Drivers of Eco-innovation in Industrial Clusters - A Case Study in the Colombian Metalworking Sector

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Abstract. Eco-innovation is the development of products and processes that contribute to searching for solutions to differentiate and position companies or businesses in the market sustainably. The cluster is considered a cooperative strategy for businesses to achieve competitive efficiency. Nowadays, companies have the intrinsic responsibility of reducing their environmental impact significantly, creating novel, enhanced products and services.

This work aims to identify the drivers or determinant factors fostering the eco-innovation within industrial clusters for a Case Study in Colombia, South America. The study was applied to 40 companies in the Colombian metalworking sector. The Fuzzy-set Qualitative Comparative Analysis (fsQCA) methodology was implemented, allowing the identification of underlying causal relationships ruling the levels of eco-innovation in industrial clusters.

Results show that the capacity, the regulatory policies, and the competitive pressure are the main drivers for the clusters to reach high innovation levels, achieving the desired economic and environmental outcomes. Furthermore, even with low-demand conditions and unclear policies, companies in the cluster can successfully generate profits and stay competitive depending strongly on the three identified factors. Future research will focus on extrapolating the study to industrial clusters in different countries, regions, and business sectors.

Keywords: Sustainable innovation · Eco-innovation · Cluster · Competitivity · Metalworking sector

1 Introduction

According to Huppes (2009), eco-innovation or environmental innovation is the (positive) transformation of activities that have economic, environmental, and social impacts.

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That definition highlights the reduction of the environmental impact through the implementation of policies and organizational strategies aiming to enhance operational efficiency, which is necessary to gain access to new markets and improve the enterprise reputation with customers, suppliers, and employees [2].

René Kemp (2007) defines eco-innovation as "*the production, assimilation, or exploitation of a good, service, productive process, organizational structure, or business management method that is novel for the enterprise or the user, and that leads (throughout its lifecycle) to reducing environmental risk, pollution, and negative impacts arising from the use of resources.*"

Moreover, the Organization for Economic Development and Cooperation [4] asserts that eco-innovation not only renders environmental benefits, but it also adds value within the organizations as it contributes to increasing productivity and competitiveness, reducing costs, and granting access to new markets (Bessant et al., 2012; González-Benito et al., 2016; Löfsten, 2014; Segarra-Oña et al., 2011; Solleiro & Castañon, 2005; Wang et al., 2008). Nevertheless, companies going through big challenges must face a globalized world and be competitive via strategies that foster their growth, establishing core policies aligned with international markets' demands, such as environmental quality requirements, certifications, training, clean technologies implementation, and innovation processes that increase the companies' response capacity.

1.1 Study Conceptualization

The metalworking sector comprises the tasks of production, manufacturing, and assembling of goods used by other sectors in their activities and, to a lesser extent, by the final user. It could be stated that metalworking depends on third parties' activities. It is a derived-demand sector, which must have the technological capacity and infrastructure to respond to its customers' needs [11]. According to the Colombian metalworking and shipyard chamber (Fedemetal), which is attached with the Colombian association of entrepreneurs (ANDI), the metalworking sector is one of the most productive sectors, as it has strengthened its export chain, expanding to new countries while increasing sales in countries such as Ecuador and the US. As of 2018, more aggressive strategies, such as innovating within the value chain and implementing new demand models, were implemented, setting out the path to the aerospace industry and strengthening the automotive industry [12].

The Colombian metalworking cluster was conceived and is coordinated by the Colombian Association of Micro, Small, and Medium Enterprises (ACOPI). Among the Colombian metalworking cluster's goals are: "*to promote cooperation, innovation, and entrepreneurial capacity to strengthen the business, as well as generate strategies to foster the competitiveness of metalworking products and services in the local, national, and international market*."

These goals aim to stimulate the sector's competitiveness through cooperation, entrepreneurial capacity, visibility, and the generation of strategies to boost the cluster's supply chain via sustainability-enabling technologies that also improve the cluster's good image. This study is in line with the cluster's goals, making it relevant in the Colombian metalworking sector. Nevertheless, this sector still experiences considerable technological gaps that make it difficult to fully implement eco-innovation. Thus, it is essential to establish strategic alliances with other organisms, universities, regional R&D centers, and implement strategies to enhance innovation capabilities and infrastructure, and gain governmental entities' support to conduct R&D.

2 Methodology

Qualitative comparative analysis (QCA) is among the most used methodologies within social sciences, particularly in the administrative area [13]. QCA is based on analyzing the necessary and sufficient conditions to model causal complexity. QCA is a fuzzy sets-based comparative research method that has evolved to perform high-throughput quantitative analysis on datasets with dichotomic variables and different settings. Moreover, QCA uses equifinality principles, setting different configurations regarding causal interactions to achieve a goal. Using this technique renders the necessary and sufficient conditions to achieve an outcome, making the relationships between the conditions explicit.

Rihoux & Ragin (2008) introduced the QCA as an efficient way to carry out hypothesis testing based on set-theoretic relations. This study proposes a model to measure and analyze the factors involved in eco-innovation and their influence on the performance (eco-innovation-wise) of the companies belonging to the Colombian metalworking cluster. The model is validated with real data from the cluster. Figure 1 illustrates the conceptual model with all the factors ruling the eco-innovation levels in industrial clusters— in contrast, most studies on industrial eco-innovation feature linear analysis such as linear regression or structural equations [15–18].

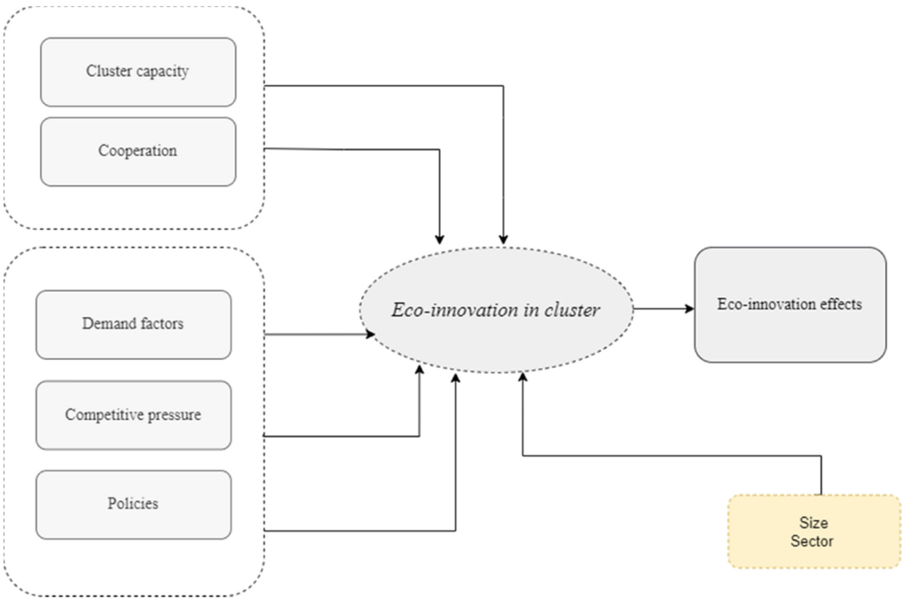

Fig. 1. Eco-innovation model for industrial clusters (Adapted from Mercado-Caruso et al., 2020)

The Fuzzy-set Qualitative Comparative Analysis (fsQCA) methodology tackles some limitations featured by regression-based methods, such as asymmetry and variables interdependence [19], being ideal to complement regression analysis, as variables exhibit interactions or "cooperation" to achieve an outcome. This model is based on five factors that boost eco-innovation-related activities: i) demand, ii) cluster capacity, iii) cooperation level, iv) competitive pressure, and v) environmental policies and regulations. In addition, the model includes three output factors: i) economic effects, ii) eco-innovative effects, and iii) access to new markets. The analysis is applied to 40 metalworking companies from Barranquilla, Colombia, belonging to the previously mentioned cluster. Data was gathered via in-person visits to the companies, all of which are classified as Small and medium-sized enterprises (SMEs). The software fs/QCA 3.0 was used to analyze the factors' contribution to the cluster's eco-innovation performance and their interactions.

The gathered data contains a rich set of measures on the demand, competitiveness, cooperation, policies, and cluster capacity, which allows studying these factors' influence on the cluster's sustainable innovation, economic benefits, and access to new markets. Data is constrained to metalworking companies from the Colombian Caribbean region, which guarantees comparability between operations. Furthermore, as data comes from companies offering services, this poses a natural variability and uncertainty in the competitive environment.

The instrument to assess the eco-innovation drivers is a structured survey based on the Likert scale with a 1–7 range, containing 29 questions appraising the input and output factors according to their importance (1 is for less important and 7 is for most important). Other authors have validated this measurement instrument [20–22]. A sensitivity test was conducted using Cronbach's alpha coefficient, obtaining values above 80%, as seen in Table 1, which validates the use of the instrument in this study.

Table 1. Results from survey to measure sensitivity

Variable	Mean	Items	Deviation	Cronbach's alpha coef.
Capacity	3,62778	1–9	1,362118	0,847
Demand	4,49000	10–14	1,762836	0,847
Cooperation	3,40000	15	2,296039	0,895
Competitive pressure	4,04375	16–18	1,926627	0,844
Policies	3,77500	19–26	1,923872	0,852
OUTEFFECTS	4,76563	27–29	1,521530	0,862

For the FsQCA analysis, inputs must be "calibrated" or re-scaled from 1–7 to 0–1. As suggested by [23], this study calibrates inputs with polytomous variables. The fuzzy membership scores range from 0–1. Three anchor points define a full membership set with a score, a full non-membership, and a crossover point [24].

The scores obtained from the 40 companies are averaged and used as a calibration baseline. This study defines the cutoff values shown in Table 2, which are based on percentiles, as suggested by [13, 25].

Table 2. Calibration of polytomous variables

Calibration variable	Full membership (percentile 90)	Crossover (percentile 50%)	Full non-membership (percentile 90)
Conditions and outcomes	0,95	0,5	0,05

The membership is computed using the following equation [26, 27]:

$$membership = \exp(\log(probability))/(1 + exp(log(probability))) \quad (1)$$

Results are fed to the software Fs/QCA 3.0, and it yields a truth table displaying all the evaluated conditions. Only those conditions complying with a consistency of at least 0.8 and a frequency of at least two (2) observations are considered. Hence, conditions with a consistency equal to or greater than 0.8 were coded as 1 and otherwise as 0. The software removes inconsistent configurations and cases that are not comparable with other case studies, as well as redundant conditions. Rows of the truth table are compared against those sufficient configurations.

The software renders three Boolean minimization results: i) the complex solution, ii) the parsimonious solution, and iii) the intermediate solution. The latter is considered the best solution to unravel the relationship between conditions and outcomes, according to [28]. For this solution, only some of the no-case configurations yield valuable results. Therefore, this study only considers intermediate solutions.

On the other hand, the model will have the following structure (Eq. (2)):

$$Y = f(Capacity, Demand, Competitiveness, Policies, Cooperation) \quad (2)$$

Using the QCA, it is possible to pinpoint those configurations that are (if any) necessary conditions to attain the desired eco-innovation levels within the cluster, as well as the combinations of causal antecedents that can explain the eco-innovation levels in the cluster.

3 Results and Discussion

As stated in the literature, a condition is necessary if it is present in all causal configurations that explain a given outcome [29]. A single condition might be necessary, but rarely will it be sufficient to explain a given outcome. Table 3 summarizes the analysis of necessary conditions. The tilde (~) represents the absence or negation of a condition, i.e., a variable preceded by ~ within a model indicates the effects of its absence on the modeled outcome.

From Table 3, we observe that all conditions exhibit a consistency smaller than 0.9. This implies that none of them is (strictly) necessary. However, some conditions exhibit a consistency close to (yet smaller than) 0.9, making them *quasi-necessary* conditions, such as *Policies* and *Capacity*. This reaffirms the importance of companies investing in eco-innovative technologies to reduce costs and comply with environmental regulations, thus rendering positive economic effects and granting the companies access to other markets.

As for the sufficient conditions, we analyze the combination of causal conditions relative to environmental effects (OUTEFFECTS) which can contribute to reaching the sufficient conditions for cluster eco-innovation.

Table 3. Analysis of necessary conditions

Outcome	OUTEFFECTS	
Analyzed conditions	Consistency	Coverage
Capacity	0.730224	0.831338
Demand	0.793324	0.823055
Competitive pressure	0.488797	0.564116
Policies	0.746228	0.793003
Cooperation	0.716964	0.766373
~Capacity	**0.821291**	0.716210
~Demand	0.794264	0.761099
~Competitive pressure	0.544402	0.468884
~Policies	0.765030	0.714212
~Cooperation	0.736349	0.683214

Along with sufficiency, equifinality is considered as several combinations of conditions may lead to a common outcome, and the causal configurations explain such outcome [30].

Table 4 presents the intermediate solution. The model shows the sufficient conditions to achieve eco-innovative effects in the cluster, as it exhibits a consistency of 0.86, indicating that the assessed configurations are highly consistent subsets for the outcome. The configuration-wise consistency values are also above 0.85, indicating that such configurations are essential for reaching the outcome. The Solution Coverage indicates the extent to which the configuration explains the eco-innovative effects on the cluster. In this case, roughly 70% of the conditions explain such effects. As for the Raw Coverage, the third configuration stands out with a greater value than that of the others. Sufficiency analysis reveals that there is not a single path to appraising eco-innovation, but there are rather four alternative paths leading to the desired outcome.

The first solution, CAPACITY*COOPERATION* ~ COMPETITIVE PRESSURE, highlights the importance of enterprises' cooperation and capacity to reach eco-innovation. Even with low competitive pressure, positive effects on eco-innovation are

Table 4. Sufficient conditions, OUTEFFECTS

MODEL: OUTEFFECTS = f(CAPACITY, DEMAND, COMPETITIVE PRESSURE, POLICIES, COOPERATION)			
Configurations	Raw coverage	Unique coverage	Consistency
CAPACITY*COOPERATION* ~ COMPETITIVE PRESSURE	0.232739	0.035665	0.902482
DEMAND*COOPERATION*COMPETITIVE PRESSURE	0.331962	0.031092	0.847141
DEMAND*COMPETITIVE PRESSURE*POLICIES	**0.576132**	**0.259259**	**0.903874**
CAPACITY* ~ DEMAND* ~ COOPERATION*POLICIES	0.189758	0.027434	0.810547
SOLUTION COVERAGE: 0.708733			
SOLUTION CONSISTENCY: 0.860156			

not penalized. It is worth pinpointing the major role of the companies' capacity, arising from personnel training, creation of R&I centers, and innovation experience and know-how. Acquiring such capacities and getting access to innovation-intended resources is essential for both SMES and large enterprises to thrive and evolve into a more sustainable production paradigm; the commitment and capacities of governments to promote technological innovation is crucial to create internal capacities in the companies of the cluster, and thus be able to stay competitive and access new markets.

The fourth solution, CAPACITY* ~ DEMAND* ~ COOPERATION*POLICIES, reveals a configuration that contains Capacity, Policies, and the absence of Demand and Cooperation; It is the result that exhibits the lowest coverage to achieve environmental effects with a consistency of 81%. The absence of cooperation and demand do not seem to penalize the path towards environmental innovation; although the literature highlights as barriers to innovation the absence of commercial partners, networks of collaborators, as well as little cooperation with research centers and universities and uncertain market demand, companies with high organizational capacity and with the development of policies that provide incentives and regulate activities are relevant to achieve environmental effects.

The third solution of the model (see Table 4), DEMAND*COMPETITIVE PRESSURE*POLICIES, is the best solution elucidated by the model. This solution exhibits the greatest Raw Coverage (0.58) and Consistency (0.9); combining demand, competitive pressure, and regulatory policies is key for achieving eco-innovation in clusters.

These results are aligned with some literature studies that pinpoint the advantages of alliances and cooperation between companies belonging to the same sector (or subsector), jointly creating projects that advance innovation and competitiveness [31]. According to [32] and Porter's hypothesis, the legal and political environment is fundamental for enterprises to advance their processes to eco-innovative activities, proving the need for demand and regulatory policies and actions.

In conclusion, as outlined by [33], environmental policies make enterprises “be the first to act” by offering eco-innovative products and services and creating new markets. Hence, the right environmental policies can promote eco-innovation and compensate for non-compliance costs. In addition, environmental regulations introduce cleaner technologies and processes, improving process efficiency and promoting growth and profitability.

Finally, we must highlight that, although the model was implemented for a particular economic sector in Colombia, its implementation can be easily extrapolated to other sectors and regions. The case study was for validation purposes, but the model’s input variables are common to any kind of clusters within a wide spectrum of economic sectors in different regions.

4 Conclusions

The FsQCA method provides an alternative approach to analyzing data compared to traditional methods such as the analysis of variance (ANOVA). The causal relationships among variables are analyzed using fuzzy sets theory instead of feeding on traditional correlational analysis. Thus, FsQCA can unravel underlying interactions even in situations where there is asymmetry and equifinality (Fiss, 2011; I. O. Pappas & Woodside, 2021; Rihoux & Ragin, 2008).

For a metalworking sector cluster located on the north coast of Colombia, the FsQCA method was implemented, giving special attention to the intermediate solution, as it best captures the relationship between conditions and outcomes. Such a solution retrieved the consistency values for the outcome variable OUTEFFECTS. The model found that the Capacity and (environmental) Policies are quasi-necessary conditions to promote eco-innovation within a cluster. The model found four alternative paths leading to the desired outcome regarding sufficient conditions. In addition, one particular solution found by the model (see Table 4), Demand*Competitive Pressure*Policies, exhibits the greatest Raw Coverage (0.58) and Consistency (0.9); this implies that combining demand, competitive pressure, and regulatory policies is key for achieving eco-innovation in clusters. Moreover, the conducted analysis demonstrates the importance of combining the presence or absence of relevant predictors. Therefore, this information helps discover asymmetric conditions that cannot manifest in multiple regression.

Results revealed different paths to achieving eco-innovation in the cluster’s enterprises and implementing a proactive (rather than reactive) strategy. The companies must not look at the compliance of environmental regulations as additional costs but as a need. Additionally, companies must realize the mid-term and long-term opportunities, benefits, and competitive advantages arising from advancing eco-innovation.

The metalworking sector stands out in the Colombian Caribbean region due to its high capacity to advance innovation. These results can help governmental entities, competitiveness centers, universities, and the cluster’s companies to strengthen their eco-innovation capacities, enhance productivity, and get important investment funding. Therefore, it is proposed that the cluster carry out open innovation practices to establish activities where different actors are involved, including society, to generate learning processes to transfer knowledge in the company.

This work contributes to the literature by proposing a model to measure eco-innovation in industrial clusters based on environmental results. Therefore, this study contributes to the field of innovation, strategy, and competitiveness in the companies of a cluster.

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