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Research on Industry 4.0 and on key related technologies in Vietnam: A bibliometric analysis using Scopus

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Abstract

Bibliometric analysis was performed to study the development of publications related to Industry 4.0 and its key technologies in Vietnam. Comparisons with data from other ASEAN countries, and with global data have been done to identify distinctive characteristics of Industry 4.0 literature from Vietnam. The collection of 1,470 retrieved papers was analysed to answer seven research questions. Our results highlighted some valuable insights of Industry 4.0 literature in Vietnam. The number of papers in Industry 4.0 in Vietnam increased rapidly in recent years, mostly focused on Computer Science, Engineering, and Mathematics. Iran, China, and South Korea were the most productive partner countries with Vietnam in Industry 4.0. Machine learning, artificial intelligence, big data, deep learning, Internet of things, neural networks, and data mining were among the most popular research themes in Industry 4.0 in Vietnam. Vietnam ranked third among 10 Southeast Asian countries, based on the number of published papers in Industry 4.0, but the gap with the two top countries was large. Compared to the global data, the annual growth rate of Industry 4.0 papers in Vietnam, and other Southeast Asian countries was lower. Findings from this work can be helpful for other scholars in establishing potential future research lines related to Industry 4.0 in Vietnam.

Keywords: Industry 4.0, 4th Industry, Fourth Industrial Revolution, bibliometric, Scopus, Vietnam

INTRODUCTION

The world has experienced three industrial revolutions and now is in the era of Industry 4.0 (Lasi et al., 2014). The term Industry 4.0 was first introduced by the Germany government in April 2011 as part of its high-tech strategy to develop its manufacturing industry, while the first recommendations for the implementation of Industry 4.0 concept were published in April 2013 (Kagermann et al., 2013). Since then, several other definitions about Industry 4.0 have appeared in the literature (Hermann et al., 2016; Lu, 2017; Qin et al., 2016; Sanders et al., 2016; Santos et al., 2017; Wortmann et al., 2017; Zhong et al., 2017). Although there is no unique definition describing the term Industry 4.0, all of these definitions have agreed that the Industry 4.0 concept is based on increasing the level of digitalization of production system (Janik & Ryszko, 2018), and the nature of Industry

4.0 can be understood basically as a digital revolution in which digital technology and intelligent technologies are integrated to optimize production processes.

Nowadays, Industry 4.0 is a common trend that brings both opportunities and challenges for many countries, especially for developing countries like Vietnam. Industry 4.0 has been increasingly affecting strongly all fields of economic and social life. It is predicted that the participation in Industry 4.0 will bring many positive results to Vietnam's economic growth in the future. Understanding the importance of Industry 4.0, since 2017, the Vietnamese government has proactively enacted policies to encourage both private and public sectors to invest more in scientific and technological research related to Industry 4.0 (Vietnam-Government, 2017; Vietnam-Politburo, 2019, 2020). It is important to evaluate the impact of these recent policies on scientific output of the country because this evaluation could be useful for the Vietnamese government and other countries with similar economic development. However, in Vietnam, to the best of our knowledge, there has not been a comprehensive study describing the overall picture of published research in different fields, related to Industry 4.0.

Bibliometric analysis as introduced by Pritchard (1969) is a useful method for quantitative investigation of scientific activities based on the form and content of the scientific literature (Broadus, 1987). Bibliometric analysis can be used to identify the trend of a research field and its evolution in time. This method was then extended by Heck and Bremser (Heck & Bremser, 1986), by adding author and institute analyses. This type of bibliometric analysis has been widely used to analyse scientific evolution of various research fields at global and local scales such as, in medicine (Tran et al., 2018; Tran, Vu, et al., 2019), remote sensing (Pham-Duc, Nguyen, et al., 2020; Zhang et al., 2017), higher education (Hallinger & Chatpinyakoop, 2019), energy research (Chen et al., 2016), tsunami research (Chiu & Ho, 2007), sustainable tourism (Della Corte et al., 2019), management and organization (Zupic & Čater, 2015), terahertz research (Li et al., 2020), social sciences (Pham-Duc, Tran, et al., 2020) or event-based control (Aranda-Escolastico et al., 2020). Bibliometric analysis of Industry 4.0 has been studied in several papers, but mostly focused on evaluation the global research trend (Cobo et al., 2018; Janik & Ryszko, 2018; Kipper et al., 2020; Mariani & Borghi, 2019; Muhuri et al., 2019). Common findings from these papers were that the number of publications related to Industry 4.0 and its new emerging technologies has increased rapidly in recent years, and cyber-physical systems (CPS), internet of things (IoT), big data, and cloud computing were the most important research themes of Industry 4.0 with the largest number of papers and citations.

In this paper, our first objective is to draw the development and evolution of Industry 4.0 literature in Vietnam, especially after 2017, to evaluate the impact of government's recent policies on the scientific output of research related to Industry 4.0. The second objective is to compare scientific output in Industry 4.0 from Vietnam to that from other countries in Southeast Asia, and to the global output. This analysis will allow us to see whether Vietnamese research in this field is distinctive with regard to some characteristics, such as document type, growth rate, and disciplines. To obtain these objectives, we conducted a bibliometric analysis of all papers related to Industry 4.0 and its key technologies, published in the Scopus database by authors with Vietnamese affiliations. Results extracted from the bibliometric analysis in this study would indicate the following information: (i) annual publication growth rate in Industry 4.0 in Vietnam compared to other Southeast Asian countries and to the globe, (ii) most active disciplines in Industry 4.0 in Vietnam compared to the globe, (iii) most popular research topics in Industry 4.0 in Vietnam, (iv) scholars and institutes with the most published papers in Industry 4.0 in Vietnam, (v) most influential publications in different research areas of Industry 4.0 in Vietnam, (vi) most popular journals publishing papers in Industry 4.0 from Vietnam, and (vii) most important partner countries with Vietnam in Industry 4.0.

Key points

- The growth of Vietnamese article output on Industry 4.0 topics is in line with worldwide growth in terms of number of articles and topics.
- Over half of all articles on Industry 4.0 from Vietnamese authors had international co-authors.
- Iran, China, and South Korea are the main research partners for Vietnamese publications on Industry 4.0.
- Vietnamese articles on the subject of Industry 4.0 are mostly in Engineering and Computer Science with a notable absence of articles in medicine, biochemistry and Biology, and social science.

RESEARCH METHODOLOGY

Formulation of research questions

In this study, we intended to answer the following seven research questions:

RQ1. What was the growth rate of publications in Industry 4.0 published by Vietnamese affiliated authors, and how does this compare to other Southeast Asian countries and to the world?

Answering RQ1 would help us to determine the annual evolution of Industry 4.0 publications in Vietnam, which can be helpful to predict the pattern of Industry 4.0 research in Vietnam in the future, and to discover the ranking of Vietnam in publishing literature in Industry 4.0 compared to other countries.

RQ2. What were the most active disciplines in Industry 4.0 in Vietnam based on the number of publications, and comparison to the globe?

Answering RQ2 would help us to identify how much research effort has been put into each category of Industry 4.0 in Vietnam and in the world. This would help to establish future research directions.

RQ3. What were the most popular and important research topics in Industry 4.0 in Vietnam?

Answering RQ3 would help researchers to define directions of research in Vietnam.

RQ4. Which scholars and institutes published the most papers in Industry 4.0 in Vietnam?

Answering RQ4 would help researchers to identify potential collaborators from Vietnam for future studies in Industry 4.0.

RQ5. Which were the most influential publications in each key research area of Industry 4.0 from Vietnam, based on the number of citations?

Answering RQ5 would help researchers to identify the core papers in each key research area within Industry 4.0 from Vietnam.

RQ6. Which journals published the most papers in Industry 4.0 from Vietnamese affiliations?

Answering RQ6 would help researchers to choose relevant journals in Industry 4.0 for their future submissions.

RQ7. Which partner countries published the most with Vietnamese affiliations in Industry 4.0?

Answering RQ7 would help researchers to identify which partner countries are investing the most in Industry 4.0 in Vietnam. This also provides information on potential foreign partners for future research projects.

Data collection

This section describes three main steps that we applied throughout this research.

The first step when conducting a bibliometric analysis is to select an appropriate bibliographic database that best fits the objectives of the study. There are five main bibliographic databases and search engines, including Web of Science (WoS), Scopus, Google Scholar, Microsoft Academic, and Dimensions (Moral-Muñoz et al., 2020). Among them, WoS and Scopus have been used the most for bibliometric analyses, but we decided to choose Scopus database as the search engine for our study because it covers a wider range of documents than WoS (Hallinger & Chatpinyakoop, 2019; Mongeon & Paul-Hus, 2016). The Scopus database also provides different format options for data exporting (in BIB, RIS, or CSV formats) that can be used in various bibliometric science mapping analysis tools (Moral-Muñoz et al., 2020). After choosing Scopus (http://www.scopus.com) as the search engine, in the second step, all relevant synonyms of the keyword 'Industry 4.0', as well as keywords describing key technologies of Industry 4.0 were used as input for the search query string (Box 1) to start the process of extracting papers (Ahmi et al., 2019). As the term Industry 4.0 was first introduced publicly in 2011 (Gilchrist, 2016), we limited our search for the 2012–2020 period. The affiliation country was set as 'Viet Nam' or 'Vietnam' to limit only publications having Vietnamese affiliations. Note that any publication with one or more authors having a Vietnamese affiliation (regardless of their nationality) is included in the publication collection. Then, we excluded all publications having document types other than 'Article' and 'Review', as well as publications written in any languages other than English. In the last step, the collection of the remaining publications was exported to BIB and CSV format files for data cleaning, and post-processing and analysing by the two most popular and effective tools for bibliometric analysis: Biblioshiny (Aria & Cuccurullo, 2017), and VOSviewer (van Eck & Waltman, 2010). Note that this search was conducted on 20th December 2020. Output of the search query string includes industrial publications, as well as other related publications describing the use of Industry 4.0 key technologies in other research fields beyond industry. As a consequence, this article studies the whole picture of Industry 4.0 in Vietnam, including articles about the use of new digital technologies in industry or in other areas.

BOX 1. SEARCH QUERY STRING USED IN THIS STUDY

(TITLE-ABS-KEY ('industry 4.0' OR '4th industry' OR 'fourth industrial revolution') OR TITLE-ABS-KEY ('computer-integrated manufacturing' OR 'digital manufacturing' OR 'digital factory' OR 'predictive manufacturing' OR 'smart factory' OR 'smart manufacturing') OR TITLE-ABS-KEY ('artificial intelligence' OR 'augmented reality' OR 'automation' OR 'advanced robotics' OR 'big data' OR 'cyber security' OR 'block chain' OR 'cloud computing' OR 'data mining' OR 'fog computing' OR 'intelligent systems' OR 'internet of things' OR 'IoT*' OR 'supply chain 4.0' OR '3D printing') AND AFFILCOUNTRY ('Viet Nam' OR Vietnam)) AND DOCTYPE (ar OR re) AND PUBYEAR > 2011 AND PUBYEAR < 2021 AND (LIMIT-TO (LANGUAGE, 'English'))

RESULTS

RQ1: What was the growth rate of publications in Industry 4.0 published by Vietnamese affiliated authors, and how does this compare to other Southeast Asian countries and to the world?

Our retrieval results found that there were a total of 1,470 publications related to Industry 4.0 and its key technologies, published in 401 sources by scholars with Vietnamese affiliations during the

2012–2020 period. Articles accounted for 97.35% of the collection (n = 1,431), while there were only 39 review papers. The percentage of articles was slightly higher for Vietnamese affiliated articles than for the worldwide publications as included within the Scopus database during the same period (n = 271,912 or 93.84% share). The global numbers were extracted by applying the search query in Box 1 without country limitation. We identified 4,378 affiliated authors, with 7,516 author appearances in 1,470 papers. There were only 57 single-authored documents (3.85%) published by 45 single-authors (1%). In average, each author had 0.34 documents, and each document had five co-authors. The total number of citations from 1,470 papers in the collection was 15,299 at the time of this study, making the average citations per document 10.45.

The annual growth of publications related to Industry 4.0 and its key technologies in Vietnam is shown in Fig. 1. It is clear that the number of publications increased rapidly in the later years. Starting with only 19 papers in 2012, it rose gradually to 82 papers in 2016, and 102 papers in 2017 before increasing sharply to 198 papers in 2018, 361 papers in 2019 and 565 papers in 2020. The last 4 years (2017–2020) contributed 83.40% of the collection (n = 1,226). A comparison against publication growth in Industry 4.0 of other Southeast Asian countries and of the world is shown in Fig. 2. In Southeast Asia, Vietnam ranked third based on the number of papers, after Malaysia (n = 5,074) and Singapore (n = 3,948). However, the gap between Vietnam (n = 1,470) and Indonesia (n = 1,427), in the fourth position, was very close. Thailand and Philippines were in the fifth and sixth positions, with 1,168 and 374 publications, respectively. Data from other ASEAN countries are not shown in Fig. 2 because their scientific output related to Industry 4.0 was very limited. Compared to global rates, annual growth rates of publications related to Industry 4.0 and its key technologies from all ASEAN countries were lower. Except for Malaysia which decreased output of scientific articles in 2020, all other five countries showed continuous growth of scientific production related to Industry 4.0 over the years, at different levels. Note that data from other countries were extracted by changing affiliation country in the search query in Box 1.

RQ2: What were the most active disciplines in Industry 4.0 in Vietnam based on the number of publications, and comparison to the globe?

When taking into account the Scopus Category of research, we found that Computer Science and Engineering were two categories with the most published papers in Industry 4.0 in Vietnam, with a 53.40% and 45.65% share, respectively. This is similar to the worldwide statistics where these two categories accounted for the largest percentages with 43.70% and 38.59% of publications related to Industry 4.0 and its key technologies. Notably, Industry 4.0 research in Medicine, Biochemistry and Biology, and Social Sciences received more attention in the world than in Vietnam as they accounted for 11.71%, 10.55%, and 8.42% of the global collection, compared to only 3.20%, 5.44%, and 5.51% of the collection in Vietnam, respectively. Classification of publications in Industry 4.0 in Vietnam and in the world, according to the Scopus 20 categories of research is shown in Fig. 3. Note that the sum of percentages of particular categories exceeds 100% because a given paper can be classified into different Scopus research categories.

RQ3: What were the most popular and important research topics in Industry 4.0 in Vietnam?

A co-occurrence network of 127 most popular keywords which appeared at least five times in the collection is shown in Fig. 4. Each node represents a keyword, and the thickness of lines between nodes represents the strength of co-occurrence which was determined by the frequency that appeared together in other papers. The most important keywords (or research topics) related to Industry 4.0 can be identified clearly such as artificial intelligence, machine learning, big data, deep learning, data mining, IoT, security, block chain, energy efficiency, and energy harvesting. All other common keywords were connected to these topics. A deeper analysis using a thematic map of the most common keywords was conducted to classify keywords into four different themes based on the levels of centrality and density (Fig. 5). Centrality measures the strength of external ties to other themes. This value can be understood as a measure of the importance of the theme in the development of the entire research field. On the other hand, density measures the strength of internal ties among all keywords describing the research theme. This value can be understood as a measure of the theme's development (Callon et al., 1991). The upper-right quadrant shows the motor themes which are important topics because they are characterized by high centrality and high density. Most important keywords classified into this quadrant were artificial intelligence, machine learning, big data, deep learning, and artificial neural networks. The upper-left quadrant contains highly developed and isolated topics as the quadrant is characterized by high density but low centrality. Data mining was classified in this quadrant. The emerging or declining themes are put into the lower-left quadrant as it is characterized by low density and low centrality. Energy harvesting was classified into this quadrant. Finally, basic and transversal topics are classified into the lower-right quadrant which contains IoT, cloud computing, block chain, security, and energy efficiency. Note that a cut-off of 15 appearances was applied for each keyword, and each node contains maximum 5 keywords.

RQ4: Which scholars and institutes published the most papers in Industry 4.0 in Vietnam?

The top 10 scholars based on the total numbers of papers (TP) and citations (TC), along with their institutes and their h-indexes, are shown in Table 1. Vo B, Bui DT, and Pham BT were in the top three positions with outstanding numbers of

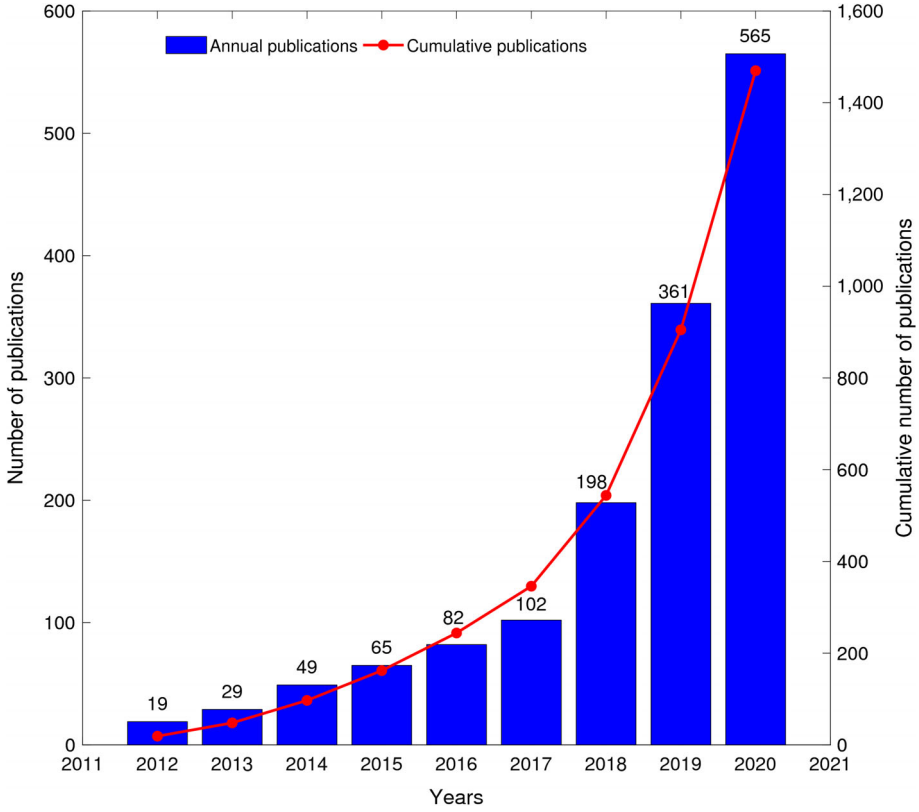

FIGURE 1 Annual number of publications and its cumulative number in Industry 4.0 from Vietnam-affiliated authors between 2012 and 2020.

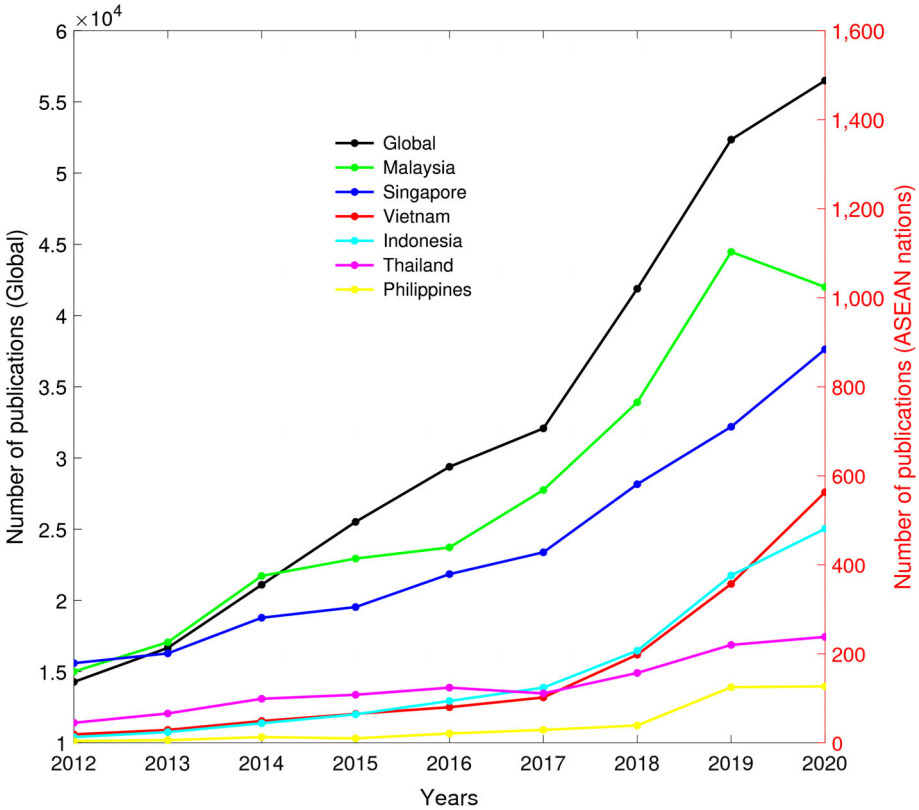

FIGURE 2 Annual publications in Industry 4.0 from six Southeast Asian countries and the world.

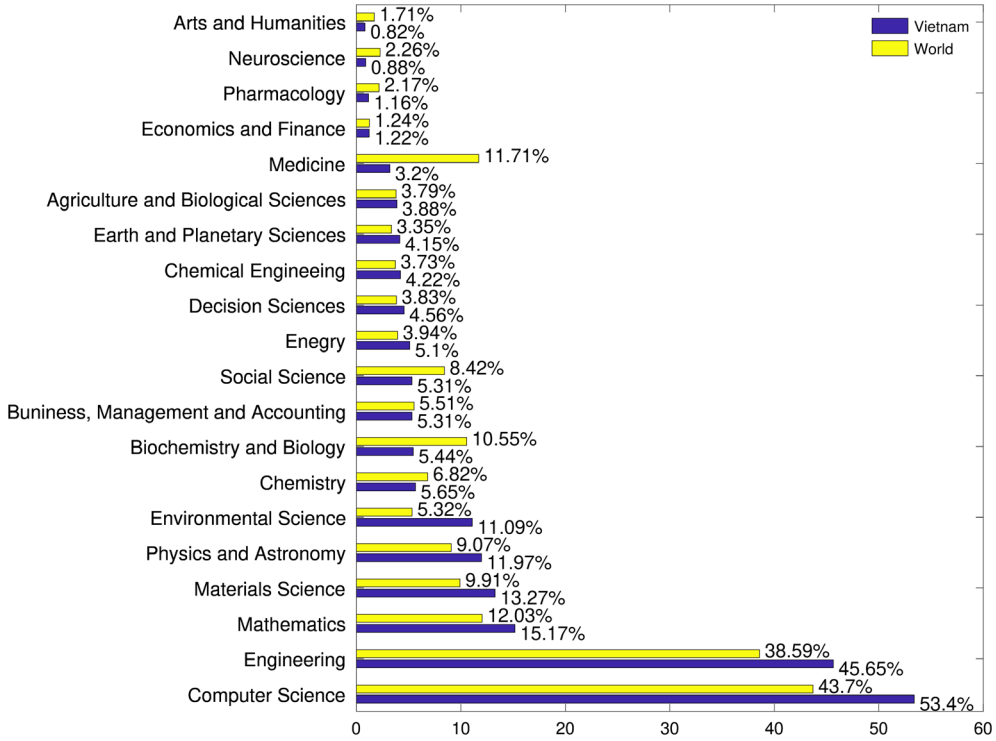

FIGURE 3 Classification of publications in Industry 4.0 in Vietnam and in the world, according to the Scopus 20 categories of research.

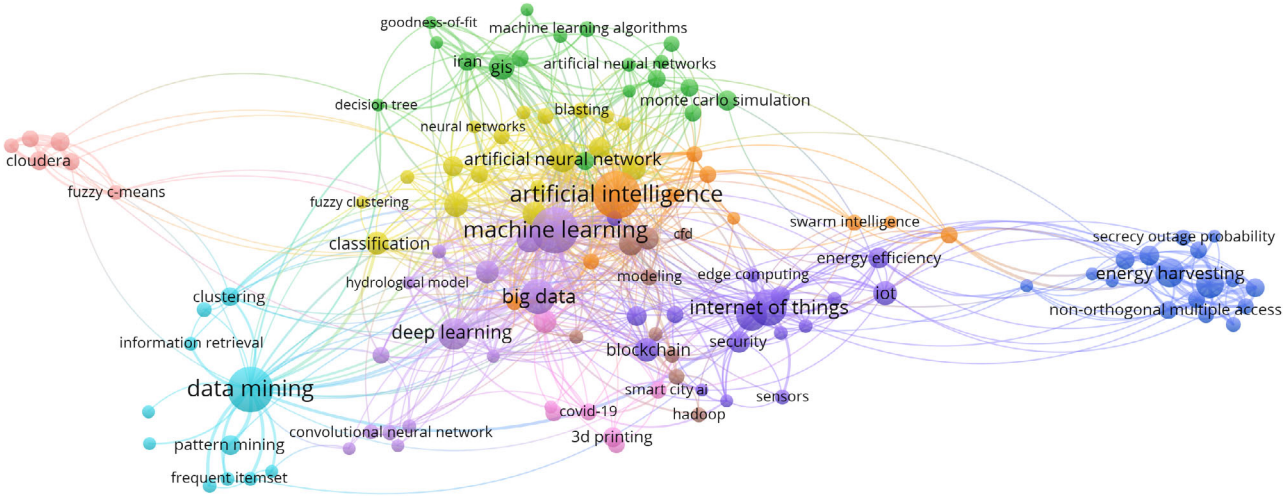

FIGURE 4 The co-occurrence of 127 most popular keywords (with at least five occurrences). The thickness of lines represents the strength of the relationship between keywords which was determined by the frequency they appeared together in published papers. Artwork generated with VOSviewer (van Eck & Waltman, 2010).

publications (81, 63, and 53) and citations (1,202, 3,107, and 1,875), respectively. The list is followed with three scholars having more than 40 papers, including Mosavi A (48 papers), Nguyen H (47 papers), and Shamshirband S (44 papers). Yaseen ZM, Le B, and Son LH were in the next positions with at least 30 papers. Finally, Hoang ND was in the 10th position with 28 publications. Two authors in the top 10 scholars are from University of South-Eastern Norway, Norway (Bui DT), and from Bauhaus-Universität Weimar, Germany (Mosavi A), but they are visiting scholars of Ton Duc Thang and Duy Tan University, and have a strong collaboration with Vietnamese scholars in the research field. The remaining eight scholars in the top 10 were from only three cities

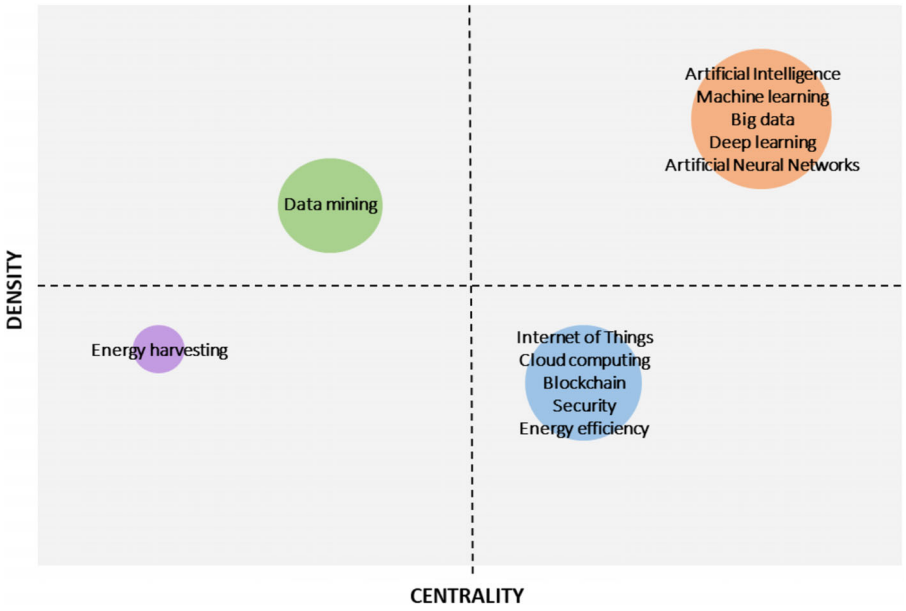

FIGURE 5 Thematic map of Industry 4.0 topics in Vietnam. Artwork generated with biblioshiny tool.

TABLE 1 Top 10 most productive authors publishing in Industry 4.0 in Vietnam based on the total number of publications (TP: total papers; TC: total citations).

Order	Author	Institute	Country	Region	TP	TC	h-index
1	Vo B	HCM City University of Technology	Vietnam	HCM	81	1,202	20
2	Bui DT	University of South-Eastern Norway	Norway		63	3,107	29
3	Pham BT	University of Transport Technology	Vietnam	Hanoi	53	1,875	25
4	Mosavi A	Bauhaus-Universität Weimar	Germany		48	365	10
5	Nguyen H	Hanoi University	Vietnam	Hanoi	47	649	14
6	Shamshirband S	Ton Duc Thang University	Vietnam	HCM	44	755	16
7	Yaseen ZM	Ton Duc Thang University	Vietnam	HCM	38	518	15
8	Le B	Vietnam National University HCM	Vietnam	HCM	34	539	13
9	Son LH	Vietnam National University Hanoi	Vietnam	Hanoi	31	924	18
10	Hoang ND	Duy Tan University	Vietnam	Da Nang	28	526	15

in Vietnam, including four scholars in Ho Chi Minh City, three scholars in Hanoi, and one scholar in Da Nang. Ton Duc Thang University was the only institution having two scholars listed in Table 1. The top 10 scholars published a total of 363 papers, which accounted for 24.70% of the collection, with 7,984 citations, which accounted for 52.18% of the total citations of the collection.

After applying the cut-off of five papers for each author, the co-authorship network of 188 co-authors is visualized in Fig. 6. Authors are grouped into clusters where the position of an author within the constellation represents how frequent their co-occurrence was with other co-authors. The number of papers by authors is visualized through the size of the circles, while the strength of collaborations between co-authors is visualized through the thickness of the connection line between them. The most productive authors normally appear at the centre of their clusters as they have strong collaborations with other co-authors. Such authors can be recognized as Vo B (dark green), Bui DT (blue), Nguyen H (light green), Mosavi A (brown), Pham BT (red), Son LH (pink), and Hoang ND (orange). Among 188 co-authors, 168 authors (89.36%) were connected. In contrast, isolated authors with no or limited connections and collaborations with other scholars normally have fewer publications.

Our results showed that the collection of 1,470 papers was produced by a total of 1,956 different research institutes/organizations, and the top 10 Vietnamese institutes based on the number of publications and citations are presented in Table 2. Note that one author can be affiliated to more than one research institute, or a paper can be contributed by co-authors from different institutes. The top 10 institutes published a total of 1,074 papers in the collection, or 73.06% share. There are five institutions located in Hanoi, four institutions located in Ho Chi Minh City,

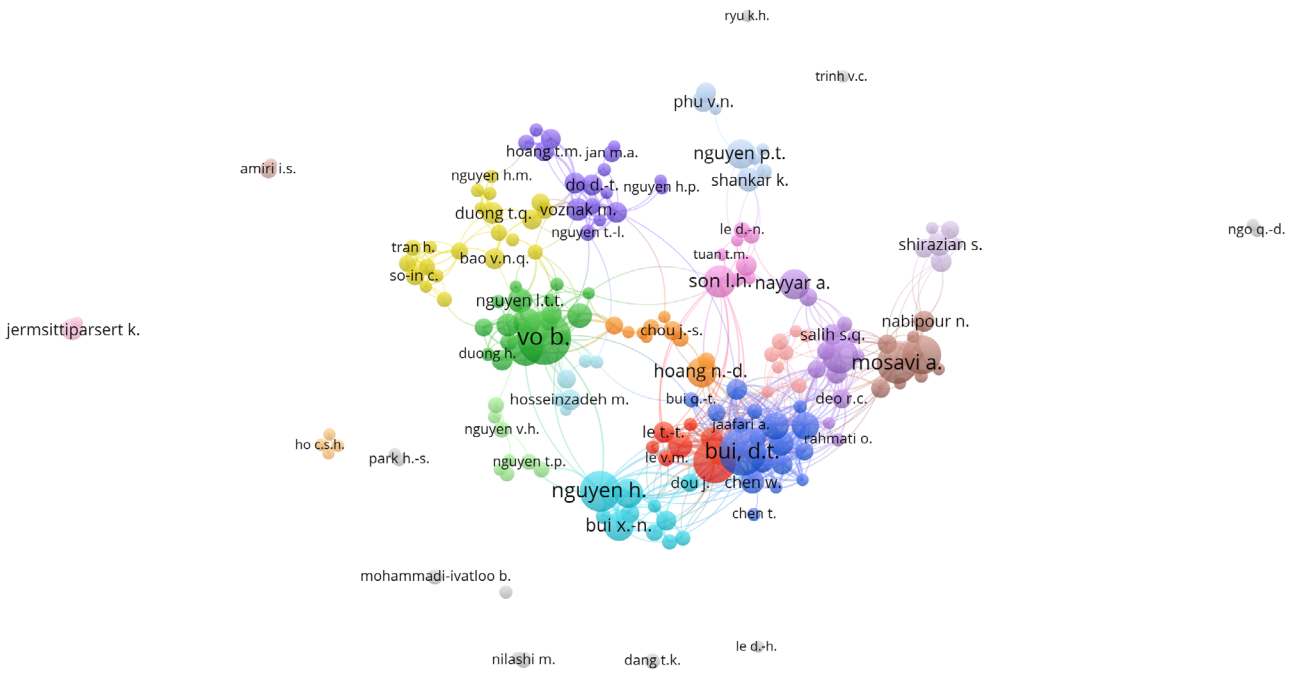

FIGURE 6 The network of 188 co-authors publishing in Industry 4.0 in Vietnam. Each node presents an author. The size of the nodes indicates the number of publications, while the thickness of the lines between nodes shows the strength of collaboration. Artwork generated with VOSviewer tool.

TABLE 2 Top 10 most productive Vietnamese institutes publishing in Industry 4.0 based on the total number of publications (TP: total papers; TC: total citations).

Order	Institutes	Region	TP	%	TC	%
1	Ton Duc Thang University (TDTU)	HCM	446	30.34	4,896	32.00
2	Duy Tan University (DTU)	Da Nang	378	25.71	3,499	22.87
3	Vietnam National University HCM (NUHCM)	HCM	170	11.56	1,419	9.27
4	HCM City University of Technology (HCMCUT)	HCM	158	10.74	1,233	8.05
5	Vietnam National University Hanoi (NUH)	Hanoi	95	6.46	1,623	10.60
6	Hanoi University of Science and Technology (HUST)	Hanoi	84	5.71	598	3.90
7	Vietnam Academy of Science and Technology (VAST)	Hanoi	48	3.26	913	5.96
8	Institute for Computational Science and Technology (ICST)	HCM	48	3.26	249	1.62
9	Hanoi University of Mining and Geology (HUMG)	Hanoi	46	3.12	1,647	10.76
10	Posts and Telecommunication Institute of Technology (PTIT)	Hanoi	45	3.06	589	3.84

and only one institution located in Da Nang (Duy Tan University, which is also the only private institution in Table 2). Ton Duc Thang and Duy Tan University were in the first two positions, with the largest number of publications (446 and 378), as well as of citations (4,896 and 3,499) compared to other contributors in Table 2. Ton Duc Thang University participated to 30.34% of the publication collection, and accounted for 32% of the total citations, while these numbers from Duy Tan University were 25.71% and 22.87%, respectively. Vietnam National University HCM (170 papers, 1,419 citations) and HCM City University of Technology (158 papers, 1,233 citations) were in the next two positions, which accounted for 10%–11% of the papers, and 8%–9% of the total citations. Six remaining institutions in the top 10 published between 45 and 95 papers. Vietnam National University Hanoi and Hanoi University of Mining and Geology ranked fifth and ninth based on number of papers, but were in the fourth and third positions based on number of citations. It is important to note that a single count was applied for the statistic of authors' and institutes' production. This means that if an article has two authors, then each is credited with a single count (and not 0.5 each).

The annual number of papers related to Industry 4.0 and its key technologies from the top 10 Vietnamese institutes is

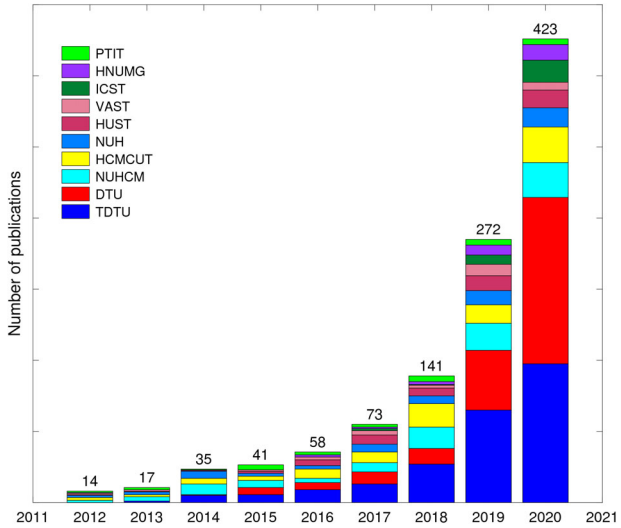

FIGURE 7 Annual publications of the top 10 most productive Vietnamese institutions publishing in Industry 4.0. Details can be found in Table 2.

presented in Fig. 7, showing a similar increase as observed in Fig. 1. Most of the papers related to Industry 4.0 from these institutes were published in the 2017–2020 period, especially during 2019–2020 which contributed to 64.71% (695 papers) of the total publications from these Vietnamese institutes. The contribution from Duy Tan University increased rapidly, especially over the last two years. In 2020, Duy Tan University overcame Ton Duc Thang University to become the biggest contributor. Note that HCM City University of Technology is a member of Vietnam National University HCM City, but they are presented separately because we respected authors' affiliations in their latest papers. In addition, HCM City University of Technology works like an independent university, therefore, it is necessary to provide its statistics so that readers can compare its scientific output in Industry 4.0 with other universities.

RQ5: Which were the most influential publications in each key research area of Industry 4.0 from Vietnam, based on the number of citations?

We found that the publication collection of 1,470 papers was cited 15,299 times in other published documents, and the list of the most cited papers in 10 key research areas of Industry 4.0 is shown in Table 3, along with its yearly average citation and the affiliation of the first author. There were only three papers in the top 10 having the first author's affiliations located in Vietnam, focusing on machine learning (Pham et al., 2016), deep learning (Ngo et al., 2017), and big data (Son & Tien, 2017). Bui DT was the only scholar having two papers as first author listed in Table 3, focusing on artificial neural networks (Bui, Tuan, et al., 2016), and data mining (Bui, Ho, et al., 2016). The first authors of the remaining six papers in Table 3 were from India (two papers), Iran, Singapore, and Italy.

RQ6: Which journals published the most papers in Industry 4.0 from Vietnamese affiliations?

The top 10 journals publishing the most papers related to Industry 4.0 and its key technologies from Vietnam are presented in Table 4, along with numbers of citations and h-indexes and journal quartiles. IEEE Access ranked first with 81 papers and 499 citations, more than twice the number of papers published by Sensors, at the second position with 36 papers. There are four journals that published more than 20 papers, including Applied Sciences (28 papers, 428 citations), Engineering with Computers (25 papers, 405 citations), Expert Systems with Applications (24 papers, 814 citations), and Applied Intelligence (23 papers, and 336 citations). The remaining four sources in Table 4 published between 15 and 19 papers related to Industry 4.0 from Vietnam. In the top 10 sources, there are four journals that belong to Multidisciplinary Digital Publishing Institute, three journals belonging to Elsevier, two journals belonging to Springer, and one journal that belongs to IEEE. All of the journals in Table 4 were classified into the Q1 quartile (seven journals) and Q2 quartile (three journals), according to classification provided by the Scimago Journal & Country Rank, dated 20th December 2020. The top 10 journals published a total of 284 papers, representing 19.32% of the total.

RQ7: Which partner countries published the most with Vietnamese affiliations in Industry 4.0?

The collection of 1,470 papers was published by co-authors from 92 countries/regions (or territories, hereafter referred to as 'countries' for simplification). The top 10 most productive partner countries with Vietnam are presented in Table 5. Iran ranked first for both number of papers (210; 14.28%) and number of citations (3,064; 20.02%), followed by China and South Korea with 176 and 172 papers, respectively. The remaining partners in the top 10 include four countries/regions in Asia [India (#4), Taiwan (#7), Malaysia (#8), and Japan (#10), the US (#5), Australia (#6), and the UK (#9)]. The top 10 partner countries participated in 873 papers which corresponded to 59.40% of the collection. The visualization of the collaboration network of 50 partner countries having at least five published papers related to Industry 4.0 is shown in Fig. 8. Each country is represented by a node, and the size of the nodes is proportional to the number of papers, while the thickness of lines between nodes represents the strength of collaboration between countries. These countries were classified into different clusters, and countries in the top 10 appeared in the centres of their clusters, for example, Iran (blue), South Korea (orange), China, India and Malaysia (violet), Australia, and the UK (red).

TABLE 3 Overview of the top 10 most cited papers in Industry 4.0 in Vietnam.

Title	Authors	Source	First author's Institution/Country	Research area	Year	Citations	Yearly average citations
Spatial prediction models for shallow landslide hazards: a comparative assessment of the efficacy of support vector machines, artificial neural networks, kernel logistic regression, and logistic model tree (Bui, Tuan, et al., 2016)	Bui Dieu Tien Tuan Tran Anh Klempe Harald Pradhan Biswajeet Revhaug Inge	Landslides	University of South-Eastern Norway/ Norway	Artificial neural networks	2016	438	87.6 (#1)
A comparative study of different machine learning methods for landslide susceptibility assessment: A case study of Uttarakhand area (India) (Pham et al., 2016)	Pham Binh Thai Pradhan Biswajeet Bui Dieu Tien Prakash Indra Dholakia MB	Environmental Modelling & Software	University of Transport Technology, Hanoi/ Vietnam	Machine learning	2016	189	37.8 (#3)
Survey of computational intelligence as basis to big flood management: challenges, research directions and future work (Fotovatikhah et al., 2018)	Fotovatikhah Farnaz Herrera Manuel Shamshirband Shahaboddin Chau Kwok-wing Faizollahzadeh Ardabili Sina Piran MD. Jalil	Engineering Applications of Computational Fluid Mechanics	SPM Lab, Sari/Iran	Artificial intelligence	2018	166	55.3 (#2)
Combining deep learning and level set for the automated segmentation of the left ventricle of the heart from cardiac cine magnetic resonance (Ngo et al., 2017)	Ngo Tuan Anh Lu Zhi Carneiro Gustavo	Medical Image Analysis	Vietnam National University of Agriculture/Vietnam	Deep learning	2017	134	33.5 (#4)
GIS-based modeling of rainfall-induced landslides using data mining-based functional trees classifier with AdaBoost, Bagging, and MultiBoost ensemble frameworks (Bui, Ho, et al., 2016)	Bui Dieu Tien Ho Tien-Chung Pradhan Biswajeet Pham Binh-Thai Nhu Viet-Ha Revhaug Inge	Environmental Earth Sciences	University of South-Eastern Norway/ Norway	Data mining	2016	128	25.6 (#5)
Real-time water quality monitoring using internet of things in SCADA (Saravanan et al., 2018)	Saravanan K Anusuya E Kumar Raghvendra Son Le Hoang	Environmental Monitoring and Assessment	Anna University Regional Campus, Tirunelveli, Tamilnadu/India	Internet of things	2018	44	14.6 (#7)
Fog computing: from architecture to edge computing and big data processing (Singh et al., 2019)	Singh Simar Preet Nayyar Anand Kumar Rajesh Sharma Anju	The Journal of Supercomputing	Thapar Institute of Engineering and Technology, Patiala/India	Cloud computing	2019	38	19 (#6)
Tune up fuzzy C-means for big data: Some novel hybrid clustering algorithms based on initial selection and incremental clustering (Son & Tien, 2017)	Son Le Hoang Tien Nguyen Dang	International Journal of Fuzzy Systems	Ton Duc Thang University, Ho Chi Minh City/Vietnam	Big data	2017	30	7.5 (#9)
3D printing of highly pure copper	Tran, Vu, et al., (2019)	Metals	National University of Singapore/Singapore	3D printing	2019	23	11.5 (#8)
Ancillary services in the energy blockchain for microgrids (Silvestre et al., 2019)	Silvestre et al., (2019)	IEEE Transactions on Industry Applications	University of Palermo Palermo, Italy	Block chain	2019	12	6 (#10)

TABLE 4 Top 10 most active journals publishing research in Industry 4.0 from Vietnam based on the total number of publications (TP: total papers; TC: total citations).

Order	Journals	Publishing house	TP	TC	h-index	Quartile[a]
1	IEEE Access	IEEE	81	499	13	Q1
2	Sensors	MDPI	36	428	11	Q1
3	Applied Sciences	MDPI	28	405	10	Q1
4	Engineering with Computers	Springer	25	342	12	Q1
5	Expert Systems with Applications	Elsevier	24	814	16	Q1
6	Applied Intelligence	Springer	23	336	13	Q2
7	Sustainability	MDPI	19	127	6	Q2
8	Energies	MDPI	17	278	7	Q2
9	Engineering Applications of Artificial Intelligence	Elsevier	16	199	8	Q1
10	Information Sciences	Elsevier	15	297	8	Q1

[a] According to Scimago Journal & Country Rank (https//www.scimagojr.com/) dated 20th December 2020.

DISCUSSION

Growth of output from Vietnam was similar to the global growth of literature related to Industry 4.0 reported in previous studies (Kipper et al., 2020; Mariani & Borghi, 2019; Muhuri et al., 2019). This increase is likely to be a result of recent policies from the Vietnamese government to encourage both private and public sectors to invest more in research and development of Industry 4.0 in Vietnam (Vietnam-Goverment, 2017; Vietnam-Politburo, 2019, 2020). Of note, on 20th April 2020, the Vietnamese Government issued Resolution No. 50/NQ-CP (Vietnam-Politburo, 2020) with an action plan to proactively participate in the Industry 4.0, requesting the involvement of all 18 over 18 ministries. As a consequence, we expect that this increase of scientific output in Industry 4.0 in Vietnam will continue in the coming years.

TABLE 5 Top 10 most productive partner countries publishing in Industry 4.0 with Vietnamese scholars based on the total number of publications (TP: total papers; TC: total citations).

Order	Country	TP	%	TC	%
1	Iran	210	14.28	3,064	20.02
2	China	176	11.97	2,329	15.22
3	South Korea	172	11.70	2,498	16.32
4	India	144	9.79	1,995	13.04
5	United States	128	8.70	1,509	9.86
6	Australia	124	8.43	1,842	12.04
7	Taiwan	111	7.55	1,215	7.94
8	Malaysia	108	7.34	2,780	18.17
9	United Kingdom	82	5.57	1,283	8.38
10	Japan	77	5.23	869	5.68

Computer Science, Engineering, and Mathematics were the three research categories that have the most published papers in Industry 4.0 in Vietnam. This is similar to the global trend, but the portions of publications in these fields in Vietnam were higher. Industry 4.0 and its new emerging and key technologies have great potential to be applied to a diverse range of other research areas, therefore, based on the distribution in Fig. 3, scholars could find opportunities to establish new research lines in other research areas. For example, Vietnamese scholars could develop potential research related to applications of Industry 4.0 technologies in the fields of medicine, biochemistry, and biology as the contribution of these research fields in Industry 4.0 in Vietnam was still limited, compared to the global statistics. For example, the keyword CPS could not be found in the co-occurrence map of the most popular keywords (Fig. 4), while it is one of the most important research themes in Industry 4.0 in the world.

The contribution of the different Vietnamese institutions indicates the impact of the creation of strong research groups based on the recruitment of well-known researchers in the research areas. This model has also been proven effective in other countries (Nguyen et al., 2020), and needs to be extended to other Vietnamese universities and research institutes to increase their scientific output. It is clear that public universities and institutes are holding the leadership in academic research in Industry 4.0 in Vietnam. This is as expected because public universities and institutes make up a large proportion of the Vietnamese higher education system with 172 over 273 universities (72.6%). Although the contribution of private universities in research related to Industry 4.0 in Vietnam is still limited (with only one private institution in the top ten), we could expect that the scientific output in Industry 4.0 from other private universities will be larger in the future. Phenikaa University and Phenikka innovation foundation launched by the Phenikka Group in November 2019 is an example since the Phenikaa group announced it would spend VND1 trillion (more than US$45 million) on the Phenikaa innovation foundation to develop

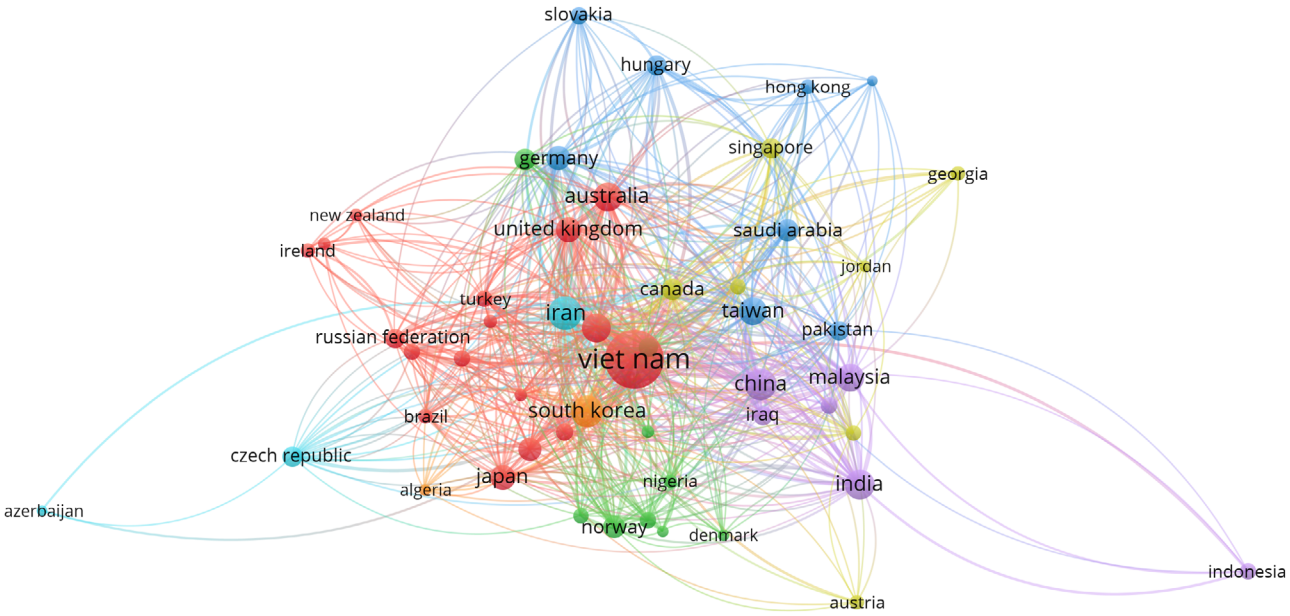

FIGURE 8 Cooperation network of 50 partner countries (with at least five papers) and Vietnam in Industry 4.0. The size of the nodes indicates the number of publications, while the thickness of the lines between nodes shows the strength of collaboration. Artwork generated with VOSviewer tool.

talents, encourage innovation, and realize novel ideas from scientists and start-ups in Vietnam (Phenikaa-University, 2019). The establishment of Vin University with the first academic year in October 2020 was another example. Under the sponsorship of Vingroup Joint Stock Company, one of the biggest conglomerates in Asia, it is expected that the contribution of Vin University in the research field related to Industry 4.0 will be larger in the near future.

By analysing the most cited papers in each research area of Industry 4.0 (Table 3), scholars might obtain information to help identify future research topics. Papers related to machine learning, artificial intelligence, artificial neural networks, deep learning, and data mining normally receive more attention from the community. However, it is notable that only three of the top-cited papers in Table 3 had first authors located in Vietnam. In addition, there was only one paper in Table 3 that had entirely Vietnamese-affiliated authors (Son & Tien, 2017). This suggests that international collaborations are very important in the field of Industry 4.0 if the research is to be highly cited.

With seven Q1 and three Q2 journals in the top 10 publishing sources in Industry 4.0, we can conclude that quality of the publication collection in this field from Vietnamese scholars was high, meeting the standard of high-ranking international journals. Choosing the right journals is important because it might affect the visibility as well as the influence of the paper and its authors to the community in the future.

Vietnamese scholars and institutions had international collaborations in Industry 4.0 and its key technologies with 92 other countries/regions, and the contribution of the top 10 most productive partner countries was large, which corresponded to 59.40% of the publication collection. Germany and China appear to be the two most important countries publishing in Industry 4.0 globally (Muhuri et al., 2019), but the only important partner publishing with Vietnam is China (Table 5). Except for Iran, the disparity in the number of papers associated other countries in the top 10 was low, and the rankings of these countries may change quickly in the future.

CONCLUSION

In this paper, bibliometric analysis was used to study the development and evolution of publications related to Industry 4.0 and its key technologies in Vietnam, indexed in the Scopus database for the 2012–2020 period. The development of the research field from 2017 could be used to evaluate the impact of recent policies from the Vietnamese government to encourage the investment from both public and private sectors in scientific and technology research related to Industry 4.0. Data from Vietnam were compared to data from other Southeast Asian countries and global data to see distinctive characteristics of Industry 4.0 research in Vietnam. Totally, 1,470 papers were retrieved during the 2012–2020 period, making Vietnam ranked third among 10 countries in Southeast Asia, based on the number of publications. Our results showed that the number of papers in Industry 4.0 from Vietnam increased rapidly in recent years, mostly in the research areas of Computer Science, Engineering, and Mathematics. The most productive scholars were all from a few universities or research institutes located in Ho Chi Minh City, Hanoi or Da Nang. The quality of publication in Industry 4.0 by Vietnamese scholars was high as all journals in the top 10 publishing sources have been classified as Q1 and Q2 journals. Iran, China, and South Korea were the most important partner countries with

Vietnam based on both numbers of papers and citations, but this order could be changed in the coming years as the gap in the number of papers between the top partner countries was small. Finally, the most important research themes in Industry 4.0 in Vietnam were similar to the global trends, focusing on machine learning, artificial intelligence, big data, deep learning, IoT, block chain, and data mining.

LIMITATIONS

The biggest limitation of this study is that our results totally depend on the quality of input data extracted from the Scopus database, but some information on this database are not standardized, such as authors' names or authors' affiliations (partly due to lack of data capture by the journals). Although data cleaning has been applied before data analysing, manual correction for the whole dataset is impossible. This could be one of the main sources of error for our analyses. Second, Scopus is the largest bibliographic database, but the use of only one database might not cover all papers related to Industry 4.0 from Vietnam. Thus, more analyses combining information extracted from other bibliographic sources such as WoS and Google Scholar could be considered as future work of this study, to cross check our findings. In addition, we might not cover a critical component of Industry 4.0 associated with industry and private sectors where emerging technologies are adopted. Research projects in the industry cannot be neglected, but they might be kept private and not published in scientific journals. Third, it is important to mention that no search query can cover all the fields of Industry 4.0 as Industry 4.0 and its technologies can be applied in all areas of life. Therefore, keywords used in the search query string in Box 1 could only cover publications related to the term Industry 4.0 and its key and most popular technologies, and false positive and false negative results may occur. Fourth, our bibliographic results provided the numbers of papers and citations, however, number of papers represents the quantity but the number of citations does not necessarily represent the quality of the research. Finally, two most popular and effective tools have been used for bibliographic analyses in this study, but some types of analyses (gender contribution, for instance) cannot be done due to technical limitations. Analyses using other tools, such as SciMAT (Cobo et al., 2012), should be investigated in future studies to complete this type of research.

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AUTHOR CONTRIBUTIONS

Trung Tran and **Binh Pham-Duc**: Conceptualization; **Ha-Thi Cao**: Data curation; Formal analysis; **Nhi-Thi Nguyen**: Methodology; Resources; **Hien-Thu-Thi Le**: Software; Visualization; **Trung Tran**: Validation; **Binh Pham-Duc**: Roles/Writing—original draft; **Binh Pham-Duc** and **Tien-Trung Nguyen**: Writing—review and editing.

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