International Journal of Management and Sustainability
2024 Vol. 13, No. 1, pp. 118-135
ISSN(e): 2306-0662
ISSN(p): 2306-9856
DOI: 10.18488/11.v13i1.3620

Risks associated with the technological adoption of industrial symbiosis: A study of its implementation by geographic regions

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Article History
Received: 6 February 2023
Revised: 2 October 2023
Accepted: 8 January 2024
Published: 30 January 2024

Keywords
Financial risk
Geographical differences
Hierarchical logistic model
Industrial symbiosis
Performance risk
Social risk.

ABSTRACT

This research investigates the factors influencing the adoption of industrial symbiosis practices, focusing on their relevance in geographical contexts within developing countries associated with the European Economic Community. The study employs geographical weighting analysis as its primary methodology, allowing for a nuanced examination of variable impacts within specific geographic regions. Data is gathered through surveys distributed to companies operating in various high-energy consumption sectors that have previously engaged in industrial symbiosis activities to varying extents. The study's findings emphasize the crucial role that financial and performance-related risks played in influencing the decision-making process surrounding the implementation of industrial symbiosis. Furthermore, the research highlights the significance of regional dynamics in influencing waste disposal practices and the overall success of industrial symbiosis initiatives. Additionally, the study underscores the impact of social media and networks in disseminating vital information that is instrumental in advancing innovative industrial symbiosis processes. These findings hold practical implications for stakeholders, including policymakers, businesses, and organizations aiming to foster sustainable economic practices. Understanding the influence of risk factors and regional intricacies enables tailoring strategies that can promote industrial symbiosis adoption. Moreover, recognizing the pivotal role of social media and networks in knowledge dissemination can accelerate the adoption of novel practices, facilitating the transition towards greener economies in developed and developing regions associated with the European Economic Community.

Contribution/Originality: This research makes an original contribution by addressing critical knowledge gaps in industrial symbiosis adoption. It innovatively combines a geographical weighting analysis with a sector-specific survey to identify the importance of risk factors and regional considerations. The study's recognition of the transformative power of social media and networks adds a contemporary dimension to the discourse on industrial symbiosis promotion.

1. INTRODUCTION

According to Chertow (2000), industrial ecology has raised the need to study the flow of materials from production processes and energy use, which impact the regional field locally and globally. Thus, industrial symbiosis appears as an area of industrial ecology that integrates the physical exchange of materials, energy, water, and products in manufacturing. A central aspect of industrial symbiosis is that it posits geographical proximity as a critical factor in companies' competitiveness since it offers synergies and collaborations in geographically concentric companies' competitiveness nations. According to the above, industrial ecology determines the need to see the industrial system as dependent on the surrounding system. This vision of the company as a system dependent on the environment makes it possible to search for strategies to optimize production cycles, materials, supplies, and finished products while keeping sight of their final disposal.

Considering the fundamentals of industrial symbiosis, the possibility of optimizing resources such as energy and capital arises. In this way, it is possible to focus on the different levels of the firm at the local, regional, and international levels that allow for improving the competitive conditions in the production processes. The concept of symbiosis is detached from the biological field and refers to relationship between an entity and nature. This relationship will be subject to the exchange of resources (materials, energy, and information) in a way that benefits the parties involved. Finally, industrial symbiosis involves exchanging different entities that generate expected benefits in a joint agreement. They can be maximized if they continue to work as a group. This type of collaboration of two-way relationships between the participants ensures the exchange for mutual benefit.

Additionally, this scenario of the industrial symbiosis field is characterized by the need for economic growth conditioned by the management of scarce resources (Agudo, Bezerra, Paes, & Júnior, 2022; Kandasamy et al., 2022). According to Wadström, Johansson, and Wallen (2021), the main interests are directed not only to the search for methodologies to optimize industrial symbiosis but also to the search for new approaches, theories, and tools that support the objectives of establishing sustainable production systems. It is essential to highlight that, according to the literature, a large part of the needs of the area are based on finding management perspectives that allow the creation of an ideal platform for implementing industrial symbiosis. Within these lines are the designs of organizational structures, stakeholder decision-making, organizational culture, and organizational and political environments (Agudo et al., 2022).

In industrial symbiosis, it is possible to find sub-areas of development that have determined the future lines on which more attention has been paid due to their initial stage of development. These areas are environmental (Cagno, Negri, Neri, & Giambone, 2023; Chen et al., 2022; Gast, Cabrera Serrenho, & Allwood, 2022; Liu, Wang, & Yan, 2022; Pang et al., 2023; Sorrenti, Zheng, Singlitico, & You, 2023; Taqi et al., 2022; Shaoqing Wang et al., 2022) Country studies (Colpo, Martins, Buzuku, & Sellitto, 2022; Giannoccaro, Zaza, & Fraccascia, 2023; Miyamoto, Costa, & Candiani, 2022; Oni et al., 2022) analysis methodologies (Agudo et al., 2022; Castellet-Viciano, Hernández-Chover, Bellver-Domingo, & Hernández-Sancho, 2022; Yazıcı, Alakaş, & Eren, 2022) Study cases (Cao, Xiao, & Zhou, 2023; Huan & Han, 2022; Liu et al., 2022; Pechsiri et al., 2023).

According to Neves, Godina, Azevedo, and Matias (2020), there are some critical gaps to analyze in industrial symbiosis. One of these gaps is related to the difficulty of the processes for quantifying the impacts that are generated. This condition is due to the complexity and type of information necessary to obtain (Hutchins, Richter, Henry, & Sutherland, 2019). In contrast, the necessity for qualification has given rise to additional challenges regarding the assessment of impacts, comprising both environmental and social dimensions. An example of the above is how the incidence of industrial symbiosis can improve air quality. This type of impact measurement requires measurements that contribute to quality improvement (Neves et al., 2020).

An essential aspect is that the social, ecological, and economic components are the least studied. This situation is a disadvantage because they are essential for developing industrial symbiosis. In this way, it is possible to develop future studies that allow a deeper understanding of the social impacts that this type of practice generates on the quality of life of a population, including the fields of health, employment, income, and infrastructure improvement surrounding the nearest communities.

Another element is that the need to have appropriate measures for the industry's context allows for improving how it contributes to business sustainability and the environment. In this way, evaluating the environmental factors surrounding this process and affecting nearby populations becomes crucial. Another gap highlighted in the literature is the need to carry out studies that allow the development of indicators and methods for industrial symbiosis.

These studies will allow the quantification of the impacts, considering four aspects: sustainability, environment, economics, and social. Although some studies have considered these dimensions, few have considered industrial symbiosis as a field of study. For writers like Van Schoubroeck, Van Dael, Van Passel, and Malina (2018), these studies in the field have made it hard to combine qualitative and quantitative measurements, think about how they work together in optimizations, and finally, include the social aspect. Thus, to overcome such restrictions, defining indicators for industrial symbioses that allow for impact assessments of these practices in companies is necessary.

This research aims to develop an industrial symbiosis measurement model, considering the different resources necessary to evaluate the impact on the firm's performance. This work has been structured as follows: In the first part, an introduction to industrial ecology and its relationship with the area of industrial symbiosis is made. In the second part, an analysis of the industrial symbiosis field and its current development state is carried out. In the third part, the methodology is described, mentioning the main variables analyzed. Finally, the results and conclusions, as well as the implications and future lines of research, are established.

2. THEORETICAL FRAMEWORK

2.1. Technology Adoption Theory Perspectives in Industrial Symbiosis

Technological adoption is subject to the influence of many theories: diffusion innovation theory, the theory of planned behavior, social cognitive theory, the Unified Theory of Acceptance and Use of Technology, and the Technology Acceptance Model (TAM). These theories have focused on explaining human behavior in interaction with technology (Yadegari, Mohammadi, & Masoumi, 2022). These perspectives are responsible for understanding the processes in which technology has a dominant role in the processes of firms and where people play a fundamental role in its implementation. In the same way, the conclusions of the studies in the field have highlighted how the results found help to generate better conditions and obtain better results by implementing many technologies. An important aspect to highlight is that the perspective of technological adoption, despite being a little over 25 years old, currently continues to have an adequate level of importance in order to understand the behavior of users of different types of technology (Marangunić& Granić, 2015; Miguel et al., 2023). Another equally relevant aspect is the ease of use of the technology under evaluation (Momani & Jamous, 2017). From the field of psychology, the acceptance of the new technology will be influenced by the perceptions of the users' attitudes towards the usefulness of the uses and the ease of its operation. This previous condition is closely related to the limitations and advantages of implementing new technologies, such as industrial symbiosis.

For scholars like Wang, Zhang, Wang, and Liu (2022), in the case of industrial symbiosis, its adoption considers factors determining how it can be implemented at an industrial level. The adoption process considers forming inter-organizational networks intending to create conditions for industrial sustainability and manufacturing. This previous dynamic also integrates elements such as strategy, management, and culture as central aspects of its implementation. Now, by adopting industrial symbiosis, it is possible to find that it allows firms to rethink their business models, focusing on their needs that allow the search for new sources of income and, thus, a greater need for new hires. The success of this type of model will allow improvements in regional capacities for sustainable strategies. This improvement in operating conditions brings with it the possibility of creating symbiotic relationships that allow firms to succeed in their business models simultaneously with the adequate flow of resources that gives them an advantage in the markets over their competitors (Miguel et al., 2023).

2.2. Industrial Symbiosis

The field of industrial symbiosis has had a development that can be established in three phases. The first is related to the fact that the field of study of industrial symbiosis has been characterized by having a very close relationship with the concepts of self-organization, planning, and even some elements related to the behavior of individuals (Ashton, 2008; Paquin & Howard-Grenville, 2012). Despite the studies carried out in the field, there is unanimity in the idea that it is necessary to continue carrying out empirical research to understand the evolution and dynamics of its application (Chen et al., 2022; Paquin & Howard-Grenville, 2012).

A second phase is directed towards an interest in theorizing its development. According to Baas and Boons (2004), it is possible to find three phases of its conceptualization: regional efficiency, regional learning, and the so-called sustainable industrial district. These three phases have been characterized by focusing on how firms can improve the commitment between them to achieve their objectives in the efficient use of resources (Oni et al., 2022). According to(Chertow & Ehrenfeld, 2012), the firms' resources and the exchanges that result from corporate strategy collaboration and organizational dynamics will determine the extent of their engagement. An important part of this phase is that organizational dynamics shift from focusing on making internal processes better to building networks with institutions that shape the dynamics in the areas where the companies operate (Gast et al., 2022; Uzzi, 1996).

The third phase refers to the relationship between the firm and the actors, establishing social interactions that impact economic and organizational dynamics. This phase focuses on dimensions concerning culture and politics (Dacin, Beal, & Ventresca, 1999; Yazıcı et al., 2022). The interaction between the different actors will be ensured if there is strength. The quality of the information flows between the actors that influence the firm's results. The norms that define actions and lower social transaction costs for both individual and organizational actions regulate these relationships (Boons & Howard-Grenville, 2009). According to the above, the cultural component is vital to the extent that it establishes the ideal scenario for the consideration of trust, the norm, and reciprocity in the authors' interactions that affect the firm's results (Colpo et al., 2022).

The fourth phase is based on the premise that culture is not the only factor that can regulate the dynamics of the different actors but also the networks and processes they carry out. This phase is based on organization theory, specifically on how, through the construction of networks, firms can coordinate resources and capabilities to create value (Kilduff & Tsai, 2003). Also called fortuitous network processes, organizations acquire a dynamic due to the possibility of benefiting from belonging to networks. These benefits may be more individual than collective, which tend to be slow-growing but highly attractive (Liu et al., 2022; Robert Baum & Wally, 2003). An essential aspect of this phase is that it requires the intentional coordination of an agent that allows efforts to be focused on achieving the objectives of a community. In this way, rules begin to be built, and roles are defined for each actor that is part of the network (Doz, Olk, & Ring, 2000; K. Liu et al., 2022).

In general terms, industrial symbiosis contains the individual associations of different actors who come together to achieve individual objectives, but where the benefits can be collected (Agudo et al., 2022; Schwarz & Steininger, 1997). For authors such as Albino, Fraccascia, and Giannoccaro (2016), this is a widely accepted definition of industrial ecology. In the same way, it has served the industrial symbiosis to be considered an opportunity to improve the report's performance by using ecological aspects and business innovation (Miyamoto et al., 2022). Despite the benefits of implementing industrial symbiosis, it is also essential to consider the different risks associated with its adoption (Escandon-Barbosa, Salas-Paramo, Meneses-Franco, & Giraldo-Gonzalez, 2021; Hoffmann, Kariuki, Pieters, & Treurniet, 2023). These risks are based on behavioral elements that companies consider before adopting. For the present study, the risks considered are those raised by Hirunyawipada and Paswan (2006), who state five risks associated with adopting a technology product (financial, time, network externality, performance, and social risk).

2.3. Financial Risk

According to Hirunyawipada and Paswan (2006), financial risk concerns negative financial results that precede product adoption. When the perception that the monetary cost is more significant than the benefits generate a loss of interest in seeking the more significant benefits of adopting it, if the cost associated with the adoption is very high, the client will want to look for more options to reduce this risk. According to scholars such as Wirdiyanti et al. (2022), there are variations in how financial risk is conceived, considering gender among those who invest in new technologies. In the case of SMEs (small and medium-sized enterprises), studies have shown that if the owner has a higher degree of education, his investments will be directed towards higher-risk technologies (Khalid, Urbański, Kowalska-Sudyka, Wysłocka, & Piontek, 2021). In this way, the high financial risk will be subject to the training levels of the owners of the company, which will make it possible to opt for new alternatives in adopting certain types of technologies (Leo, Sharma, & Maddulety, 2019; Li, Yigitcanlar, Erol, & Liu, 2021; Stjepić, Pejić Bach, & Bosilj Vukšić, 2021). According to Twumasi, Asante, Fosu, Essilfie, and Jiang (2022), financial risk is a limitation of adopting new technologies. Therefore, policies that improve market conditions will facilitate the adoption of new technology to the extent that they reduce this risk.

H_1 (Hypothesis 1): Low levels of financial risk make implementing an industrial symbiosis process more likely.

2.4. Time Risk

In the case of time, the main concern is that adopting new technology wastes time. Additionally, the learning process can take too long, which could be harmful. Notably, these new generations of technology have incorporated the characteristic of being friendly to those who consume them, improving this perception (Hirunyawipada & Paswan, 2006). For scholars such as Mao, Zhou, Ying, and Pan (2021), an essential aspect of time risk is that it determines the adoption of new technology and the sensitivity to future rates of adoption revenue. Time risk is also correlated with the level of adoption of a company when there is a lower rate. Ignorance of the processes will become a limitation for adopting the same, even more so in the case of processes such as industrial symbiosis, where it is still an incipient technology. This characteristic will generate a greater degree of uncertainty in its adoption. For scholars such as Sellars et al. (2022), two factors related to time determine the possibility of adopting new technology. One is the value for money, and the second is the uncertainty of the market in specific time ranges. Therefore, depending on the dynamics of these factors over time, they may make investments in new technologies less attractive.

H_2 (Hypothesis 2): Low levels of Time risk increase the likelihood of implementing an industrial symbiosis process.

2.5. Network Externality Risk

This risk is conceived as a consumer's perception of product development by seeking more information about a product and its introduction in each market. Similarly, those who have the possibility of adopting this type of technology tend to find themselves in situations in which they must reassure themselves of the purchase decision and make sure that if something goes wrong, they can quickly and easily obtain support (Hirunyawipada & Paswan, 2006). According to Tseng (2022), the technological spillover generated in the environment is crucial to adopting new technologies. These dynamics of the sector will allow them not only to take advantage of the platform on which the companies operate but will also help to manage the potential impact of the risks associated with adopting the new technology and the return on investment to the customer. It is possible to observe in the market that implications related to the intangible assets, that is, the increase in the value of the company's assets, will be associated with the adoption of a new technology that improves the firm's image in the market that operates due to the technological innovations (Pástor & Veronesi, 2009). Finally, to the extent that the environmental conditions are favorable for the implementation of new technologies and the risks of their implementation are reduced, there will be a stimulus for adopting industrial symbiosis (Ponis, 2020).

H_3 (Hypothesis 3): Low levels of Network Externality Risk increase the likelihood of implementing an industrial symbiosis process.

2.6. Performance Risk

Performance risk is a behavior associated with knowledge and ability about a particular product type (Mitchell & Harris, 2005). This perception is possible if individuals have a high level of knowledge about the operation of a type of technology. An essential element to establish is that in the field of new technologies, this type of risk is controlled due to the existing guarantees in current purchases (Hirunyawipada & Paswan, 2006). According to Stjepić et al. (2021), firms such as SMEs tend to consider technology adoption if it allows them to increase efficiency, maintain sustainability, and develop capabilities that allow them to improve their competitive position. This competitive advantage will also be related to improving the scope of the objectives as a business, especially in consolidating the markets it serves (Da Silva, da Silveira, Dornelas, & Ferreira, 2020). On the other hand, to the extent that users of a technology that has been adopted can see that its use contributes to performance, their perception of its use will be better. In this way, the perception of use is decisive in adopting a particular technology, such as industrial symbiosis (Khalid et al., 2021).

H_4 (Hypothesis 4): Low levels of performance risk increase the likelihood of implementing an industrial symbiosis process.

2.7. Social Risk

The desire to buy a type of technology can also be a social issue. This dynamic may be reflected in the image projected on others, be they competitors, friends, or colleagues, that has a component of recognition of an effort to achieve this type of technology (Hirunyawipada & Paswan, 2006). For scholars such as Guo, Zhu, Tan, and Gu (2021), the social risk is also linked to the firm's technological progress since it is associated with social learning processes and familiarity with innovation processes. Because there is a lot of uncertainty surrounding technology adoption, the previous situation exists. Its critical success factor is built on the company's social platform and permanent learning dynamics. Other studies in the field have identified the importance of social aspects in adopting technology (Bonan et al., 2021). In this way, social risk has a fundamental role in the adoption of new technologies because it is formed as a hardly observable variable where networks of social relations are built based on the preferences of individuals, and that affects the success of the implementation of technologies such as industrial symbiosis (Bonan et al., 2021).

H_5 (Hypothesis 5): Low levels of social risk increase the likelihood of implementing an industrial symbiosis process.

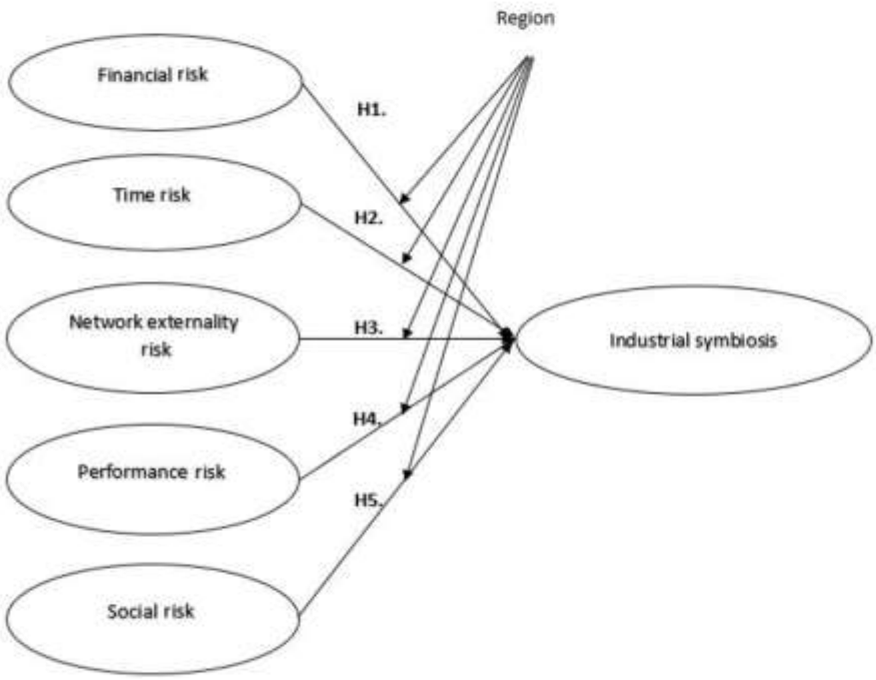

Figure 1. Conceptual model.

In Figure 1, the data collected and visually represented show how the different hypotheses are reflected in the relationships observed between the variables studied.

3. METHODOLOGY

3.1. Data

This study surveyed 400 businesses in six Colombian cities—Bogota, Medellin, Cali, Barranquilla, Cartagena, and Santander. The survey was conducted in businesses across all production sectors between August and September 2022. According to the National Statistical Office, the cities are chosen following Colombia's industrial distribution, where 67% of commercial activities are concentrated (Dane, 2022). A polling company is carrying out the survey, and it first gets in touch with the company to find out whether it plans to participate before conducting a personal interview to ensure the survey's thoroughness. The response rate is 87%, and the survey was completed with an average diligence of 24 minutes. 3% of the surveys were discarded due to incomplete responses or because the respondents decided not to move forward for lack of interest or time.

The businesses participating in the survey are Bogota, Cali, Medellin, Barranquilla, Cartagena, and Santander. The data show that 70% of the businesses surveyed intensively use energy, water, gas, coal, and other natural resources. 65% claim to use their waste products in new production processes within their businesses, while 25% claim that their waste products are used as raw materials in other industries. In 80% of cases, industrial symbiosis is achieved because the business owner believes there are benefits to implementing sustainable processes. Between 15% and 28% of the company's raw materials are products of previously implemented processes. Companies involved in agriculture devote the most attention to implementing symbiotic processes (63%), and then sugar companies (46%) and paper companies (36%).

3.2. Variables

The variables utilized in this study are provided in Table 1 with their definitions and measurements.

Table 1. Scale measurements and contextualization of variables.

Variable	Definition	Scale
Financial risk	The risk connected with a new technology's financial costs and economic gains influences the likelihood of an industrial symbiotic process's adoption.	Measured by three objects created by Stone and Grønhaug (1993). Alpha Cronbach. 0.87
Time risk	The risk is associated with the time spent learning how to use and successfully adopt a technology.	Measured using six items from the Stone and Grønhaug (1993). Alpha Cronbach. 0.89
Social risk	Risk of adopting technology and others' perceptions of its benefits and drawbacks.	Measured using four items from the Stone and Grønhaug (1993). Alpha Cronbach. 0.91
Networking externality risk	The risk relates to relationships with other actors or stakeholder groups and their influence on using new technology.	Measured using four items from the Stone and Grønhaug (1993).Alpha Cronbach. 0.90
Performance risk	The risk relating to the performance of a product or process that is used.	Measured using five items from the Stone and Grønhaug (1993). Alpha Cronbach. 0.86
Industrial symbiosis adoption	It is the option to carry out or implement processes for using waste again or reusing it in other parts of the organization or industry.	Value 1: If the business adopts industrial symbiosis Value 0: If Industrial Symbiosis is not adopted.

Additionally, a factorial exploratory analysis is performed as a data reduction method because risk-related variables were measured using a multi-item scale. However, for statistical analysis, one factor must represent each risk. As a result, all the medical data for each risk factor is included, and a rotational component analysis is developed. Five factors are created thanks to the commonalities and the size of the factorial loads. Additionally, related items succeed in fitting into the same factor, proving the existence of discriminatory validity.

3.3. Model

Two methods are used. The first one determines the significance of the variables, and the other one determines whether there are differences in the relevance and distinction of the variables by cities.

3.4. Geographic Differences Analysis

We employed a geographical Bayesian model and the Gray forecasting approach to analyze our data. The symbol Wi signifies a city-specific n x n weighted diagonal matrix containing the vector. A geospatial analysis is performed to assess if the industrial symbiosis behavior was grouped on purpose or was dispersed randomly among Colombian cities. The geographic autocorrelation in the frequency of industrial symbiosis behavior might be measured using Global Moran's n statistics. The Global Moran I tool was employed to determine the general pattern and trend of the data. Z-scores and p-values were used to analyze the spatial variance of clustered industrial symbiosis behavior occurrences.

Symbiosis industrial behavior prevalence clustering is significant when the Z score is positive and low when the Z score is negative. A high value for Moran's I index indicates a tendency towards clustering, whereas a low value demonstrates a tendency towards distribution for the indicator.

The Getis-Ord Gi* statistic was utilized to compute the Hot Spot Analysis in this article. Clusters of Industrial Symbiosis that are high or low are identified using hot spot analysis. The hot spot analysis image indicated that Colombia had more geographical grouping than would be anticipated by chance.

As Equation 1 shows, when the municipal total differs considerably from the predicted municipal amount and the difference is too significant to be due to random chance, a statistically significant z-score is created. As seen in Equation 2, the preceding occurs when the municipal total of a feature and its neighboring city are compared proportionately to the sum of all characteristics.

As the z-score grows in Equation 3, the clustering of high values gets more severe for statistically significant positive z-scores (hot spots). The clustering of low values becomes more evident for statistically significant negative z-scores as the z-score becomes lower (cold spot). Statistics Equations:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - \bar{X}\sum_{j=1}^{n} w_{ij}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{1,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (1)$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3)$$

3.5. Multivariant Analysis

A four-level hierarchical logistic regression model was fitted. Some important aspects of the organization remained significant in the final model. The final model was associated with a greater chance of industrial symbiosis. Consider the instance where there are two levels in the hierarchy (such as primary effects) to simplify the creation of the hierarchical logistic regression model. The second level is the group level, indicated by$i = 1,\ldots,J$. The indication for the subject (firm) level, or level one, is$i = 1,\ldots,nj$, allowing for a variable number of subjects in each group. The typical logistic technique predicts the chance that the binary response Y will have the value 1. In the most basic case, where there is only one predictor variable, the basic logistic regression model is created without considering data clustering.

$$logit(\pi_{ij}) = \beta_{ij} + \beta_1 x_{ij}, \quad (4)$$

Where:

$$logit(u) = \log\left(\frac{u}{(1-u)}\right) \quad (5)$$

In Equation 4, $x_{ij}$is is used to symbolize the predictor. The model presupposes that the result variable's distribution is Bernoulli:$Y_{ij} \sim B(\pi_{ij})$.

By including random effects in the model, the hierarchical logistic regression model considers the clustering structure in the data (See Equation 5). In this scenario, where there are only two levels, we may assume that either one or both coefficients (the intercept and slope of the linear logit expression) vary arbitrarily between level 2 groups. Additionally, Equation 6 shows the hierarchical logistic model:

$$logit(\pi_{ij}) = \beta_{0j} + \beta_{1j} x_{ij}, \quad (6)$$

$\beta_{0j} = \beta_0 + \mu_{0j}$ and $\beta_{1j} = \beta_1 + \mu_{1j}$ respectively. Typically, it is believed that the random effects follow a normal distribution, hence$\mu_{0j} \sim N(0; \sigma_0^2)$ and $\mu_{1j} \sim N(0; \sigma_1^2)$. Furthermore, the random effects do not always need to be uncorrelated, so it generally has Cov $\mu_{0j}, \mu_{1j} = \sigma_{01}$. Note that, at level 1, we have $Y_{ij} \sim B(\pi_{ij})$due to random effects. When the random effects are substituted in Equation 7, and the terms are rearranged, the modelshows in the hierarchical logistic regression matrix representation, where x equals firms, a response associated with each risk variable is assigned, and a response rate related to symbiosis is created.

$$logit(\pi_{ij}) = (\beta_{ij} + \beta_1 x_{ij}) + (\mu_{0j} + \mu_{1j} x_{ij}) \quad (7)$$

Additionally, it suggests a general matrix representationfor the hierarchical logistic regression model proposed by Equation 8.

$$y = \pi + \epsilon, \quad (8)$$

Where y is a $N \times 1$ vector of binary outcomes and a probability vector. The link function connects the response to the data:

$$logit(\pi) = X\beta + Z\mu \quad (9)$$

This is a$N \times 2$ matrix for the model given in Equation 9, with the first column holding ones and the second column carrying the vector of values for the predictor variablex_{ij}. The vector is the appropriate $p \times 1$vector of the model's fixed part parameters. This is the 2×1 vector$p \times 1$ in our example.

Equation6 represents the fixed effects of an $N \times 2$ matrix. Under the $\beta(\pi)$distributional assumption (conditioned on random effects), the vector of level-one errors has mean zero and variance:

$$Var(\epsilon) = W = diag[\pi_{ij}(1 - \pi_{ij})] \quad (10)$$

In Equation10, the term $Z\mu$ introduces random effects and denotes the difference between the hierarchical and standard logistic regression models. The matrix is blocked diagonal, with the blocks representing the hierarchy's groups. The vector μ is a $1 \times 2J$ random effect vector. The elements for each group in the hierarchy are the random intercept and random slope. The vector is assumed to have the distribution $\mu \sim N(0, \Omega)$ and a block diagonal covariance matrix.We are the dependent variable vector at each hierarchical level (our model has three levels: control, direct impact, and moderating effect) and variables for each city. There are data when there is more than one observation per place (with our data, each variable has a minimum of 280 observations, which is the number of observations on the πlocation).

4. RESULTS

The most common industrial symbiosis was the use of water and organic material (45%) for agribusiness and thermal power energy generation, followed by paper and cartons (33%), which are used in the paper industry, and carbon residues, which are used in the cement industry.

Other materials used in symbiotic processes include polyester, animal fats, polyurethane foams, plastics, rigid PVC (Polyvinyl chloride), sawdust, cloth, periodicals, leather, wood, and journals.

The general model summary is shown in Table 2, and the omnibus test determines that the logistic regression model produced statistically significant results (X2 = 48.456, p< 0.05). A significant value of -2LL (maximum verisimilitude log statistic) = 721 659 was used to time the model's adjustment to the data. The Pseudo R Cox and Snell (1989) is 44,675%, demonstrating the model's good capacity for an explanation. Additionally, the Hosmer and Lemesbow (1980) test did not yield a significant result (X2 = 8 345, p > 0.10), allowing for confirmation of the model's good adjustment.

Table 2. Tests and model summary.

Model	Omnibus tests of model coefficients			Model Summary			
	Chi-squared	Sig.	-2LL (Log likelihood)	R2 Cox y snell	R2 nagelkerke	Chi squared	Sig.
Partial model	48.456	0.00	432.1	25.42	34.971	6.891	0.18
Model complete	48.456	0.00	721.65	44.675	46.251	8.345	0.10

Table 3 identifies the overall correct classification percentage, showing that 86% of the 400 cases under study are correctly classified. Of them, 316 cases demonstrated the performance of Industrial Symbiosis processes, correctly classifying 287 as "really positive," representing 90.8% prevalence (sensitivity of the model). Of the 84 individuals who indicated they did not develop industrial symbiosis, 73 (really negative) individuals are correctly classified, accounting for 86.9% of the total (specificity of the model).

Table 3. Observations and forecast.

Observation	Forecast		
	Industrial symbiosis	Industrial symbiosis is not adopted	Percent correct
Industrial symbiosis	287	29	90.8
Industrial symbiosis is not adopted	11	73	86.9

Table 4 shows the B regression coefficients, standard errors of the coefficients, the Wald statistic, and the exponentials of coefficients Exp (B) (odds ratios) for each independent variable. It also shows the 95% confidence intervals for each of these numbers.

Table 4. Results.

Variables	B	S.D. (Standard deviation)	Wald	Sig.	Exp.	Lower	Higher
Constant	-	0.324	5.56	0.00	0.231	-	-
Financial	0.245	0.161	3.465	0.00	1.277	0.861	3.364
Time	0.345	0.31	3.677	0.05	1.411	1.234	4.5257
Social	0.501	0.521	3.147	0.00	1.651	0.678	2.982
Performance	0.5334	0.135	3.638	0.023	1.704	0.369	4.359
Networking	0.341	0.248	6.325	0.045	1.401	0.985	6.538
Model	48.456	0.00	721.65	44.675	46.251	8.345	0.10

The parameter Exp (B) confirms that financial risk affects how likely an industrial symbiosis process will be adopted (hypothesis 1). In statistical terms, the Exp(b) or odd value ratio of financial risk (e0.245) = 1.277 indicates evidence that companies reporting low levels of financial risk have 1.2 times more chances of adopting industrial symbiosis than companies reporting high levels of this risk. According to the findings of the geographic analysis, there are no significant differences between regions in how this variable affects them (see Figure 2). As a result, it is determined that financial risk is significant for all examined regions.

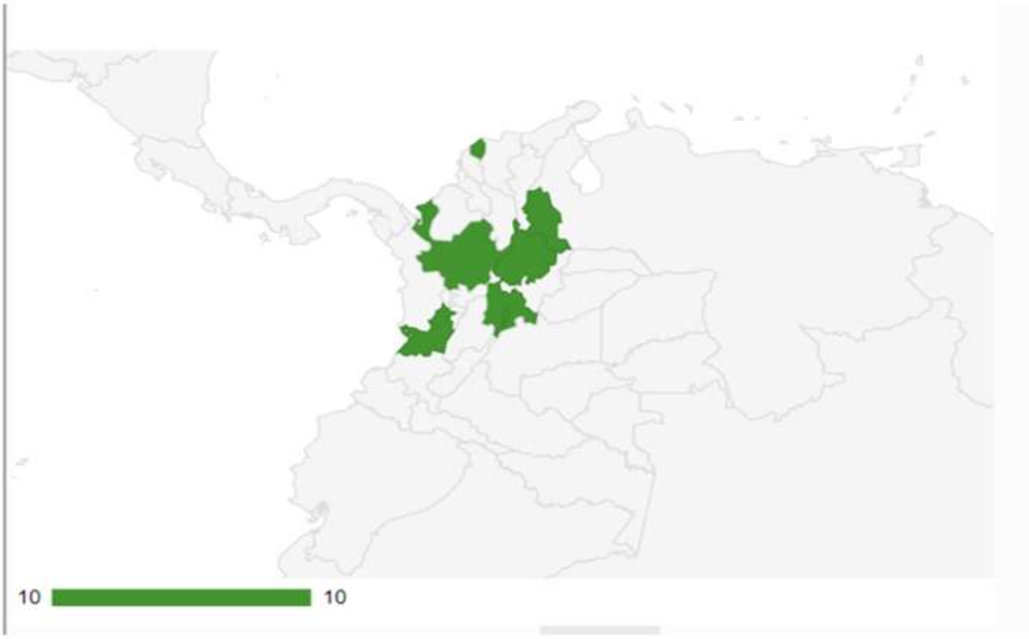

Figure 2. Financial risk differences Bogota (Center), Medellin, Cali (southwest), Santander, and Cartagena (North).

Hypothesis 2 is confirmed (e0.345 = 1.411), though with regional variations. It states that low levels of time risk increase the possibility of establishing an industrial symbiosis process. Bogota, Medellin, and Cali, which are large cities, are seen as having greater relevance, but this differs in smaller regions like Santander. These geographical differences result from the two factors—currency value and market uncertainty—that together constitute time risk, (see Figure 3). Due to the size of market, larger cities generally have better market access and investment recovery options. In small or medium-sized cities, uncertainty tends to be greater, which leads businesses to adopt technologies that have since been proven successful in other regions (large cities).

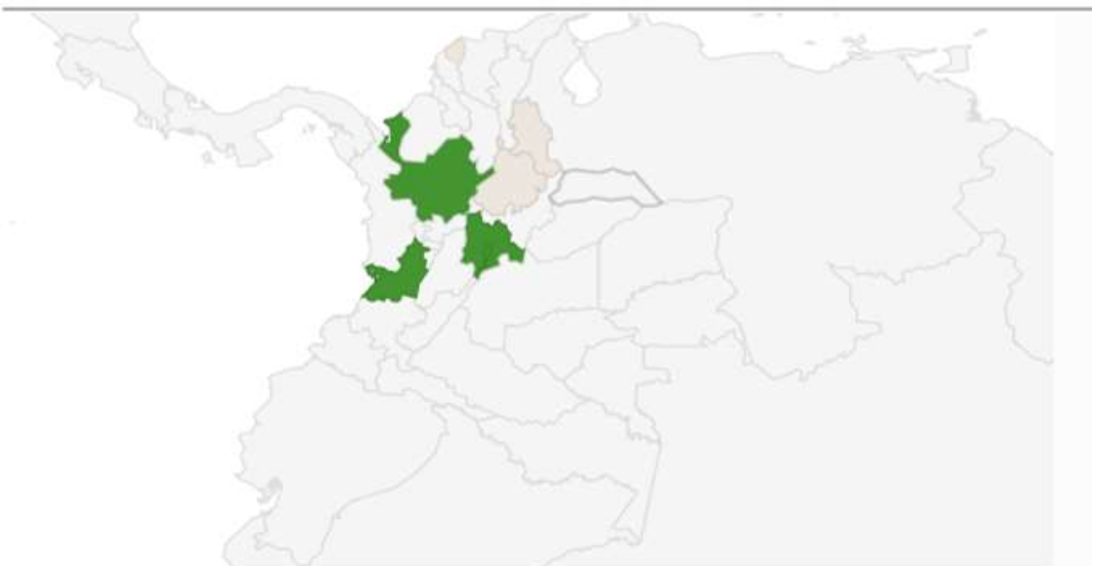

Figure 3. Time risk differences.

According to Hypothesis 3, it is confirmed that adopting an industrial symbiosis process is more likely when network externality risk is low (e0.341 =1.401), and it is established that stakeholders will succeed in spreading their perception and influencing the decision to adopt industrial symbiosis among more businesses (see Figure 4).

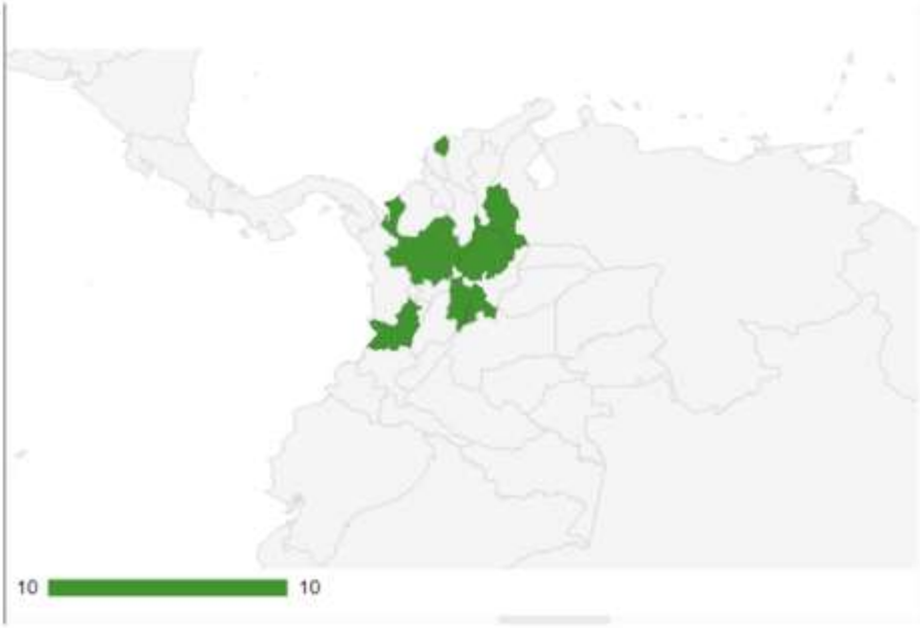

Figure 4. Network externality risk differences.

However, Hypothesis 4, which states that low levels of performance risk improve the likelihood of implementing an industrial symbiosis process, is confirmed (e0.5334 =1.704, as shown in Figure 5. In terms of regional relevance, changes that clearly distinguish between city differences have yet to be established. A standard normative context determines the interactions and performance of new technologies. In this condition, businesses tend to have investments that can guarantee results, which lessens the likelihood of high-risk situations.

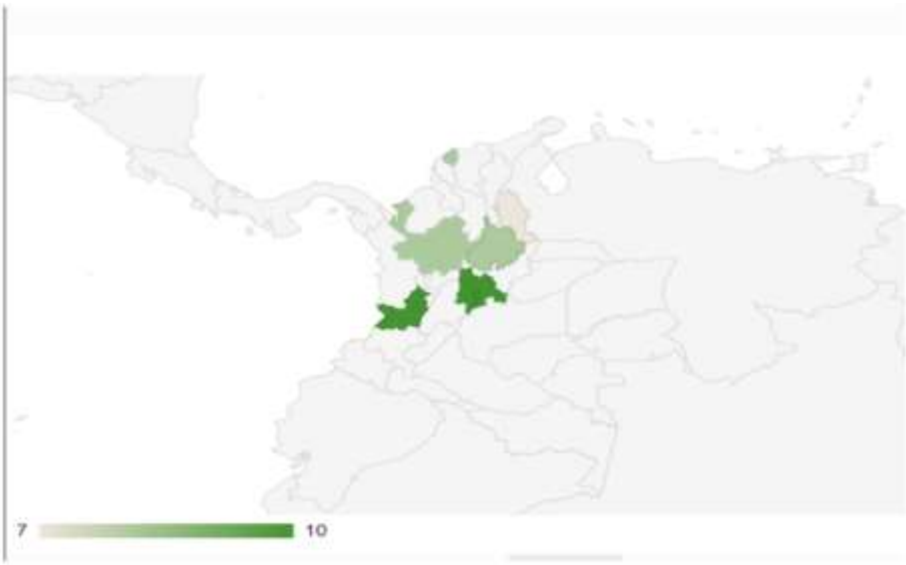

Figure 5. Performance risk differences.

Finally, this study enables confirmation of Hypothesis 5 (Low et al. Increases the Likelihood of Implementing an Industrial Symbiosis Process) (e0.501 =1.651) and establishes that it achieves high levels of relevance in all cities, as shown in Figure 6. As a result, the findings have no significant differences (t=1.021, p>0.10) because the social risk effect tends to be a risk that affects all regions related to norms, values, and cultural aspects.

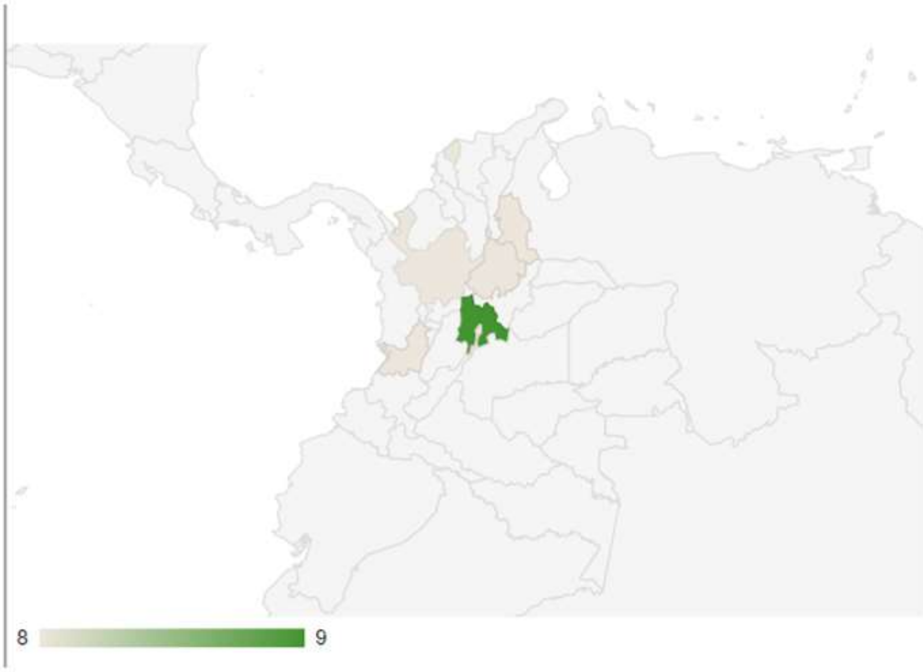

Figure 6. Social risk differences.

5. CONCLUSION

This study aimed to identify any geographical variation in industrial symbiosis in Colombia and investigate its risk factors. An analysis of the risks related to adopting industrial symbiosis in businesses in Colombia is conducted by determining which risks are crucial and how they are considered in each of the Colombian cities.

The findings show that the most significant and busiest cities (Bogota and Medellin) can engage more businesses in Industrial Symbiosis processes. Smaller cities (such as Cartagena and Santander) have slower technology-related processes.

Financial risk is the most prevalent in all participating cities since it relates to the costs and benefits of developing innovative processes like Industrial Symbiosis. These risks' existence is consistent with findings from Leo et al. (2019) and Mao et al. (2021), who proposed that businesses with highly knowledgeable executives tend to be less risk-averse. As a result, businesses embrace alternative technologies to improve processes more effectively since they can better assess costs and benefits with more data.

Regional differences are established by the fact that most industrial symbiosis cases involved companies operated by master's and doctoral-degree owners. Business owners have been trying to find ways to show higher levels of viability and make better use of their leftovers in these circumstances. Like other modern technologies, symbiotic processes are associated with high uncertainty, with small businesses experiencing the most significant risk associated with their adoption.

On the other hand, time risk is one of the most relevant research topics. However, it is more significant in cities like Bogota, Cali, and Barranquilla, with less significance in Santander. The implementation of industrial symbiosis in some areas is adaptive because, theoretically, regional variations in time risk or variations in the level of uncertainty in each market.

Our findings support Hirunyawipada and Paswan (2006) suggestion that businesses should take the implementation time and learning curve into account before making any changes to processes in accordance with industrial standards. In these situations, it is recognized that business owners in major cities like Bogota, Cali, Barranquilla, and Medellin tend to be more analytical in their evaluation of possible future levels of revenue and, as a result, are more critical of adopting modern technologies. Like other modern technologies, symbiotic processes are associated with high uncertainty, with small businesses experiencing the most significant risk associated with their adoption.

The risk of performance, which, according to Mitchell and Harris (2005), is related to the knowledge and capacity to produce results due to modifications to a process or product, is another risk. Our results validate that people's opinions differ based on their level of technological comprehension, and that the agriculture and sugar industries are the ones where this process has been implemented most extensively. These industries are well known for their environmental efforts and have more government policies supporting initiatives to improve waste use. Hirunyawipada and Paswan (2006) suggest that partnering with organizations that support their implementation and guarantee that the results are suitable for the company can be fulfilled in this regard.

Overall, among businesses with high network externality risk, there is a low incidence of reported industrial symbiosis adoption in Colombia. The previous results were in line with other research that claims that this risk increases when detailed information about the technology being adopted is not sought after. As a result, the advantages of creating circular economic processes should be appreciated. Therefore, this risk can be reduced if businesses in the same industry (competitors) adopt the Industrial Symbiosis and produce information about its advantages.

The social risk was finally connected to the desire to embrace technology through similar companies' projected images of benefits and information. According to the findings, this factor will successfully impact all the cities without any appreciable differences (Hirunyawipada & Paswan, 2006). As a result, it is concluded that social risk will allow industrial symbiosis to expand or contract as other businesses begin using it and developing market analyses of its advantages and disadvantages.

Generally, the factors associated with adopting Industrial Symbiosis relate to its implementation risks and vary by area. The findings also demonstrate the need for a multisectoral response as industrial symbiosis levels rise. This response includes education for capacity building, sharing its benefits, and government support for developing aid strategies based on the amount of waste used or reducing the environmental impact of symbiosis. Finally, develop environmental awareness among enterprises so that they recognize that investing in environmental technologies is an investment rather than a threat to return on investment. As a result, they are adopting these or other technologies that enable societal and economic benefits, such as protecting the environment while increasing profits.

6. MANAGERIAL CONTRIBUTION

Within managerial contributions, there is a need to identify the critical factors associated with implementing technology. In the case of this investigation, it was possible to identify the most critical risks associated with the implementation of industrial symbiosis. Additionally, the risks associated with adopting technology may vary depending on the factors associated with geographic location. The preceding allows organizational decision scammers to observe the need to consider the differential factors of the regions in which they operate, and even many of the company policies must adjust to the environments in which they operate.

7. LIMITATIONS AND FUTURE RESEARCH LINES

Considering that industrial symbiosis is recent, studies need to be conducted that allow further understanding of its dynamics at the company level. The present study is limited by the geographical space used, which serves as the environment in which the research is carried out. Given that, future comparative studies should be established that allow for a deeper understanding of the processes of technological adoption of this type of technology. An important aspect to consider in the future is knowing the role of other sustainability variables that allow evaluating industrial symbiosis's contribution to sustainable business growth and development with the environment.

Funding: This research is supported by Pontificia Universidad Javeriana (Grant number: 020100819).
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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