METHODOLOGY PROPOSAL FOR MULTI-CRITERIA INDUSTRIAL SITE GEOLOCALIZATION FOR PHOTOVOLTAIC PANELS MANUFACTURING IN BRAZIL

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Abstract: This paper introduces an ongoing study of industrial location analysis for solar panel manufacturing in Brazil. The decision-making process of industrial location involves a series of criteria that address economic, technical, environmental, and social aspects. A literature review of location theories and their classifications is presented. Follows the presentation of a methodology for the analysis based on a sequence of tools to support data analysis and multi-criteria of geographic macro locations to determine the optimal points for industrial implementation.

Keywords: Industrial location, multi-criteria analysis, fuzzy logic, photovoltaic panels.

PROPOSTA METODOLÓGICA PARA GEOLOCALIZAÇÃO INDUSTRIAL MULTICRITÉRIO PARA A FABRICAÇÃO DE PAINÉIS FOTOVOLTAICOS NO BRASIL

Resumo: Este artigo apresenta um estudo em andamento de análise de localização industrial para a fabricação de painéis solares no Brasil. O processo de tomada de decisão de localização industrial envolve uma série de critérios que abordam aspectos econômicos, técnicos, ambientais e sociais. É apresentada uma revisão teórica das teorias de localização e suas classificações. Em seguida, é apresentada uma metodologia de análise baseada em uma sequência de ferramentas de apoio à análise de dados e multicritérios de macrolocalizações geográficas para determinar os pontos ideais para a implementação industrial.

Palavras-chave: Localização industrial, multicritério, lógica fuzzy, painéis fotovoltaicos.

1. INTRODUCTION

Geolocation gained notoriety as a science and a field of study of geography after the publication of the work of the German Johann Heinrich von Thünen in 1826, especially after the publication of the translation of the work. Previously, authors such as Richard Cantillon, Leon Lalanne and Jean Reynaud were some of the first to study the financial impact on the choice of location. [1]

Due to the simplifications made in von Thünen's theory, subsequent works were carried out in order to complement and add greater robustness to the model. In [2] there are two classifications of models of locational theories, the first splits into only two divisions, starting from before the 70s and after the 70s. The first division is marked by theorists von Thünen, Alfred Weber, Walter Christaller, August Lösch and Walter Isard, introducing models from a static market perspective, and simplified and ideal considerations, to models with dynamics perspectives, more robust considerations and with more variations. The second division is dedicated to the production changes from Fordist and Taylorist models to Toyotism, implying a modification in the locational decision of the production process, aiming more qualified labor.

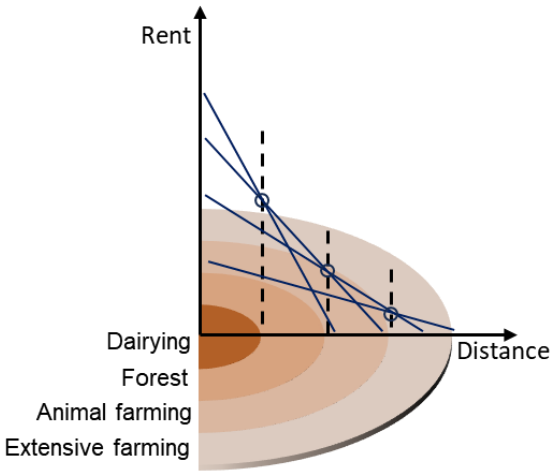
An alternative classification of location theories is presented by [3] in which theories are categorized into 5 classes, the neoclassical, behavioral, systemic, Marxist and contemporary.

It is described that the neoclassical school, guided by authors such as: Alfred Weber; August Lösch; Walter Isard; Alfred Marshall. Seek to obtain the optimal location through the choice guided by the influence of transport costs. The behavioral approach, pioneered by the geographer Carl Sauer, differs from its predecessor by presenting the locational decision with emphasis on the company's objectives, including the analysis of competition to maximize profits. The systemic school was introduced together with the so-called "New Geography",[4] now postulating a mathematical and scientific theoretical orientation for geography. Walter Christaller is a notable author of this school, based on his theory of central places. The incorporation of social and political issues was the artifact for the elaboration of Marxist schools. Names as Alain Lipietz and Georges Benko addressing issues such as production crises and criticism of the capitalist system. Finally, the contemporary schools, authors such as Peter Drucker, Michael Porter, Kenichi Ohmae are cited. The emphasis is dedicated on local and regional scales with information playing a role in all sectors.[3]

The question of explaining the economic influences that drive business location choice was a target of interest in classical theories. This topic, with its emphasis on modeling transportation costs, was spearheaded by von Thünen and Alfred Weber. With the difference that von Thünen's model seeks the type of production associated with each location, such as proximity to urban centers associated with more perishable goods while Weber's theory seeks to determine the location for a given production, such as through considering proximity to market or raw material as well as conglomerates [5].

Von Thünen’s model [6] investigates the costs of a farmer from a correlation between transportation costs and land rent. Depending on the type of good produced, there will be a greater or lesser propensity or capability to pay higher rents in proximity to the center of consumption, as shown in Figure *1*.

Figure 1. Von Thünen's lend rent model. [6]

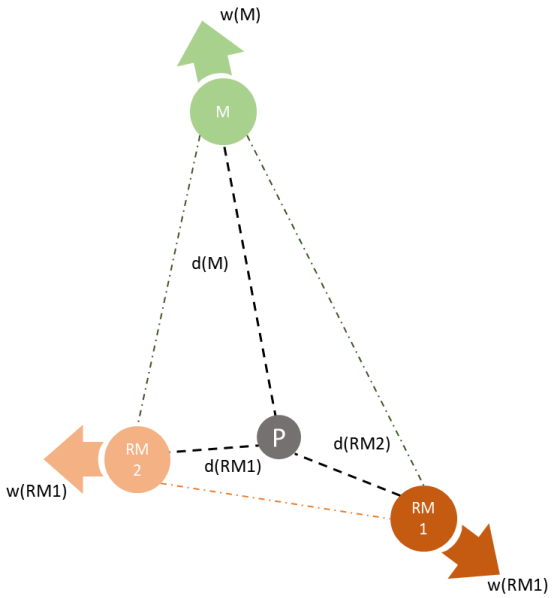


One of the greatest weaknesses of this model is that it does not consider what happens outside cities, making it difficult to interpret with this model where there are analyses that present interaction between cities. A more balanced analysis should consider different sizes for different cities, leading to a variation in rental values, but that still different cities may present different functions and organizations making interpretation through the model difficult [7].

Weber's model, on the other hand, seek to analyze the economic influence on industrial location. Emphasizing transport costs by addressing 3 pillars: Transport costs, labor costs and finally, the agglomerations forces [5].

The first pillar of his study is exemplified through the Weber triangle, which starts considering a single commercial center and two raw materials sources in different sites (Figure *2*).

Figure 2. Weber's site location triangle. [8]



The M point indicates the consumption market, RM1 and RM2 points identify raw material sources and P represents the lowest production cost position relative to the forces. Point P is therefore the variable to be optimized in this model, presenting the lowest value of the sum of the product of the mass transported times the transported distance. [8] introduces the concepts of market-oriented and raw material-oriented location. It is defined by the proximity of the processing unit either with the market or the raw material source. Products with characteristics of greater mass losses during processing will tend towards the raw material, thus being raw material-oriented. Products with lower losses while processing will tend to be market-oriented, located closer to the commercial centers. The raw material mass ratio relative to the finished product's mass is known as the material index. Raw material-oriented productions tend to agglomerate towards raw material centers, while market-oriented productions are more flexible to locate, thus being non-agglomerative.

The second pillar addressed is Labor Costs, it seeks to compare labor and transport costs. The comparison is carried out through the labor cost index and the transportation costs. Labor cost index is calculated as a labor cost and product mass ratio. The analysis should then consider whether labor costs are more significant than transportation costs, driving the decision.

The last pillar addresses agglomeration forces. This aspect can be significant in gaining advantages through proximity to auxiliary industries, access to labor, marketing, or larger economies. Advantages should be compared to transportation costs, and only when higher, the decision should be driven by agglomeration forces.

A proposal for locational analysis based on multicriteria choice was presented at [9], [10] this analysis uses tools such as fuzzy interference systems (FIS), multicriteria analysis (MCDA), geographic information system (GIS), analytical hierarchy process (AHP) and expert systems (ES). The method is divided into 10 steps to obtain the results of the best geographical positions of industrial facilities, which in this work were customized to the specificity of the problem.

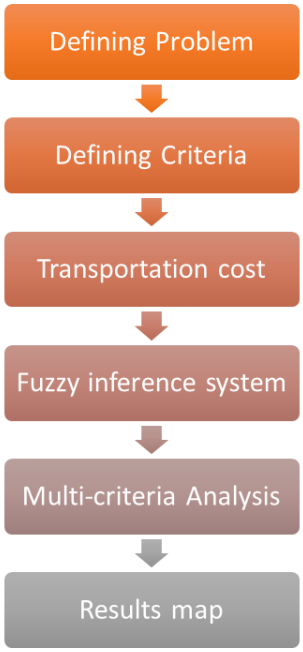
2. METHODOLOGY

Aiming the selection of the optimal industrial site to produce solar panels, starting from the production of solar cells, the project methodology relies on a sequence of steps for this analysis as shown in figure 3.

The first step, problem definition, involves the operation's context. This implies understanding the environment, the industry, the players, demands and any other relevant aspects that should be considered as a criteria and how significant they are for the decision. Therefore, in the context of the solar panels manufacturing industry, boundary conditions such as the transportation costs, infrastructure, energy supply, labor availability, and quality play important roles for the decision. The model should then be capable of reflecting the influence of those aspects in the final decision. Transportation costs must consider in the macro-location analysis the Brazil's main clients and most significant suppliers. The country's northeast region represents the biggest client cluster, while the raw material, such as mining residuals of silica, are

concentrated in the southeast region. The model will therefore consider the industrial site based on such information.

Figure 3. Analysis steps



As for the second step, defining the criteria, to be used in the analysis, according to the problem definition requirements, the following were prioritized: A) Transportation cost; B) Rent cost; C) water and energy cost; D) labor quality; E) Transport infrastructure available; F) distance from the available transport infrastructure; G) water and energy availability; H) industry clusters; I) distance from innovation centers. Table 1 summarizes the criteria, along with the data obtaining method and the criteria's best condition.

Table 1. Analysis selected criteria.

No	Criteria	Source	Best condition
1.	*Transportation cost*	*Calculated*	*Lowest*
2.	*Rent cost*	*Open database*	*Lowest*
3.	*Water and energy cost*	*Open database*	*Lowest*
4.	*Labor quality*	*Open database*	*Medium*
5.	*Transportation available*	*Open database*	*Highest*
6.	*Distance from the available transport infrastructure*	*Calculated*	*Lowest*
7.	*Water and energy availability*	*Open database*	*Highest*
8.	*Industry clusters*	*Open database*	*Highest*
9.	*Innovation centers distance*	*Calculated*	*Lowest*

Criteria such as A) and D) demand considerations upon it before being considered for the analysis, while the others will be analyzed by the degree of how high or low, they are according to the fuzzy analysis, and its influence measured by the applied weight on it.

The analyzed database for the A) Transportation cost, consists of an interface with the routs generated using GIS by google maps taking the latitude and longitude of each Brazilian municipal location, since in this phase of the project, the macro-location is our only concern. Following Weber's theory [8], fixed spots with the market and the raw material will be established, and by calculating the distance times the transported mass, each municipal is assigned to a specific transportation index. This index is further analyzed with the fuzzy logic. FIS allows an intelligent decision support system to be established, considering qualitative and quantitative criteria. Expanding the possibility to improve its estimation by training data. [11], [12]

Labor quality implies that a specific level of qualification of the labor is required, to achieve the industry goals. Therefore, due to the high level of automatization of the solar panels manufacturing, labor with technical and high school education represent the higher demand. Labor quality will be therefore quantified by the weight that municipals receive according to the availability of labor with this qualification.

The remaining criteria rely on the analysis of available database considering as the higher the better for E) Transport infrastructure available; G) water and energy availability. And the lower the better for B) Rent cost; C) water and energy cost; F) distance from the available transport infrastructure; I) distance from innovation centers.

The following step consists of the fuzzy criteria analysis. Further investigations will be made to determine the fuzzification and defuzzification ranges for each of the presented criteria, along with the fuzzy logic.

Fuzzy classification will be taken into five levels of qualitative range, depending on the logic applied for each criterion. Excellent (E), Good (G), Satisfactory (S), Regular (R), Insufficient (I).

After the defuzzification process, a degree of membership is outputted with a range from a float value from 0 to 1, grading how good a criteria perform in each municipal, allowing the next step to take place.

Multi-criteria analysis works by defining weights to every degree of membership generated. The definition of weights will also be a topic of further investigations on the work.

Finally, a thermal map generation takes place, by ranging on a normalized scale the suitability of each municipality. According to the degree of membership calculated during the fuzzy process, and its respective weight assigned the best site location will be determined.

4. CONCLUSION

This paper presented a work in process of an industrial site selection method optimizing solar panels manufacturing industry location based on multiple criteria. The study investigated methods to incorporate multiple criteria of requirements to assist the decision-making process, along with the definition of those requirements. A workflow of the transportation costs was established based on the Weber's location theory, combining the data from client demand and raw material location. Fuzzy information system is used to quantify in a non-binary scale the municipal performance for each criteria. Finally, a multi-criteria analysis is used to apply weights and determining the relevance of the criteria for the analysis as whole, indicating an optimized site for producing solar panels.

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