Exploratory study on adoption of Industry 4.0 technologies by Small and Medium Enterprises (SMEs) in Ireland: A Comprehensive Review of Barriers and Opportunities

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***Abstract*— Industry 4.0 represents a comprehensive digital transformation in the way companies operate, incorporating advanced technologies. While Industry 4.0 and similar technologies have many conceivable benefits for manufacturing, most of these technologies are developed for or by large companies. This article proposes to investigate the adoption of Industry 4.0 technologies by Small and Medium Enterprises (SMEs) in Ireland, exploring the challenges faced by these companies and identifying the potential opportunities arising from this adoption. An exploratory systematic review of the literature was made. In total, 43 studies satisfied the screening and selection criteria. The consolidated factors were grouped into categories to help understand the challenges faced by small and medium-sized companies in the transition to Industry 4.0 in Ireland. This research observed several barriers for SMEs, but also identified numerous opportunities related to Industry 4.0. The main barriers analyzed in Ireland are organizational and technical barriers and the main opportunities are associated with horizontal and vertical integration opportunities.**

Keywords—SMEs, Industry 4.0, Ireland

I. INTRODUCTION AND CONCEPTAL BACKGROUND

The industry 4.0 is transforming the way companies produce and operate. Small and medium-sized enterprises (SMEs) are a major driver of the global economy, but they often face unique challenges in embracing Industry 4.0 [1], [2]. Thus, SMEs face several barriers in the adoption of Industry 4.0 [2]. In addition, SMEs can struggle to attract and retain technology-savvy talent, which can limit their innovation and implementation capabilities [3]–[5]. On the other hand, Industry 4.0 also offers many opportunities for SMEs [2], [5], [6]. Digital technologies enable SMEs to improve the efficiency and effectiveness of their operations, reduce costs, increase productivity and reach new markets [3], [7], [8]. The adoption of Industry 4.0 can also help SMEs to remain competitive in an increasingly globalized and dynamic market. To overcome the barriers and take advantage of the opportunities offered by Industry 4.0, SMEs need to develop a clear and comprehensive strategy for digital transformation[9], [10]. The adoption of Industry 4.0 brings new opportunities for SMEs, helping them to innovate and compete in global markets. Industry 4.0 represents an opportunity for SMEs to increase efficiency and competitiveness, but for it, it is necessary to invest in advanced technologies [11]–[13]. It is essential to have an understanding of the potential difficulties and advantages related to the adoption of Industry 4.0, in order to establish the profile of the project manager responsible for coordinating the implementation of I4.0, as well as to carry out the risk analysis of the referred project of Implementation. Thus, the integration of SMEs into the concept of Industry 4.0 has the potential to bring significant economic benefits but requires a supportive ecosystem to facilitate the process. SMEs need access to resources and support to overcome the challenges associated with the adoption of Industry 4.0 technologies, and to reap the benefits of this integration.

Ireland surges as a potential interesting case because it is carrying out a specific industry 4.0 strategy, recognizing manufacturing as a pillar of the country's economy, with the vision of maintaining a competitive manufacturing market and encouraging global economic growth [5]. The European Union, for its part, also encourages the digitalization of the industry with policies such as "The Digital Europe Programme", creating initiatives and focusing investments so that European countries can move to the digital world [14].

The benefits of digitalization can be difficult to achieve as they can be a challenge for companies. The need for investment, qualified workers, resistance to change, can prevent digitalization initiatives in a country like Ireland from being successful. Despite the government initiatives, other complicating factors deserve to be analysed, such as the perception and knowledge of companies in the country about

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these initiatives and the motivation for the implementation of these strategies [15].

Research published between 2019 and 2023 was reviewed to summarize the barriers and opportunities faced by SMEs in Ireland. So far, most studies have been a) focused on the particular barriers faced for the adoption of Industry 4.0 in multinationals and large companies e.g. [8], [16], [17] b) have focused on analyzing the digital transformation of some European countries, e.g. [13], [14], [18] d) have demonstrated the potential benefits of I4.0 for SMEs e.g. [6], [7], [19] e) focused on the particular barriers faced by SMEs in developing countries e.g. [7] f) classified the main barriers in dimensions (e.g. organizational, technical, technological, legal) e.g. [7]. The scope of the review was defined by the following research questions (RQ):

RQ1: What are the main barriers stopping the adoption of Industry 4.0 by SMEs in Ireland?
RQ2: What are the main opportunities for Industry 4.0 adoption for SMEs in Ireland?

II. Research Approach

The research approach, based on a systematic literature review, has followed the recommendations of [20] that is divided on three steps: 1) scope, 2) planning (through PRISMA following [21]), and 3) study quality (Fig.1), based on the approach\proposals from [7]. The research was based on a systematic search to find all relevant papers that could answer RQ1 and RQ2. The inclusion and exclusion criteria used in the research are described on Table 1, based on the approach\proposals from [7]. The selected research terms were taken from recent studies related to SMEs, Ireland, and Industry 4.0 (Fig.1) [Title/Abstract]: "SME" OR “Small and Medium Enterprises” AND "Industry 4.0" OR “I4.0” OR "Fourth industrial revolution" OR "Digitalization" OR "Smart Manufacturing " AND "Ireland" OR “Irish”. The main platform databases used during the research were B-ON from University of Minho, Science Direct and Emerald Insights. The research returned 794 documents and 45 articles were eligible for full reading and inclusion in the research review.

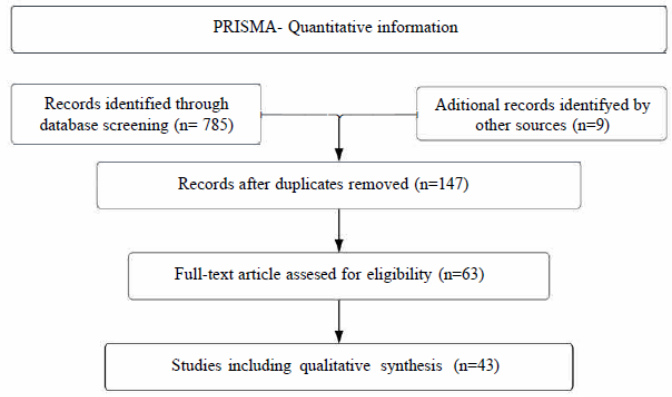


Fig. 1. PRISMA

TABLE I. Explanation of the Criteria Used

Exclusion/ Inclusion	Criteria	Explanation
Exclusion	**NR**- Not Related	**NR1**- Research result was not matching with this study
		NR2- Studies about I4.0 and SMEs not related to Ireland
		NR3- Not related to academic paper.
	LR- Loosely Related	**LR1**- I4.0 generally discussed
		LR2- I4.0 is only used as a reference
		LR3- I4.0 challenges not related to SMEs/Ireland
		LR4- SMEs challenges not related to Ireland/I4.0
		LR5- I4.0 opportunities not related to SMEs/Ireland
		LR6- SMEs opportunities not related to Ireland/I4.0
Inclusion	**CR**- Closely Related	**CR1**- Research paper is mainly dedicated to I4.0 adoption in SMEs in Ireland
	PR- Partially Related	**PR1**- Opportunities/Challenges related to I4.0/SMEs in Ireland
		PR2- Studies related to Opportunities/Challenges of adopting of I.4 technologies for SMEs e.g., IoT/AR/Cloud-computing in Ireland
		PR3- I4.0 adoption in Ireland is discussed or surveyed or reviewed

III. Discussion

The barriers of I4.0 adoption in SMEs in Ireland are classified in the four main dimensions proposed by [22] associated with a sustainability and supply chain (SC) perspective: 1) Technical, 2) Organizational, 3) Technological and 4) Legal barriers. Each dimension includes a set of possible barriers that can be identified as a subset of a dimension, as can be seen on Table II. Technical Barriers (TB) are defined as: a) information communication technology, cloud computing, IoT, etc.), b) lack of skilled employees and skilled managers, which is one of the most significant barriers to Irish manufacturing. Organizational Barriers (OB) include lack of financial resources, lack of management support, resistance to change, lack of R&D infrastructure, lower ability to react to demand changes, and fear of failure of I4.0 technologies. Technological Barriers (TECB) evolve from the fact that I4.0 is based on advanced technologies to support innovation, a) due to the lack of knowledge to use advanced services technologies like ERP or CAD, Artificial Intelligence or I4.0 applications, b) due to the complexity of maintenance or usage of the said applications. Legal Barriers (LB) were not described in the research analyzed as barriers to Industry 4.0 in Ireland. The barriers that are included in this category are related to the lack of collaboration and integration between managers and departments, and privacy concerns, or Cloud-computing limited in SMEs due to some privacy concerns. Table II shows the summary of the classifications for the barriers analyzed in this article.

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TABLE II. CLASSIFICATION OF THE BARRIERS

Barriers	
1	**Technical Barriers (TB)**
	Information communication technology (ICT) infrastructure
	Lack of skilled employees and skilled managers
2	**Organizational Barriers (OB)**
	Lack of financial resources
	Lack of management support
	Resistance to change
	Lack of R&D infrastructure
	Fear of becoming unemployed
	Lower ability to react to demand changes
	Fear of failure of I4.0 technologies
3	**Technological Barriers (TECB)**
	Lack of knowledge to use advanced services technologies
	Due to the complexity of maintenance or usage of the said applications
4	**Legal Barriers (LB)**
	Lack of collaboration and integration between managers and departments
	Privacy concerns
	Cloud-computing is limited in SMEs due to some privacy concerns

The opportunities of I4.0 adoption in SMEs in Ireland are classified into two main dimensions, vertical and horizontal integration. The competitive advantages created by integration and the potential of minimizing transaction costs are important opportunities associated with I4.0. Horizontal integration consists of strategies that allow companies to cut their costs and increase their production. Some of these strategies are based on sharing value that allows companies to cut down costs by sharing technologies and research and development (R&D). Horizontal (external or internal) integration (HI) strategies include adopting technologies that help companies reduce competition, increase revenue, improve efficiencies, access new markets, integrate across different customers, and gain market share, greater competitiveness in the market, and other benefits. The implementation of IT technology and digitization are keys to the adoption of Horizontal integration (HI), Internet of the tings, (IoT), Big Data Analytics. I4.0 technologies helps SMES to manage data, inventory, forecast demand and maximize sustainability at every stage along the supply chain. Vertical Integration (VI) aims to do better use of resources, reduce manufacturing costs, define economy scopes, improve control and planning, facilitate customized-products, and improve quality. It includes the integration between different departments inside enterprises. Table III shows the classifications of the opportunities and benefits of vertical and horizontal integration.

TABLE III. CLASSIFICATION OF THE OPPORTUNITIES

Opportunities	
1	**Horizontal (external or internal) IT Integration (HI)**
	Enable the integration and management between different customers, suppliers, and manufacturing plant
	Efficiently forecast demand
	Manage inventory
	Effectively perform logistics activities
	Increase competition in domestic and foreign markets
	Enabling better decision making
	Increasing operational performance,
	Improving business performance for SMEs competing with large enterprises
	Ability to enhance productivity
	Costs reduction
	Promising opportunity for SMEs to be more competitive in the market
2	**Vertical (internal) IT Integration (VI)**
	Integration between different departments inside enterprises to ensure better production
	Customized products to ensure better production
	Planning Customized products
	Quality Planning
	Reducing waste and costs

The barriers and difficulties analyzed in the studies can be summarized on Table IV.

TABLE IV. BARRIERS AND OPPORTUNITIES IN IRELAND

No.	Ref.	Dimension	Barriers	Opportunities
1	[23]	OB, TB	Financial constraints, Lack of skilled employees, lack of management support.	Sustainable Economy
2	[13]	TB, TECB	Lack of skilled employees, technical expertise, lack of knowledge.	Flexibility, cost reduction
3	[24]	VI	N/M	Sustainable Economy, VI
4	[25]	OB, TB	Lack of knowledge, ICT infrastructure	Smart manufacturing, HI
5	[26]	TB, TECB	Lack of knowledge, Reluctance in embracing new technologies	Flexibility, mass-customization, smart manufacturing, HI

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6	[27]	OB, TB	Lack of knowledge, ICT infrastructure	smart manufacturing, HI
7	[28]	OB	N/M	Sustainable Economy, Government support
8	[29]	OB, TB	Lack of knowledge, lack of management support.	HI, real-time information, digital collaboration,
9	[30]	HI	N/M	Smart manufacturing, HI
10	[31]	OB	Financial constrains	Sustainable Economy, Waste reduction
11	[10]	OB, TB	Financial constraints, Lack of skilled employees, lack of training	HI, global competition.
12	[32]	OB, TB, TECB	Lack of knowledge, ICT infrastructures, lack of data integration, lack of management support.	Flexibility, cost reduction, saving resources sustainability. HI
13	[33]	OB	Financial constraints, lack of management support. OB	Digital collaboration, saving sources
14	[14]	OB	Financial constrains	VI
15	[34]	OB, TB	Lack of knowledge, lack of management support.	Flexibility, smart manufacturing, HI
16	[19]	OB	N/M	Sustainable Economy, High mentoring expertise
17	[9]	OB	Financial constraints.	N/M
18	[35]	OB, TB	Financial constraints, lack of management support, Lack of technical expertise.	Flexibility, Sustainable Economy
19	[36]	OB, TECB	Reluctance to embrace new technologies Lack of knowledge, lack of technical expertise.	Flexibility, Sustainable Economy, VI
20	[15]	OB, TB, TECB	Financial constraints, lack of management support, Lack of technical expertise, lack of skilled employees, Reluctance to embrace new technologies.	Smart manufacturing, flexibility, saving sources, reduce costs, VI
21	[37]	HI, VI	N/M	HI, VI
22	[38]	OB, TB	Lack of knowledge, lack of management support.	N/M
23	[39]	OB	Financial constraints, lack of management support.	Digital capability, trained professionals
24	[40]	TB, TECB	Lack of knowledge, lack of technical expertise.	Digital capability, trained professionals
25	[41]	OB, TECB	Financial constraints, Reluctance in embracing new technologies.	N/M
26	[42]	OB	N/M	Sustainability, Infrastructure
27	[11]	OB, TB, TECB	Lack of training, financial constraints, lack of knowledge, lack of top management support. Reluctance to embrace new technologies.	HI, VI
28	[43]	HI	N/M	HI
29	[44]	OB, TB	Financial constraints, lack of knowledge, Lack of management.	Flexibility, Adaptability
30	[45]	OB, TB	Financial constraints, Lack of knowledge in support of SMES, lack of skilled employees, lack of knowledge.	Sustainable Economy
31	[46]	OB, TB, TECB	Reluctance to embrace new technologies, Lack of knowledge, Lack of governmental support	Sustainable Economy, productivity
32	[47]	HI	N/M	Security, privacy, HI

33	[12]	OB, TB, TECB	Financial constraints, Lack of technical expertise, lack of skilled employees, lack of knowledge.	Digital collaboration, Global competition
34	[18]	OB, TB, TECB	Financial constraints, Lack of knowledge, Reluctance to embrace new technologies, Lack of knowledge in support of SMES.	Government Support, Financial opportunities
35	[48]	OB, TB, TECB	Financial constraints, Lack of knowledge, Reluctance to embrace new technologies, Lack of technical expertise, lack of skilled employees.	HI, global competition
36	[49]	TB	Lack of skilled employees	N/M
37	[50]		N/M	Government Support
38	[51]	HI	N/M	HI
39	[52]	HI	N/M	Flexibility, smart factory, HI
40	[53]	OB, TB, TECB	lack of management support, ICT infrastructures, data integration.	Smart manufacturing, Digital collaboration, Flexibility
41	[54]	TECB	Data integration, lack of knowledge	Smart manufacturing, Digital collaboration, Flexibility
42	[55]	OB, TB	Financial constraints, Lack of knowledge, lack of skilled employees, Reluctance to embrace new technologies.	N/M
43	[56]	OB, TB, TECB	Lack of technical expertise, lack of skilled employees, Reluctance to embrace new technologies.	Time reduction, Digital collaboration, Smart manufacturing, real-time data, efficiency, cost-saving VI

The most mentioned barriers are related to financial resources, lack of knowledge, lack of skilled employees and technical expertise, management support and reluctance to embrace new technologies. 86% of the studies mentioned one or more of those barriers on the implementation of industry 4.0. According to the proposed classifications, Organizational Barriers represent 52% of the barriers studied, Technical Barriers represent 34%, and Technological barriers 14% of the difficulties faced by SMES in the implementation of Industry 4.0 in Ireland as shown on Fig. 2.

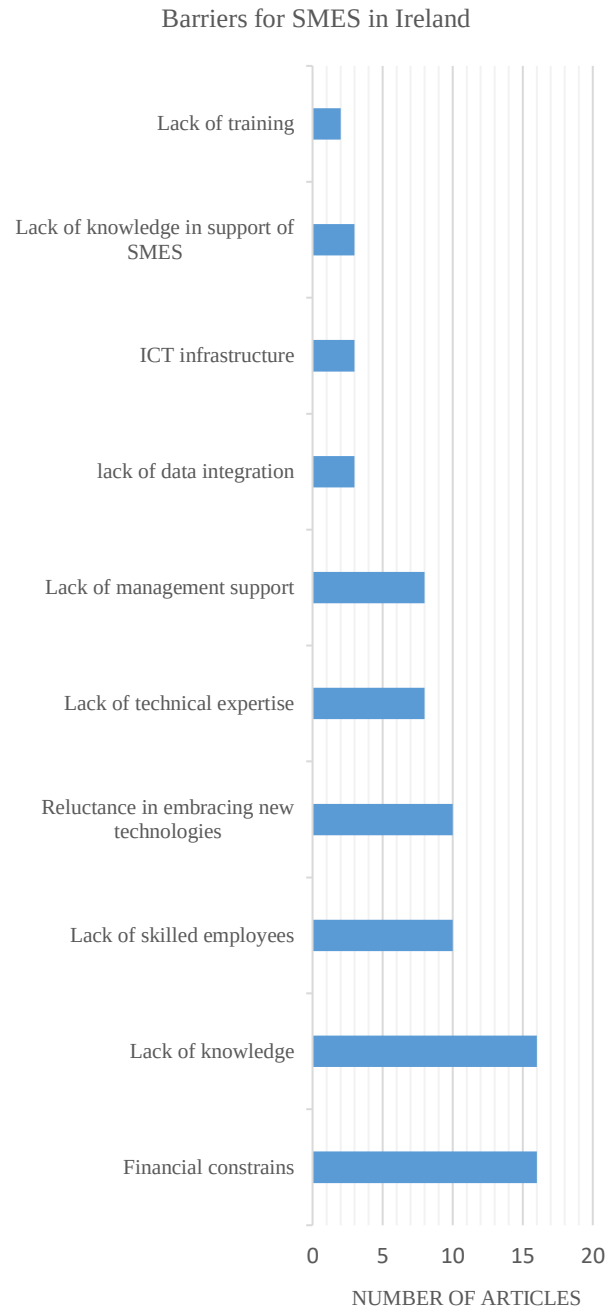


Fig. 2. Barriers for SMEs in Ireland

The opportunities mentioned in the studies were classified according to the vertical and horizontal integration criteria explained in the Table III, summarized as vertical and horizontal integration HI, VI. Other benefits mentioned in the

studies can be seen on Fig.3. The most mentioned benefits as an opportunity in the implementation of industry 4.0 were Horizontal integration, flexibility, Smart Manufacturing, Sustainable Economy, Digital Collaboration and Vertical integration, cost reduction and these represent 66% of the benefits expected by the SMES.

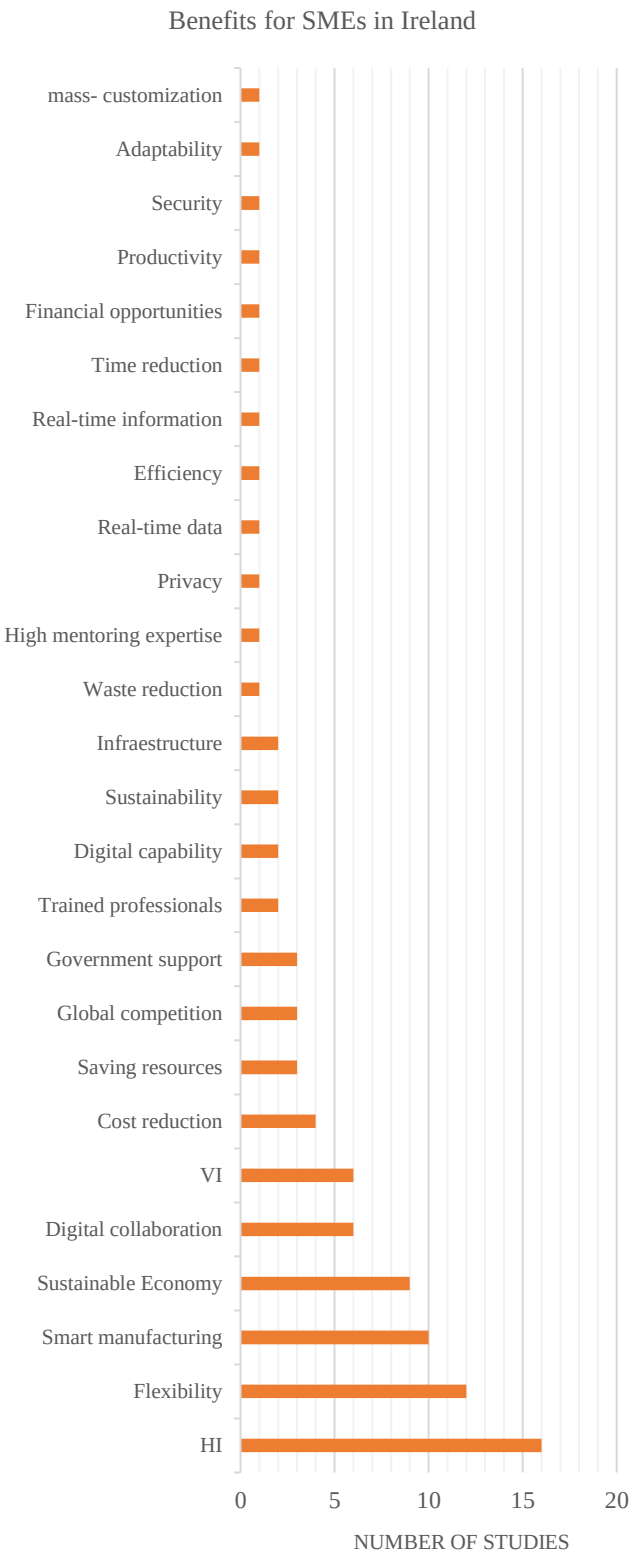


Fig. 3. Benefits for SMEs in Ireland

The main opportunities perceived in the implementation of industry 4.0 are related to the vertical and horizontal integration, efficiency y flexibility as shown on Fig.4.

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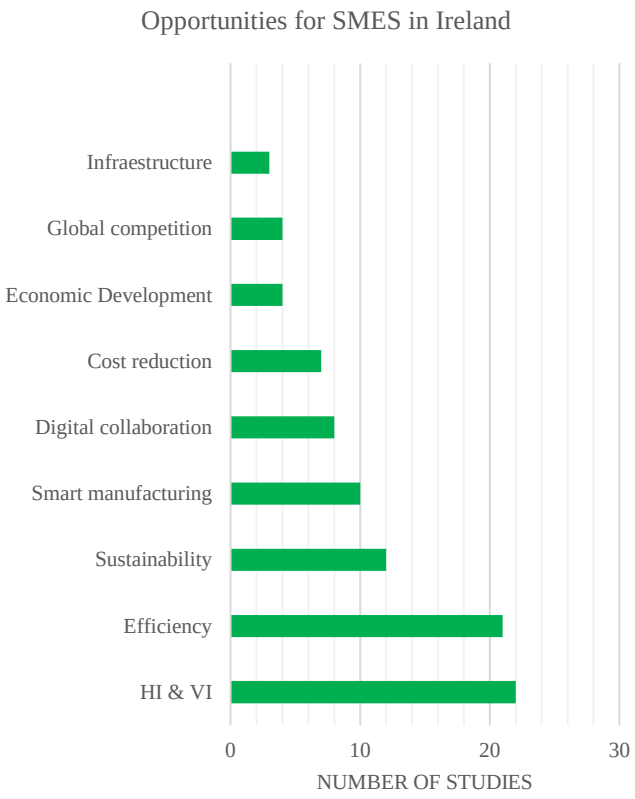


Fig. 4. Opportunities for SMEs in Ireland

IV. Conclusion

This work has thoroughly identified the main challenges and opportunities for the implementation of Industry 4.0 by small and medium sized companies in Ireland, through a systematic literature review. The study identified numerous barriers faced by firms, but also saw many opportunities related with the implementation of technologies of Industry 4.0. So, the successful integration of Industry 4.0 by SMEs in Ireland will be crucial for ensuring a competitive manufacturing foundation in the coming years. This integration will not only boost national productivity and enable SMEs to improve the efficiency and effectiveness of their operations, reduce costs, increase productivity, and reach new markets. Organizational and technical difficulties have been the main types of obstacles studied for SMEs in Ireland and the main opportunities are associated with horizontal and vertical integration opportunities.

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