

Analysis of the Integration of Industry 4.0 in Industrial Clusters: The Case of Ecuador

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Abstract

The current research analyses the implementation of Industry 4.0 in industrial clusters, considering the case of Ecuador. A literature review of recent works was conducted to review potential advantages, disadvantages and determining factors for the implementation of these technologies in clusters. The research will reveal that, on the one hand, the implementation of Industry 4.0 has the advantage of increasing the competitiveness and economic productivity of companies through increased efficiency. However, significant obstacles exist, such as lack of technological infrastructure, cultural and organizational factors, and lack of a skilled workforce. In Ecuador, despite recent government efforts, the development of Industry 4.0 within the metal-mechanics and agro-industry clusters are on an initial stage.

Keywords: Industry 4.0, industrial clusters, digital transformation, competitiveness, Ecuador.

Códigos JEL: O14, O25, O33, L60, L66

1 Introduction

The impact of Industry 4.0 on traditional business models in today's digital era is significant. According to Brettel, Friederichsen, Keller and Rosenberg (2014), Industry 4.0 involves the integration of digital technologies in manufacturing and logistics, as well as the digitization of business models and services (p. 36). The industrial revolution has led to various technological advancements, including artificial intelligence, the internet of things, 3D printing, and cloud computing. These advancements are transforming production processes and value chains (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Schwab, 2016).

The adoption of Industry 4.0 is not limited to individual companies but also involves integrating these technologies into industrial clusters. Porter (1998) defines an industrial cluster as a geographically dense group of related firms and institutions in a particular field, united by common and complementary traits (p. 199). Industrial clusters are crucial for a country's competitiveness and economic development as they foster innovation, knowledge transfer, and supply chain efficiency (Delgado, Porter, & Stern, 2014; Ketels, 2013; Navarro, 2003).

In this context, integrating Industry 4.0 into industrial clusters represents a significant challenge, especially in developing countries like Ecuador. According to the World Bank (2020), 'Ecuador faces significant challenges to improve its competitiveness and productivity, which requires a structural transformation of its economy' (p. 1). The adoption of advanced technologies in industrial clusters could be crucial to drive this transformation and strengthen the country's competitive position in global markets (United Nations Industrial Development Organization [UNIDO], 2018; Schwab, 2019).

2 Methodology

This study is based on a systematic literature review, with the objective of analysing the current state of Industry 4.0 integration in industrial clusters, with a specific focus on the case of Ecuador. This methodology

allows synthesising and critically evaluating the findings and contributions of previous research on the topic of interest (Snyder, 2019).

To carry out the literature review, searches were conducted in recognised academic databases such as Scopus, Web of Science and Dimensions. The keywords used in the searches were: "Industry 4.0", "industrial clusters", "technological integration", "digital transformation", "Ecuador", and various combinations of these. In addition, filters were applied to select peer-reviewed articles published in indexed journals and in English and Spanish.

The selection process of relevant studies was carried out in several stages. Initially, the titles and abstracts of the retrieved articles were evaluated to determine their relevance to the research topic. Subsequently, a full-text review of potentially relevant articles was conducted, applying predefined inclusion and exclusion criteria (Moher et al., 2009).

The inclusion criteria were:

- Studies addressing the integration of Industry 4.0 technologies in industrial clusters.
- Research analysing the challenges, opportunities and key factors for the adoption of Industry 4.0 in clusters.
- Articles examining the impact of Industry 4.0 on the competitiveness and productivity of industrial clusters.
- Case studies or empirical analyses related to the integration of Industry 4.0 in clusters in developing countries, with special emphasis on Ecuador.

On the other hand, the exclusion criteria were:

- Articles not directly related to the research topic.
- Studies that do not meet the established academic quality standards.
- Publications that are not in English or Spanish.
- Duplicate articles in the different databases consulted.

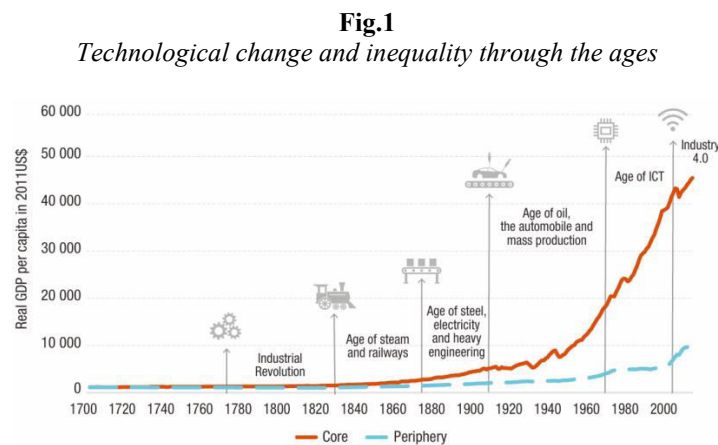
Once the relevant studies had been selected, the key findings were analysed and synthesised in order to generate a comprehensive vision of the integration of Industry 4.0 in industrial clusters, with a particular focus on the Ecuadorian case.

It is important to mention that the systematic literature review allows for the identification of research gaps and opportunities, which can serve as a basis for future empirical or theoretical studies around interest (Torraco, 2016).

3 Development

Surfing the Industry 4.0 Wave

We are at the crest of a technological revolution, led by developed nations, originating from the dawn of industrialisation. This evolution has widened the economic gap between countries. Industry 4.0, characterised by digitisation and interconnectedness, is highlighted in Fig. 1 as an exponential leap in prosperity for developed countries, marking a new phase of accelerated growth. This new technological paradigm offers a unique opportunity for developing nations, especially those in East Asia that are already making progress, to ride the wave of technological innovation and adaptation, potentially levelling the international playing field.



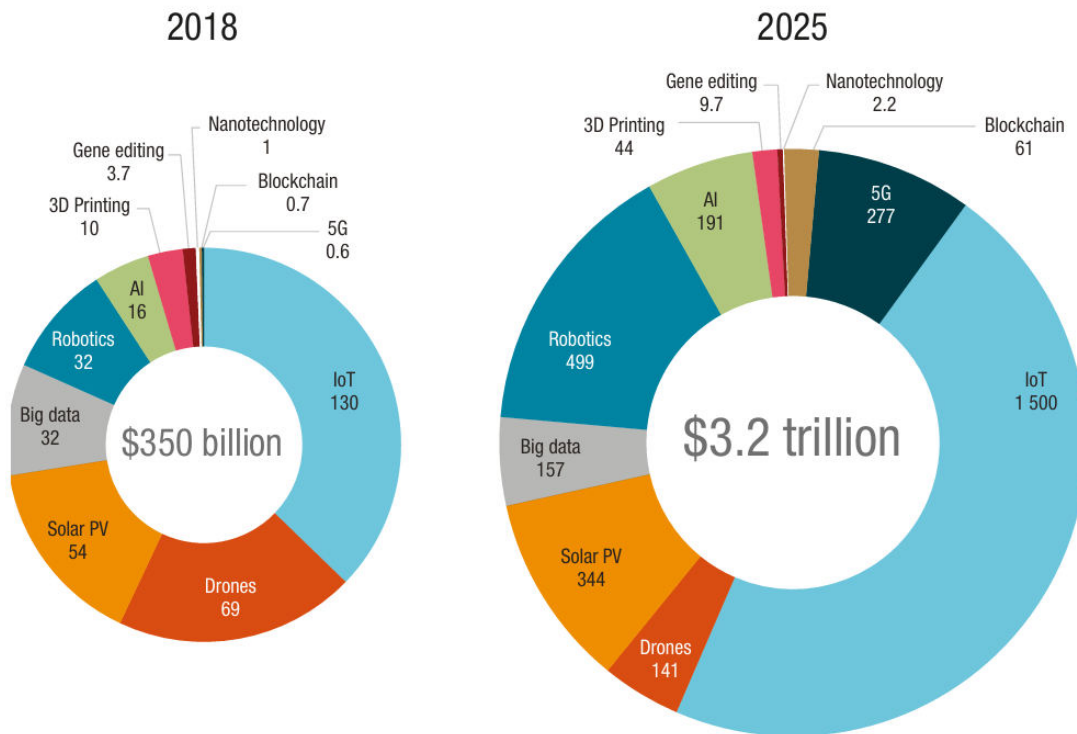
Source: UNCTAD, based on data from Maddison Project Database, version 2018, Bolt et al. (2018), Perez (2002), and Schwab (2013). Notes: "Core" corresponds to Western Europe and its offshoots (Australia, Canada, New Zealand and the United States) with Japan. "Periphery" corresponds to the world, excluding the "core" countries.

Impact of Advanced Technologies ('frontier technologies') on Productivity and Livelihoods

The term 'frontier technologies' refers to a group of emerging technologies that utilize digitalization and connectivity to increase their impact through cohesive integration. This group includes 11 key technologies: artificial intelligence (AI), the Internet of Things (IoT), big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology, and solar photovoltaic (Solar PV). These technologies have the potential to revolutionise productivity, enhance livelihoods, and shape the future of various industries and sectors.

Cutting-edge technologies are revolutionizing productivity and livelihoods. These innovations, valued at \$350 billion, are projected to reach \$3.2 trillion by 2025. In finance, they streamline credit decisions, risk management, fraud prevention, trading, personalized banking, and automation. In manufacturing, they enhance predictive maintenance, quality control, and human-robot collaboration. The US and China lead in technology development, with a significant share of patents and publications.

Figure 2
Market size estimates of frontier technologies, \$billions



Source: UNCTAD based on data estimates from Froese (2018), Sawant and Kakade (2018), Raza (2019), Tewari and Baul (2019).

Benefits and challenges of integrating Industry 4.0 in industrial clusters

Industry 4.0 represents a paradigm shift in the way production systems are organised and managed. According to Kagermann, Wahlster and Helbig (2013), "Industry 4.0 is characterised by the integration of cyber-physical systems in manufacturing and logistics, as well as the use of the Internet of Things and services in industrial processes" (p. 13). This digital transformation is driven by a number of disruptive technologies, such as artificial intelligence, advanced robotics, big data and cloud computing (Schwab, 2016; Strange & Zucchella, 2017).

In the context of industrial clusters, the adoption of Industry 4.0 can generate multiple benefits, such as optimising production processes, improving energy efficiency, reducing costs and creating new business models (Kagermann et al., 2013; Rübmann et al., 2015). In addition, the integration of digital technologies can facilitate collaboration and information sharing among cluster firms, thus fostering innovation and competitiveness (Zheng, Xu, Chen, Huang, & Zeng, 2020).

However, the adoption of Industry 4.0 in industrial clusters also faces significant challenges. According to Müller, Buliga and Voigt (2018), "the main obstacles to the implementation of Industry 4.0 in clusters include

the lack of adequate technological infrastructure, the shortage of digital skills and competences in the workforce, and cultural and organisational barriers" (p. 5). In addition, the small and medium-sized enterprises that make up much of the industrial clusters often have limited resources to invest in advanced technologies (Mittal, Khan, Romero, & Wuest, 2018).

In the case of Ecuador, the integration of Industry 4.0 in industrial clusters is at an early stage. According to a report by the United Nations Industrial Development Organization (UNIDO, 2019), "Ecuador faces significant challenges in improving its competitiveness and productivity, including the limited adoption of advanced technologies in industrial sectors" (p. 23). However, the Ecuadorian government has recognised the importance of digital transformation and has implemented policies and programmes to foster the adoption of Industry 4.0, such as the National Development Plan 2017-2021 and the National Strategy for Productive Transformation (Ministry of Production, Foreign Trade, Investment and Fisheries, 2020).

Situation in Ecuador and the case of the metal-mechanic cluster

One of the most relevant industrial clusters in Ecuador is the metal-mechanic sector, which includes companies dedicated to the manufacture of machinery, equipment and metal products. According to Carvajal, Carvajal and Samaniego (2020), "the integration of Industry 4.0 technologies in the Ecuadorian metal-mechanic cluster could improve efficiency and product quality, as well as facilitate access to new markets" (p. 12). However, the authors also identify barriers such as lack of technical training and limited investment in research and development.

The integration of Industry 4.0 in industrial clusters represents an opportunity to boost firms' competitiveness and productivity, but it also implies significant challenges that need to be addressed through appropriate policies and strategies. In the case of Ecuador, while efforts have been made to foster digital transformation, more support and resources are still required to facilitate the adoption of Industry 4.0 in the country's key industrial clusters.

Below is a table summarising the key aspects addressed in the development of Industry 4.0:

Table 1
Key aspects of Industry 4.0

Aspect	Description
Benefits of Industry 4.0 in Clusters	<ul style="list-style-type: none"> - Optimization of production processes - Improvement of energy efficiency - Cost reduction - Creation of new business models - Promotion of collaboration and innovation
Challenges for Integration	<ul style="list-style-type: none"> - Lack of appropriate technological infrastructure - Shortage of digital skills and competences - Cultural and organizational barriers - Limited resources of small and medium-sized enterprises
Situation in Ecuador	<ul style="list-style-type: none"> - Adoption of Industry 4.0 in an initial stage - Challenges to improve competitiveness and productivity - Government policies and programs to promote digital transformation - Metal-mechanic cluster as a key sector

Opportunities and Challenges	<ul style="list-style-type: none"> - Opportunity to boost competitiveness and productivity - Need to address challenges through appropriate policies and strategies - Greater support and resources to facilitate the adoption of Industry 4.0 in key industrial clusters
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Integration of Industry 4.0 in other industrial clusters in Ecuador.

In addition to the metal-mechanic cluster, another relevant industrial sector in Ecuador is the agro-industrial sector, which includes activities such as food processing, beverage production and the processing of products derived from agriculture and aquaculture.

According to Espinel, Rojas and Villavicencio (2021), "the application of Industry 4.0 technologies in the Ecuadorian agro-industrial cluster could improve traceability, resource efficiency and product quality, thus contributing to the sustainability and competitiveness of the sector" (p. 8). However, the authors point out that there are significant challenges, such as the lack of investment in research and development, limited staff training and resistance to change in some companies.

On the other hand, it is important to note that the integration of Industry 4.0 in industrial clusters depends not only on technological factors, but also on organisational and cultural aspects. According to Dalenogare, Benitez, Ayala and Frank (2018), "digital transformation in clusters requires a change in mindset and organisational culture, as well as increased collaboration and trust between companies and stakeholders" (p. 387).

It is worth mentioning that the integration of Industry 4.0 in industrial clusters may have significant social and employment implications. According to a report by the World Economic Forum (2018), "the adoption of advanced technologies in industry could lead to increased demand for digital and technical skills, which will require investment in human capital development and the implementation of training programmes" (p. 17).

In this regard, it is critical that governments, businesses and educational institutions work in a coordinated manner to prepare the workforce and mitigate potential negative impacts on employment.

Social and employment implications of the integration of Industry 4.0

It is important to mention that the integration of Industry 4.0 in industrial clusters may have significant social and employment implications. According to a report by the World Economic Forum (2018), "the adoption of advanced technologies in industry could generate increased demand for digital and technical skills, which will require investment in human capital development and the implementation of training programmes" (p. 17). In this regard, it is critical that governments, businesses and educational institutions work in a coordinated manner to prepare the workforce and mitigate potential negative impacts on employment.

One of the main challenges is the possible replacement of jobs by automated systems and intelligent robots. According to a study by the International Labour Organization (ILO, 2021), "it is estimated that about 14 per cent of current jobs in developing countries could be displaced by automation and artificial intelligence in the coming years" (p. 8). While this could lead to greater efficiency and productivity in industrial clusters, it also implies the need to implement labour protection policies and retraining programmes for affected workers.

Furthermore, the integration of Industry 4.0 into industrial clusters could exacerbate existing gaps in terms of access to education and training in digital skills. According to the Inter-American Development Bank (IDB, 2020), "in Latin America and the Caribbean, only 30% of workers have access to training and skills development programmes" (p. 19). This situation could deepen disparities and limit job opportunities for those who lack the skills required in the Industry 4.0 era.

It is therefore crucial that governments, in collaboration with businesses and educational institutions, implement comprehensive strategies to address these social and employment implications. This includes investing in training and retraining programmes, developing labour protection policies, promoting digital inclusion and equitable access to education and training in digital skills.

Role of governments and public policies

Governments play a key role in promoting and facilitating the integration of Industry 4.0 in industrial clusters. Through appropriate public policies, governments can create an enabling environment for the adoption of these technologies, while addressing the associated social and employment challenges and implications.

First, governments should invest in the development of technological and digital infrastructure, such as high-speed communication networks, data centres and information-sharing platforms.

According to the Economic Commission for Latin America and the Caribbean (ECLAC, 2022), "the availability of a robust digital infrastructure is a prerequisite for the effective adoption of Industry 4.0 in productive sectors" (p. 12). This will allow companies, especially small and medium-sized ones, to access the technologies needed for digital transformation.

In addition, governments should implement training and digital skills development programmes for the workforce. These initiatives should be aligned with the specific needs of industry clusters and can be carried out in collaboration with educational institutions and technical training centres.

According to the Organisation for Economic Co-operation and Development (OECD, 2021), "investment in human capital and training in digital skills are key to reaping the benefits of Industry 4.0 and mitigating negative impacts on employment" (p. 28).

Governments should foster collaboration and networking between the different actors involved in industrial clusters, such as companies, universities, research centres and civil society organisations. This can be achieved through the implementation of incentive programmes, the creation of knowledge-sharing platforms and the promotion of public-private partnerships.

The United Nations Industrial Development Organisation (UNIDO, 20/23) mentions that "multi-stakeholder cooperation is essential to foster innovation, share best practices and develop solutions tailored to local needs" (p. 6).

Training and Human Talent Development as Pillars for Innovation in Industrial Clusters

In the context of Industry 4.0, training and human talent development play a crucial role in Ecuador's industrial clusters. These clusters, which group related companies in a geographical area, face the challenge of adapting to new technologies and digital processes. In this section, we will explore how investment in worker training and the promotion of specific skills can drive innovation and competitiveness in this evolving industrial environment.

Training and Human Talent Development in the Digital Age: According to Smith (2019), continuous training is essential for workers to adapt to the new technologies of Industry 4.0. Acquiring digital skills, such as programming, data analytics and cybersecurity, enables employees to meet technological challenges and contribute to innovation in industrial clusters.

Collaborative Learning and Knowledge Transfer: Garcia et al. (2020) highlight the importance of collaboration between companies within a cluster. The exchange of knowledge and experiences between organisations facilitates the adoption of advanced Industry 4.0 practices. Joint training and the creation of learning communities are effective strategies to strengthen human talent.

Sustainability and Social Responsibility in the Era of Industry 4.0

The adoption of advanced technologies and automation in Industry 4.0 cannot be oblivious to ethical and environmental considerations. The conscious integration of Industry 4.0 can contribute to sustainable development and the creation of social value.

Industry 4.0 offers opportunities to optimize processes, reduce waste, and minimize the environmental footprint. However, it also poses challenges, such as energy consumption and the management of electronic waste. Investment in clean technologies and the implementation of eco-efficient practices are essential to achieve sustainable integration.

Social Responsibility and Ethics

Social responsibility must be an integral part of the digital transformation. Companies must consider the impact of their decisions on society as a whole. Transparency, equity, and respect for human rights are fundamental values. Industry 4.0 is not only about efficiency, but also about contributing to the well-being of communities.

Purpose-Driven Innovation

Innovation in Industry 4.0 must be aligned with social and environmental objectives. Companies can develop products and services that address global challenges, such as health, education, and equality. Conscious integration implies not only creating economic value, but also positively impacting society.

4. Discussion

Based on the literature review results, it can be concluded that the implementation of Industry 4.0 in industrial clusters is a great opportunity to improve companies' competitiveness and productivity. Nevertheless, there are various challenges and constraints that need to be considered. In Ecuador, some initiatives to boost digital transformation have been undertaken through government policies and programs; however, challenges are considerable. Villavicencio, A., & Romero, D. (2022). argued that "Ecuadorian industry faces situational

barriers such as the lack of adequate technological infrastructure, the scarcity of digital skills in workers and the financial boundaries of small- and medium-sized enterprises”.

Nevertheless, the integration of Industry 4.0 in key clusters such as metalworking and agro-industry could generate significant benefits, such as process optimization, improved efficiency and quality, and access to new markets (Carvajal et al., 2020; Espinel et al., 2021). These findings highlight the importance of implementing strategies and policies specific to each sector, considering their particular characteristics and needs.

Furthermore, it is essential to address the organizational and cultural aspects associated with digital transformation in clusters. Promoting a culture of innovation, collaboration between companies and stakeholders, and the establishment of strategic alliances are key elements to maximize the opportunities of Industry 4.0 (Dalenogare et al., 2018).

It is crucial to consider the social and labor implications of the integration of Industry 4.0 in industrial clusters. Preparing the workforce, providing training in digital skills, and mitigating the negative impacts on employment must be priorities for governments, companies, and educational institutions (World Economic Forum, 2018).

5. Results

Based on the literature review, the following key results can be identified:

Potential benefits of integrating Industry 4.0 in industrial clusters:

- Optimization of production processes
- Improvement of energy efficiency and resource use
- Cost reduction and creation of new business models
- Promotion of collaboration, innovation and competitiveness
- Challenges and obstacles to the adoption of Industry 4.0 in clusters:
- Lack of adequate technological infrastructure
- Shortage of digital skills and competencies in the workforce
- Cultural and organizational barriers
- Limited resources of small and medium-sized enterprises

Situation in Ecuador:

- Adoption of Industry 4.0 in the initial stage
- Government policies and programs to promote digital transformation
- Metalworking and agro-industrial clusters as key sectors
- Specific opportunities and challenges for each sector
- Key factors for successful implementation:
- Strategies and policies adapted to the needs of each cluster
- Promotion of an innovation and collaboration culture
- Establishment of strategic alliances between stakeholders
- Workforce preparation and training in digital skills

Social and labor implications:

- Increased demand for digital and technical skills
- Need for investment in human capital development
- Mitigation of negative impacts on employment

These results provide a comprehensive view of the challenges and opportunities associated with the integration of Industry 4.0 in industrial clusters, with a particular focus on the Ecuadorian context. They also highlight the importance of adopting a holistic approach that considers not only technological aspects, but also organizational, cultural, social and labor factors.

6. Conclusions

This literature review has allowed analyzing the integration of Industry 4.0 in industrial clusters, with a specific focus on the case of Ecuador. Based on the findings, the following main conclusions can be drawn:

The adoption of Industry 4.0 technologies in industrial clusters represents a significant opportunity to improve the competitiveness, productivity, and efficiency of the companies involved. However, there are various challenges and obstacles that must be addressed, such as the lack of technological infrastructure, the shortage of digital skills, and cultural and organizational barriers.

In the case of Ecuador, while government efforts have been made to promote digital transformation, the integration of Industry 4.0 in industrial clusters is in an initial stage. The metalworking and agro-industrial clusters have been identified as key sectors for the implementation of these technologies, but they face specific challenges such as the lack of investment in research and development, limited staff training, and resistance to change.

The successful implementation of Industry 4.0 in industrial clusters requires a holistic approach that considers not only technological aspects, but also organizational, cultural, social, and labor factors. It is essential to foster an innovation culture, collaboration between companies and stakeholders, and the establishment of strategic alliances.

The integration of Industry 4.0 in industrial clusters can have significant implications in the social and labor spheres, such as an increased demand for digital and technical skills. Therefore, it is crucial to prepare the workforce through training programs and mitigate the potential negative impacts on employment.

The integration of Industry 4.0 in industrial clusters represents both opportunities and challenges that must be addressed through a comprehensive and strategic approach. This will enable companies and clusters to harness the full potential of digital transformation and contribute to sustainable and socially responsible development.

7. Recommendations

Based on the conclusions obtained, the following recommendations are proposed:

Develop and implement specific policies and strategies to promote the adoption of Industry 4.0 in key industrial clusters in Ecuador, such as the metalworking and agro-industrial sectors. These policies must consider the particular needs and characteristics of each sector.

Invest in the development of adequate technological infrastructure and training programs for the personnel of the companies that make up the industrial clusters. This will help overcome barriers related to the shortage of digital skills and resistance to change.

Promote collaboration between companies, educational institutions, research centers, and government agencies to foster an innovation culture and the exchange of knowledge within the industrial clusters.

Establish strategic alliances and cooperation mechanisms between the companies that make up the clusters, with the aim of taking advantage of the opportunities of Industry 4.0 and strengthening the competitiveness of the sector.

Implement training and capacity-building programs to prepare the workforce for the changes and new demands of digital and technical skills associated with Industry 4.0. It is also essential to develop strategies to mitigate negative impacts on employment and facilitate the transition to new roles and professional profiles.

Encourage research and development of technological solutions adapted to the needs and characteristics of Ecuadorian industrial clusters, involving companies, universities, and research centers.

Promote the dissemination and exchange of good practices and success stories in the integration of Industry 4.0 in industrial clusters, both at the national and international levels, in order to take advantage of experiences and lessons learned.

These recommendations aim to contribute to the development and implementation of effective strategies to drive the adoption of Industry 4.0 in Ecuador's industrial clusters, taking advantage of its benefits and addressing the existing challenges in a comprehensive and collaborative manner.

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