located at level l in the hierarchy (below g_r).

To have better understanding about the above notation, it is shown in the hierarchy structure of the Fig. 3 where Level 1 contains the macrocriteria g_1, g_2 and g_3. The elementary criteria $g_{(1,1)}, g_{(1,2)}, g_{(1,3)}$ descending from g_1 is represented by $E(g_1)$, and are decomposing the sub problem g_1. In g_2, two subcriteria (non-elementary criteria) $g_{(2,1)}$ and $g_{(2,2)}$ integrates the sub problem in g_2. In Level 3 elementary criteria $g_{(2,1,1)}$ and $g_{(2,1,2)}$ belong to leaf $g_{(2,1)}$ (at upper Level 2). And, the elementary criteria $g_{(2,2,1)}, g_{(2,2,2)}$ and $g_{(2,2,3)}$ belong to leaf $g_{(2,2)}$. Those elementary criteria from the Level 3 are represented by $E(g_2)$. And the elementary criteria of $E(g_3)$ are $g_{(3,1)}$ and $g_{(3,2)}$. The all set of elementary criteria is contained in E_G. As is shown in Fig. 3 a different approach for the multiple criteria decision aid problem can be implemented when a hierarchy structure is generated concerning the criteria of interest in a particular level of the hierarchy.

FIGURE 3. PROBLEM STRUCTURE OF THE PROBLEM IN THE MULTIPLE CRITERIA HIERARCHY PROCESS



Source: Own elaboration

3.4. The hierarchical ELECTRE III method and distillation process

The adapted version of the hierarchical ELECTRE III was introduced first by (Corrente et al., 2017). For each elementary criterion $g_t, t \in E_g$.

The elementary concordance index, for each elementary criterion g_t.

$$\varphi_t(a,b)=\begin{cases}1 & if \quad g_t(b)-g_t(a)\le q_t,(aS_tb)\\ \dfrac{p_t-[g_t(b)-g_t(a)]}{p_t-q_t} & if \quad q_t<g_t(b)-g_t(a)<p_t,(bQ_ta)\\ 0 & if \quad g_t(b)-g_t(a)\ge p_t,(bP_ta)\end{cases}. \tag{1}$$

The elementary discordant index, for each elementary criterion g_t.

$$d_t(a,b)=\begin{cases}1, & if \quad g_t(b)-g_t(a)\ge v_t,\\ \dfrac{[g_t(b)-g_t(a)]-p_t}{v_t-p_t} & if \quad p_t<g_t(b)-g_t(a)<v_t,\\ 0, & if \quad g_t(b)-g_t(a)\le p_t.\end{cases} \tag{2}$$

The partial concordance index for each non-elementary criterion G_r,

$$C_r(a,b)=\frac{\sum_{t\in E(G_r)} w_t\varphi_t(a,b)}{\sum_{t\in EL} w_t}, \tag{3}$$

Partial credibility index,

$$\sigma_r(a,b)=\begin{cases}C(a,b)\ x\ \prod_{g_t\in E(g_r)}\dfrac{1-d_t(a,b)}{1-C_r(a,b)} & \text{if} \quad d_t(a,b)>C_r(a,b).\\ C(a,b) & \text{otherwise}\end{cases} \tag{4}$$

Distillation cut-off level at MCHP

To compute the cut-off level, it is needed to find in each non-elementary criterion the highest value on $\sigma_r(a,b)$, $\lambda_0=\max(\sigma_r(a,b))$.

The distillation threshold function $s(\lambda_k)$ is computed in the same way $s(\lambda_k)=\alpha\ x\ \lambda_k+\beta$, following (Roy, 1978), $\alpha=-0.15$ and $\beta=0.30$.

For the next cut-off level $k+1$, the highest value of $\sigma_r(a,b)$ is found, which is smaller than the previous cut level $k(\lambda_k)$ minus discrimination threshold $s(\lambda_k)$.

$$\lambda_{k+1}=\max_{\{\sigma_r(a,b)<\lambda_k-s(\lambda_k)\}}(\sigma_r(a,b)) \tag{5}$$

With the intersection of the two distillation, a final preorder is obtained. For the pairs $a,b\in A$ in the hierarchical

process, the alternatives are ranked in a partial or complete preorder on the non-elementary criterion g_r as follow:

aP_rb: *a is strict preferred to b on the macrocriterion* g_r, if in one order, a is positioned before b, and if in the other a is in the same or better position than b.

aI_rb: *a is indifference to b on macrocriterion* g_r, if a and b belong to the same position in the two pre-orders.

aR_rb: *a is incomparable to b on the macrocriterion*g_r. if a is in better position than a in one order and b is in better position than a in other order, or vice versa.

The above method is an integration of the MCHP and the ELECTRE III method. The result is an outranking approach to deal with a hierarchy of criteria structure. The first work to integrate them was Corrente et al. (2017) and Del Vasto-Terrientes et al. (2015) applied it calling ELECTRE III-H. The integration of MCHP with ELECTRE is the hierarchy-ELECTRE III. It is systematized and shared as a computational tool available on GitHub (https://github.com/pavelalvarez/hierarchy-ELECTREIII) for practitioners dealing with MCHP.

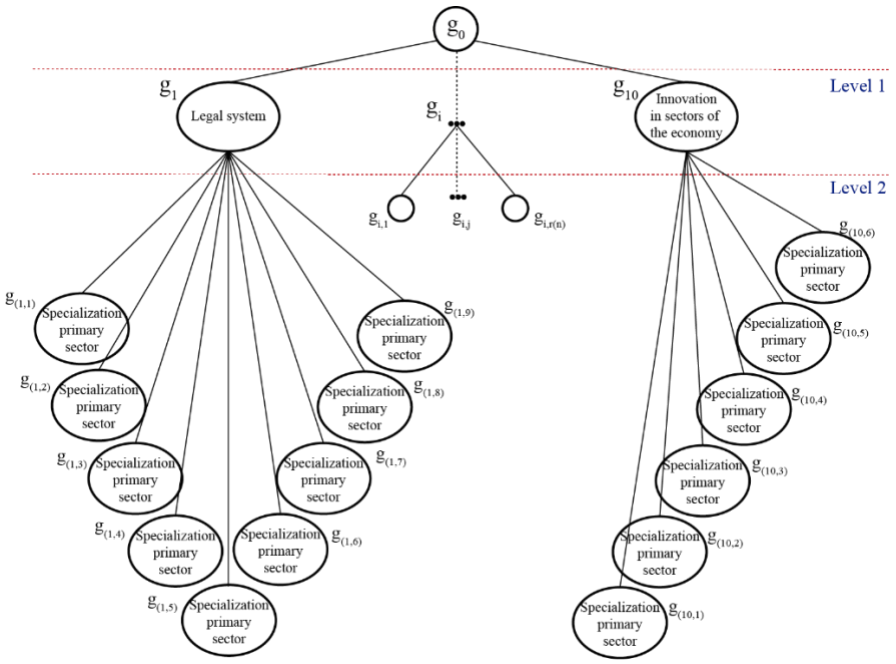
4. Analysis of competitiveness with Multiple Criteria Hierarchy Process (MCHP)

Regarding the methodology proposed in Section 3.3, the MCHP is applied to solve the competitiveness problem of Mexican regions. In the problem definition stage, the problem is structured in a multiple criteria hierarchy, decomposing the competitiveness problem in 10 macrocriteria as subproblems of the competitiveness (see description of Table 1).

The problem of competitiveness of the regions can be approached as a hierarchical problem, where some macrocriteria can integrate elementary criteria from a deeper level of the hierarchy. Figure 4 illustrates a summarized structure (two macrocriteria) of the complete hierarchy problem of the competitiveness of regions of Mexico. The macrocriteria Legal system (g_1) integrates nine elementary criteria; Sustainable environmental management (g_2) integrates 12 elementary criteria, among others, until the macrocriteria Innovation in sectors of the economy (g_{10}) integrating six elementary criteria. The competitiveness evaluation of Mexican regions includes 100 elementary criteria and it is structured in the two levels hierarchy, on the first level 10 macrocriteria (non-elementary criteria) is defined. On Level 2, 100 elementary criteria are constituting the macrocriteria from Level 1.

As shown in the hierarchical structure of Figure 4, the competitiveness of Mexican regions is structured in a hierarchy regarding the 10 macrocriteria and 100 elementary criteria. The schematic hierarchy is shown in Figure 5. The new hierarchical structure for the competitiveness problem allows the analysis approaching the MCHP. This implemented approach in this paper evaluates each macrocriterion allowing to analyze the interaction between immediate descending subcriteria directly related to the macrocriterion. Moreover, it is carried out by generating preferential models and ranking for each macrocriterion to understand how any region performs against other regions and, at the same time, how it impacts in the comprehensive competitiveness problem.

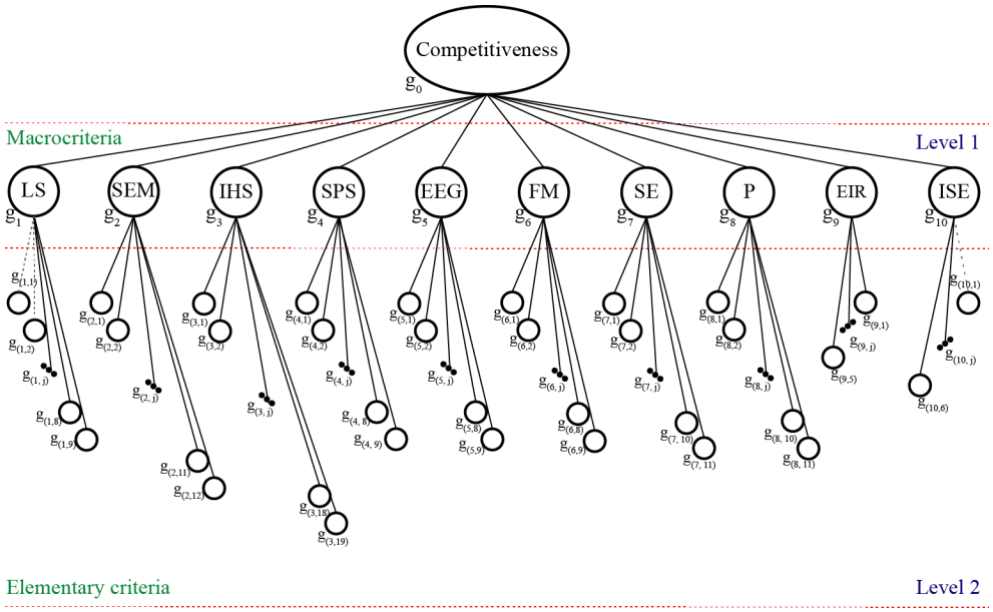
FIGURE 4. SIMPLIFIED STRUCTURE OF THE MCHP FOR THE COMPETITIVENESS OF REGIONS OF MEXICO



Source: Own elaboration

The Hierarchical ELECTRE III and distillation methods from Section 3.4 were applied to solve each subproblem g_i (macrocriterion) and the comprehensive level.

FIGURE 5. HIERARCHICAL STRUCTURE OF COMPETITIVENESS OF MEXICAN REGIONS



Source: Own elaboration

Table 3 shows the macrocriteria for competitiveness problems, their corresponding weights, and elementary criteria. Due to space limitations, details are reported in the Appendix of the online supplemental data (H-Competitiveness.xlsx). The supplemental data H-Competitiveness presents information related to data description and results. Data description regards, elementary criteria, evaluation table of regions, preferential information related to the parameters. Results show DM's preferential model and ranking of alternatives (different illustration formats) for each macrocriteria g_i.

TABLE 3. MACROCRITERIA AND ELEMENTARY CRITERIA OF COMPETITIVENESS REGIONS

Index	Macrocriterion	Weight	Number of elementary criteria
g1	Legal system (LS)	0.0364	g(1,1), …, g(1,9)
g2	Sustainable environmental management (SEM)	0.1818	g(2,1), …, g(2,12)
g3	Inclusive, prepared and healthy society (IHS)	0.1636	g(3,1), …, g(3,19)
g4	Stable and functional political system (SPS)	0.1091	g(4,1), …, g(4,9)
g5	Efficient and effective governments (EEG)	0.1273	g(5,1), …, g(5,9)
g6	Factor market (FM)	0.0727	g(6,1), …, g(6,9)
g7	Stable economy (SE)	0.0182	g(7,1), …, g(7,11)
g8	Precursors (P)	0.1455	g(8,1), …, g(8,11)
g9	Exploitation of international relations (EIR)	0.0909	g(9,1), …, g(9,5)
g10	Innovation in sectors of the economy (ISE)	0.0545	g(10,1), …, g(10,6)

Table 4 contains the rankings of each macrocriterion ($g_1 \ldots g_{10}$) and the comprehensive problem (g_0). Each macrocriterion is evaluated by a subset of subcriteria (elementary criteria belonging to the last level of the hierarchy). The generated ranking is the result of the interaction of elementary criteria evaluating the corresponding macrocriteria. For the competitiveness problem, it is analyzed how the interaction of subset of elementary criteria influence the region of Mexico in macrocriteria (Level 2 of the hierarchy) and then the interaction of macrocriteria impact for the comprehensive competitiveness problem (Level 1).

The comprehensive ranking g_0 allocates Aguascalientes (A1), Hidalgo (A14), Querétaro (A22) and Nuevo León (A19) in the first four positions as the most competitive regions. The macrocriteria should be analyzed considering those with higher importance value for the DM. The relative importance of the most important macrocriteria is $g_2 > g_3 > g_8 > g_5$, with the weights *0.18, 0.16, 0.14, 0.12*, respectively. It is shown in *Sustainable Environmental Management* (g_2) the first positions for A1>A14>A5>A19, the macrocriterion *Inclusive Prepared and Healthy Society* (g_3) macrocriterion shows A19>A23>A17>25, *Precursors* allocates (g_8) A9>{A3,A14}>A26>A1, *Efficient and Effective Governments* (g_5) shows A1>A22>A19>A5. It is obvious that A1 and A19 are shown twice each in the first position in different macrocriteria, however A19 is first just in one of the most important macrocriterion *Healthy Society* (g_3), *Exploitation of international relations* (g_9) do not correspond to the most important macrocriteria.

TABLE 4. COMPREHENSIVE AND INDIVIDUAL RANKINGS OF THE COMPETITIVENESS REGIONS.

Position	g0	g1	g2*	g3*	g4	*g5	g6	g7	g8*	g9	g10
1	A1	A4	A1	A19	A5	A1	A3	A25	A9	A19	A17
2	A14	A18	A14	A23	A4	A22	A23	A15	A3, A14	A8	A22
3	A22	A5	A5	A17	A28	A19	A1	A31	A26	A14	A15
4	A19	A6	A19	A25	A32	A5	A9	A6	A1	A2	A26
5	A5	A7	A22	A14	A6	A6	A18	A9	A17, A28	A26	A6
6	A6	A1, A11, A19	A29	A1	A25	A24	A15	A3	A25	A9	A4
7	A28	A13	A6, A17	A22	A24, A31	A27	A19	A1	A15	A5	A1
8	A26	A26	A18	A28	A7	A4	A25	A26	A2	A1	A21
9	A25	A32	A28	A10	A8, A13	A28	A28	A21	A23	A23	A14
10	A4	A30	A26	A18	A14	A8	A22	A22	A27	A24	A31
11	A17	A25	A10	A4	A2	A29	A26	A13	A31	A28	A3
12	A18	A31	A32	A3	A27	A14	A4	A2	A29	A22	A13
13	A29	A22	A25	A26	A16	A25	A30	A18	A24	A32	A8
14	A9	A21	A13	A32	A18	A31	A24	A11	A21	A11	A19
15	A24	A10	A15	A24	A17	A9	A2, A13	A4	A18	A21	A2
16	A15	A16	A4	A2	A11	A21	A27	A14	A16	A17	A24
17	A8	A24	A23	A15	A1	A3	A5, A21	A29	A19	A3	A27
18	A3	A8	A8	A31	A26	A17	A6	A24	A11	A4	A11
19	A32	A28	A11	A9	A22, A23	A26	A14	A16	A12	A27	A28
20	A27	A29	A16	A27, A29	A29	A18	A8	A27	A22	A15	A5
21	A31	A20	A20	A13	A19	A13	A29	A19	A5	A12	A32
22	A23	A27	A24	A5	A3	A32	A11	A10	A4, A7	A29	A25
23	A2	A23	A21	A11	A9	A10	A32	A30	A6	A6	A30
24	A11	A3	A9	A6	A20	A16	A16	A12	A8	A20, A30	A20, A29
25	A13	A14	A30	A16	A30	A20	A31	A23	A32	A18	A16
26	A21	A15	A2	A21	A10	A11	A17	A8	A30	A7, A10, A25, A31	A18
27	A10	A12	A3	A8	A21	A2	A12	A28	A10	A13, A16	A9
28	A16	A9	A31	A30	A12	A15	A7	A17	A13	A16	A10
29	A30	A2	A27	A7	A15	A7	A10	A5	A20		A7
30	A7	A17	A7	A20		A23	A20	A7			A12
31	A20		A12	A12		A30		A20			A23
32	A12					A12		A32			

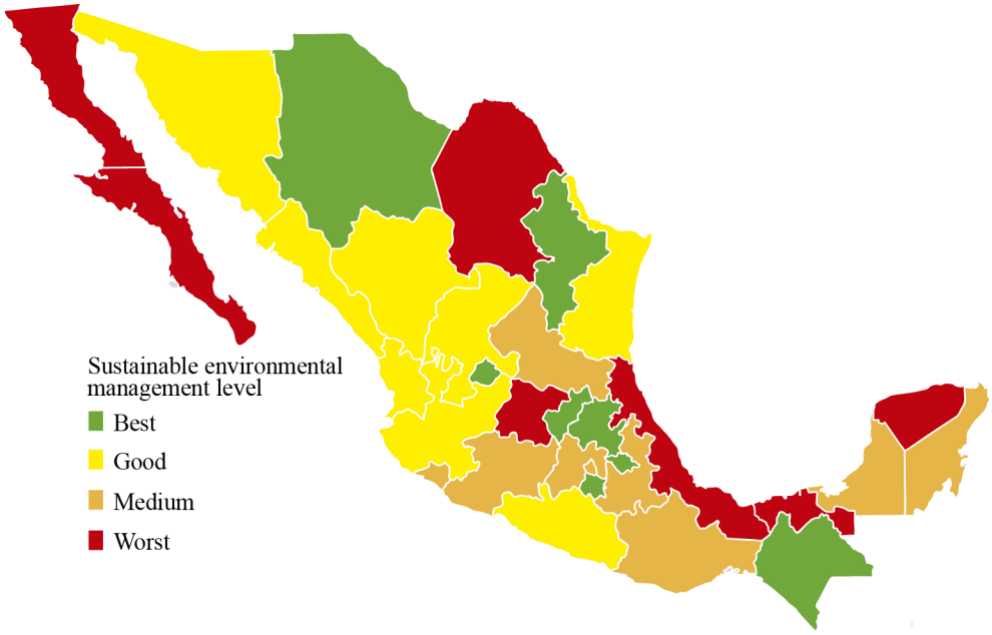
* The most important macrocriteria defined by the expert

On the other hand, A1 is the first in two of the most important macrocriteria g_2 and g_5. Thus, A1 is the most competitive region of the comprehensive ranking (g_0). The region A14 is allocated in second position in the two most important macrocriteria

(g_2, g_8) and third position in (g_9). Moreover, A22 is second in macrocriterion g_5 and g_{10}.

The Sustainable environmental management (g_2) level of regions is shown in Figure 6. The regions with the best level are dispersed on the north, center and south of Mexico. However, most of the regions with good level are concentrated mainly on the west and north-west. Some regions with potential on g_2 (medium level) are concentrated in the center and south of the country. The regions with the worst performance are allocated mainly in some external points of the country.

FIGURE 6. REGIONS LEVEL OF SUSTAINABLE ENVIRONMENTAL MANAGEMENT MACROCRITERION (G2)

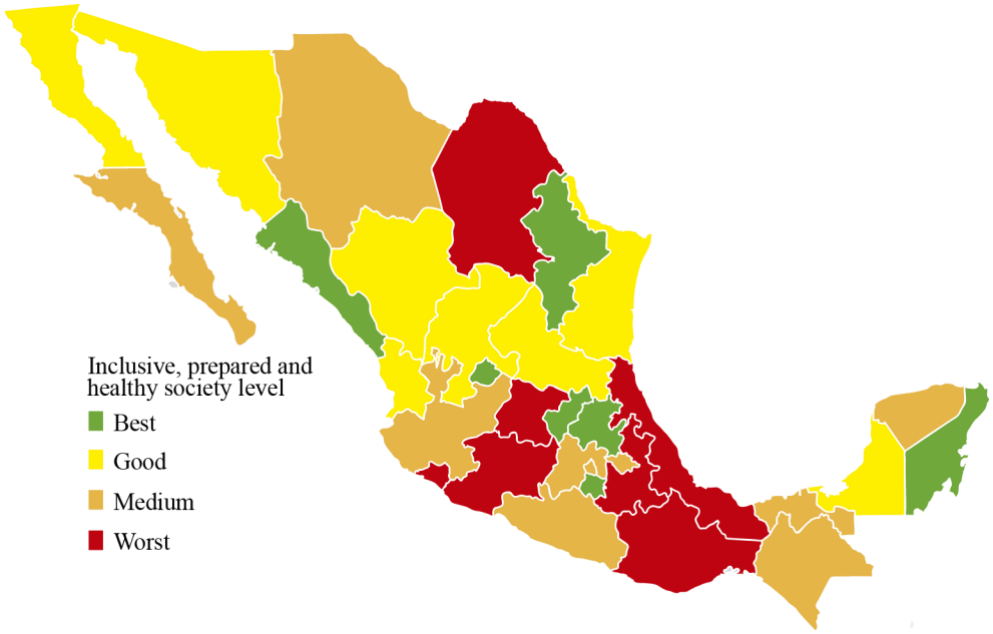


Source: Own elaboration based on the Sustainable environmental management macrocriterion ranking

The Inclusive prepared and healthy society (g_3) level of regions is shown in Figure 7. Some best regions on this macrocriterion are concentrated in the center and some on external sides of the country. Regions with good levels are concentrated a little to the north but closer from the center and some external sides. Medium level regions on g_3 are dispersed mostly in the south of the country and two regions on the north. Regions with the worst performance are agglomerated in the center and south area of the country, but with just one region in the north.

Some interesting revealed aspect from analyzing the interaction of elementary criteria is that some not particularly important regions in the comprehensive problem (Level 1) are the best region in a specific macrocriterion (Level 2). E.g., A4, A5, A3, A25, A9, A17 are on the first positions on macrocriterion *Legal system* (g_1), *Stable and functional political system* (g_4), *Factor market* (g_6), *Stable economy* (g_7), *Precursors* (g_8), *Innovation in sectors of the economy* (g_{10}), respectively.

FIGURE 7. REGIONS LEVEL OF INCLUSIVE, PREPARED AND HEALTHY SOCIETY MACROCRITERION (G3)



Source: Own elaboration based on the inclusive, prepared and healthy society macrocriterion ranking

But those regions are not very well positioned as competitive regions in g_0 because they present low performance on other macrocriteria (some of them important macrocriteria).

Figure 8 shows the competitive regions g0 of Mexico. It presents at best competitiveness level three regions in the north, two regions in the center, and one region in the south. The region with good and best competitiveness is agglomerated mainly in the center and north of the country, leaving the region with the worst competitiveness level, mostly in the south of the country and just two regions in the north. However, some regions, with the potential to increase their competitiveness, are allocated in the center and west. Also, some regions are allocated on the outer sides of the country, showing maritime capacities.

It seems low competitive development is presented in regions on the south of Mexico. Coahuila (A7), Oaxaca (A20) and Guanajuato (A12) are the lowest competitive Mexican regions. A12 is one of the lowest positions in five macrocriteria, A20 is one of the lowest positions in four macrocriteria, and A7 is in the lowest positions in six macrocriteria. Some interesting aspects of those regions are the competitive potential for A7 and A12 even they are one of the worst regions ranked. The region A7 is allocated in g_1 and g_4 in positiosn 5 and 8, respectively. It means region A7 presenst good opportunities to attract inversion because of its *Legal system* and *Stable and functional political system*, respectively. On the other hand, region A12 is allocated in g_8 and g_9 in positions 19 and 21. Even they area far distance for the best competitive region; they can be improved on some macrocriteria that allocate them in better competitive positions.

This focused analysis can be used to show the region with more promising opportunities to get support and increase their competitiveness. Identifying the

promising regions, a new development of policies can be performed based on the analysis of the competitiveness of regions. Some strategies can be developed to boost competitiveness in general for those regions with good potential (medium or good levels). On the other hand, if a social aspect is relevant for government, identifying promising regions with very low development, point out which regions to boost with some competitive aspect to improve opportunities to markets and society translating in quality of life in the region.

FIGURE 8. REGIONS LEVEL OF COMPREHENSIVE COMPETITIVENESS (G0)

Source: Own elaboration based on the comprehensive competitiveness ranking

4.1. Sensitively analysis for the competitiveness ranking

In the study, a sensitivity analysis was performed to validate results with hierarchy-ELECTRE III method. Eight configuration scenarios of indifference (q) and preference (p) threshold values in the elementary criteria are considered, impacting the macrocriteria of the upper level and the global problem. The scenarios are detailed in Table 5 and described below.

The scenery 1 and scenery 2 impact in the elementary criteria g(2,8) and g(2,9), respectably. However, impacting as well on the macrocriteria g(2) Sustainable environmental management. The scenery 3 and scenery 4 regards the elementary criteria g(3,2) and g(3,11), respectably. Nevertheless, they impact the macrocriteria g(3) Inclusive, prepared and healthy society as well.

The scenery 5 and scenery 6 impact in the elementary criteria g(8,8) and g(8,9), respectably. However, impacting as well on the macrocriteria g(8) Precursors. The scenery 7 and 8 modify three and six elementary criteria at the same time, respectively. The sceneries 7 and 8 impact on macrocriteria g2, g3 and g8 at same time.

TABLE 5. CONFIGURATION SCENARIOS FOR THE SENSITIVITY ANALYSIS

	Elementary criteria	q	p
Scenery 1	g(2,9)	15	25
Scenery 2	g(2,8)	5	25
	g(2,9)	15	25
Scenery 3	g(3,2)	5	25
Scenery 4	g(3,2)	5	25
	g(3,11)	15	25
Scenery 5	g(8,9)	10	25
Scenery 6	g(8,8)	12	23
	g(8,9)	10	25
Scenery 7	g(2,9)	15	25
	g(3,2)	5	25
	g(8,9)	10	25
Scenery 8	g(2,8)	5	25
	g(2,9)	15	25
	g(3,2)	5	25
	g(3,11)	15	25
	g(8,8)	12	23
	g(8,9)	10	25

Source: Own elaboration based on the sensitive analysis

The macrocriterion Legal system presents the most variation in scenery 1 because the elementary criteria g(2.9) is the most important criterion from the complete set of criteria. Eleven inversions of position are shown with the scenery 1 and 6 inversions of scenery 2. The two scenarios impact the macrocriteria level g(2) Sustainable environmental management; however, the g(2) ranking does not present any inversion on the ranking (see Table 7). The g(3) Inclusive, prepared and healthy society macrocriteria regards the scenery 3 and 4, showing any inversion in the ranking, the ranking is the same. The ranking in the global problem does not change with the scenery 3 and 4; it remains the same. The g(8) Precursors macrocriteria regards scenery 5 and 6, no changes are present on those scenarios. On the global problem, the scenery 5 remains the same, scenery 6 present one inversion.

TABLE 6. SENSITIVITY ANALYSIS ON MACROCRIERIA.

	Legal system (g2)			Sustainable environmental management (g3)			Precursors (g8)		
Pos.	Final	Esc. 1	Esc. 2	Final	Esc. 3	Esc. 4	Final	Esc. 5	Esc. 6
1	A1	A1	A1	A19	A19	A19	A9	A9	A9
2	A14	A5, A14	A14	A23	A23	A23	A3, A14	A3, A14	A3, A14
3	A5	A19, A22, A29	A5	A17	A17	A17	A26	A26	A26
4	A19	A6	A19, A22, A29	A25	A14, A25	A14, A25	A1	A1	A17
5	A22	A18	A6	A14	A1	A1	A17, A28	A17, A28	A25
6	A29	A25	A18	A1	A22	A22	A25	A25	A1
7	A6, A17	A17	A28	A22	A28	A28	A15	A15	A15
8	A18	A28	A10	A28	A10	A10	A2	A2	A28
9	A28	A26	A17	A10	A4	A18	A23	A23	A2
10	A26	A10	A26	A18	A18	A4	A27	A27	A23
11	A10	A32	A25	A4	A3	A9	A31	A31	A27
12	A32	A15	A32	A3	A26	A3	A29	A29	A31
13	A25	A13	A15	A26	A32	A26	A24	A24	A29
14	A13	A4	A8	A32	A2	A32	A21	A21	A21
15	A15	A8	A13	A24	A24	A24	A18	A18	A24
16	A4	A23	A4	A2	A15	A2	A16	A16	A18
17	A23	A16	A23	A15	A29	A15	A19	A19	A19
18	A8	A20	A16	A31	A31	A29	A11	A11	A16
19	A11	A11	A20	A9	A9	A31	A12	A12	A12
20	A16	A24	A9	A27, A29	A11	A27	A22	A22	A22
21	A20	A21	A24	A13	A27	A11	A5	A5	A11
22	A24	A9	A21	A5	A6	A13	A4, A7	A4, A7	A4, A5
23	A21	A2	A11	A11	A13	A6	A6	A6	A6
24	A9	A30, A31	A31	A6	A5	A16	A8	A8	A7, A8
25	A30	A3	A2	A16	A16	A5	A32	A32	A32
26	A2	A27	A3	A21	A21	A21	A30	A30	A30
27	A3	A7	A30	A8	A8	A30	A10	A10	A10
28	A31	A12	A27	A30	A30	A8	A13	A13	A13
29	A27		A7	A7	A7	A7	A20	A20	A20
30	A7		A12	A20	A20	A20			
31	A12			A12	A12	A12			
32									

The sensitivity analysis configuration for the global ranking on scenery 7 regards three elementary criteria, the global ranking in this scenery remains the same (see Table 7). The scenery 8 regards six macrocriteria, those impact in the global ranking presenting eight inversions (see Table 7). The sensitivity analysis presented shows some minimal variations in the global ranking.

TABLE 7. SENSITIVITY ANALYSIS OF THE GLOBAL PROBLEM.

Pos.	Final g	Esc. 1	Esc. 2	Esc. 3	Esc. 4	Esc. 5	Esc. 6	Esc. 7	Esc. 8
1	A1	A1	A1	A1	A1	A1	A1	A1	A1
2	A14	A14	A14	A14	A14	A14	A14	A14	A14
3	A22	A22	A22	A22	A22	A22	A22	A22	A22
4	A19	A19	A19	A19	A19	A19	A19	A19	A19
5	A5	A5	A5	A5	A5	A5	A5	A5	A5
6	A6	A6	A6	A6	A6	A6	A6	A6	A6
7	A28	A28	A28	A28	A28	A28	A28	A28	A28
8	A26	A26	A25, A26	A26	A26	A26	A26	A26	A25, A26
9	A25	A25	A4	A25	A25	A25	A25	A25	A4
10	A4	A4	A18	A4	A4	A4	A4	A4	A18
11	A17	A17	A17	A17	A17	A17	A17	A17	A17
12	A18	A18	A29	A18	A18	A18	A18	A18	A29
13	A29	A29	A9	A29	A29	A29	A29	A29	A9
14	A9	A9	A24	A9	A9	A9	A9	A9	A24
15	A24	A24	A15	A24	A24	A24	A24	A24	A23
16	A15	A15	A8	A15	A15	A15	A23	A15	A15
17	A8	A8	A3	A8	A8	A8	A15	A8	A8
18	A3	A3	A32	A3	A3	A3	A8	A3	A3
19	A32	A32	A27, A31	A32	A32	A32	A3	A32	A32
20	A27	A27	A11	A27	A27	A27	A32	A27	A27
21	A31	A31	A23	A31	A31	A31	A27	A31	A31
22	A23	A23	A13	A23	A23	A23	A31	A23	A11
23	A2	A2	A2	A2	A2	A2	A2	A2	A13
24	A11	A11	A21	A11	A11	A11	A11	A11	A2
25	A13	A13	A10	A13	A13	A13	A13	A13	A21
26	A21	A21	A16	A21	A21	A21	A21	A21	A10
27	A10	A10	A30	A10	A10	A10	A10	A10	A16
28	A16	A16	A7	A16	A16	A16	A16	A16	A30
29	A30	A30	A20	A30	A30	A30	A30	A30	A7
30	A7	A7	A12	A7	A7	A7	A7	A7	A20
31	A20	A20		A20	A20	A20	A20	A20	A12
32	A12	A12		A12	A12	A12	A12	A12	

The ranking with the more inversion regards that with the most important elementary criteria g(2,8) and g(2,9) on macrocriteria Legal system (g2). However, those inversions do not affect the global ranking significantly, as shown in Table 7. The scenery 8 shows some inversion because it regards changing the indifference and preference parameters from eight elementary criteria.

5. CONCLUSIONS

This paper analyses the regional development differences in the competitiveness components in Mexico. It measures the variables that affect the competitiveness of the regions, with 10 macrocriteria and 100 elementary criteria. From a methodological perspective, it is used a Multiple Criteria Hierarchy Process (MCHP) to analyze the competitiveness of the regions in Mexico in two levels. In Level 2, subgroups of elementary criteria are evaluated to understand their interaction and impact of a macrocriteria in the upper level of the hierarchy. In Level 1, subgroups of macrocriteria are evaluated (regarding their elementary criteria from Level 2) to understand their interaction and impact of the competitiveness of Mexican regions. The hierarchical approach allows the generation of a preferential model and ranking for each macrocriterion, and a comprehensive ranking for the competitiveness problem. The hierarchical analysis allows for understanding how each macrocriterion has improved the regions.

The MCHP allows assessing interaction among subcriteria in all levels of the hierarchy to analyze their influence at any level. For the competitiveness regions problem, it illustrates the opportunities and needs of regions and allows DMs to improve the competitiveness indexes of the regions. The use of MCHP to evaluate the competitiveness of Mexican regions could be used as an instrument in the formulation of more assertive policies and decisions within organizations. Consequently, it would

achieve favorable conditions for the promotion of public and private investment.

The studies developed by the Institute of Competitiveness of Mexico (IMCO) establishes a ranking based on a compensatory method. In this sense, the ELECTRE III method provides support for decision making for real-world problems with a non-compensatory approach. For future lines of research, it is considered to analyze other areas of social sciences and economic phenomena that allow minimizing the degree of uncertainty in decisions by managers in public or private organizations.

The current research presents some limitations related to the approach implemented. The ELECTRE method constructs a fuzzy relation between regions, aggregating the decision criteria. However, some linguistic techniques could be used to evaluate the decision criteria in a priori process to the comparison between regions. It would be able to evaluate some uncertainties that could be presented because of the retrieval and data type.

The implication of the current research allows a deeper analysis of performances of regions because of the process of evaluation of region in subgroups of decision criteria. It is measurable how a region is competitive, considering certain groups of criteria and the comprehensive criteria at once. The major implication of this kind of analysis is in relation to the generation of policy and decision-making to develop regions' performance. The decision-makers would like to see which factor of competitiveness is more relevant to attend, in consequence, in which area the funds should be applied.

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