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Abstract

Purpose – Environmental sustainability is quickly becoming one of the most critical issues in industry development. This study aims to conduct a systematic literature review through which the author can provide various research areas to work on for future researchers and provide insight into industry 4.0 and environmental sustainability.

Design/methodology/approach – This study accomplishes this by performing a backward analysis using text mining on the Scopus database. Latent Semantic Analysis (LSA) was used to analyze the corpus of 4,364 articles published between 2013 and 2023. The authors generated 10 clusters using keywords in the industrial revolution and environmental sustainability domain, highlighting ten research avenues for further exploration.

Findings – In this study, three research questions discuss the role of environmental sustainability with industry 4.0. The author predicted 10 clusters treated as recent trends on which more insight is required from future researchers. The authors provided year-wise analysis, top authors, top countries, top sources, and network analysis related to the topic. Finally, the study provided industrialization's effect on environmental sustainability and the future aspect of automation.

Originality/value – This research is the first-ever study in which a natural language processing technique is implemented to predict future research areas based on the keywords-document relationship.

Keywords: Text Mining, Latent Semantic Analysis, Industry 4.0, Environmental Sustainability, Revolution

1. Introduction

The Industrial Revolution began in the late 18th century and brought about significant manufacturing, transportation, and technological changes (Kaswan et al., 2021). While it significantly improved living standards and increased economic growth, it also had a negative impact on the environment, including air and water pollution, deforestation, and soil degradation (Brewster, 2021). Substantial developments in mechanization and invention took place during this period, and they eventually expanded to a significant chunk of the rest of the world. The accumulation of raw materials such as coal and iron was one of the primary motivating factors that led to the start of the Industrial Revolution (Kumar et al., 2023; Growiec, 2022). Even though the beginning of industrialization was essential to the achievement of economic prosperity, it also brought about an increase in population, the expansion of urban areas, and a glaring strain on the crucial life-supporting systems, all while simultaneously bringing environmental impacts closer to the limits of what is tolerable at the same time. The rapid growth of industry, combined with the limited availability of land suitable for industrial use, has pushed the issue of environmental sustainability to the forefront of the conversation regarding industrial policy (Ferrannini et al., 2021; Rathi et al., 2021). This has resulted in the ascent of ecological sustainability as an essential factor to consider. There is mounting data that suggests it may be able to protect natural resources and improve the region's economy by engaging in environmentally appropriate activities, and this goal is only attainable by implementing successful planning. An integrated framework in line with the environment is required, as is in-depth research of the present and the historical aspects of the area under consideration (Nemarumane et al., 2022). Industrial energy sources shifted drastically after steam technology's development and the steam engine's introduction. Paper, wheat, cotton mills, ironworks, distilleries, and waterworks were all able to benefit from steam power thanks to the development of the steam engine. Coal is an essential raw resource for most businesses. Thanks to steam engines, it is now possible to acquire them swiftly and efficiently, improving metal quality. After that, a technological advancement called the power loom revolutionized the textile industry. Since the invention of the power loom, large amounts of inexpensive, lightweight fabric have been produced with remarkable efficiency (Agarwal & Agarwal, 2017). In addition, consistent power allowed industries to run nonstop for extended periods, resulting in greater output. The manufacturing industry remained a dangerous place to work, despite the advent of new technologies. The beginning of the Industrial Revolution can be traced back to Great Britain in the 18th century. This was a time of fast industrialization and the growth of technology, both of which profoundly affected the natural environment and society. Table 1 is a selection of statistical information regarding the Industrial Revolution and the long-term viability of the environment:

Table 1: Analytical Retrospection of Environment Sustainable Key Areas

Environmentally Sustainable Key Area	**Analytical Retrospection**
Greenhouse gas emissions	The Industrial Revolution was responsible for a considerable rise in the number of emissions of greenhouse gases. According to the Global Carbon Project findings, the amount of carbon dioxide that the world's industries and fossil fuels produced in 2019 were 33.1 billion tonnes, a significant increase from the 2.8 billion

	tonnes produced in 1850 (Raihan & Tuspekova, 2022).
Air pollution	Industrialization led to an increase in air pollution levels. According to the World Health Organization (WHO), 91% of the world's population lives in areas with air quality that exceeds WHO's acceptable levels of particle matter (Peláez et al., 2020).
Carbon emissions	The Industrial Revolution saw a significant increase in carbon emissions due to the widespread use of fossil fuels for energy production. According to the Global Carbon Project, global carbon dioxide emissions from fossil fuels and industry increased by 2.6% in 2019, reaching a record high of 36.8 billion tonnes (X. Wang & Yan, 2022).
Water pollution	Industrial waste and chemicals caused extensive water contamination throughout the Industrial Revolution. According to the United Nations, over 80% of the world's untreated wastewater is discharged into the environment, resulting in substantial environmental and health repercussions (Whelan et al., 2022).
Deforestation	As a result of the exploitation of natural resources to fuel industrial activity, the Industrial Revolution caused extensive deforestation. According to the Food and Agricultural Organization of the United Nations, between 1990 and 2022, the globe lost 178 million hectares of forest (Zahoor et al., 2022).
Sustainable development goals	The Sustainable Development Goals (SDGs) of the United Nations aim to solve several environmental and socioeconomic issues stemming from the Industrial Revolution. For example, goal 7 aims to ensure everyone can access affordable, dependable, sustainable, and modern energy, whereas Goal 12 aspires to promote sustainable consumption and production patterns (Biswas et al., 2022).
Renewable energy	The development of renewable energy sources such as solar and wind power is one solution developed in reaction to the Industrial Revolution's negative environmental effects. According to the International Renewable Energy Agency, in 2019, renewable energy was responsible for 72% of all new power capacity

	increases worldwide (Sayed et al., 2021).

Industry 4.0 reduces its environmental impact by conserving energy, recycling more, eliminating unnecessary steps in the production process, and extending the life of its machinery and tools (Marnewick & Marnewick, 2020). The convergence of these factors and technical improvements will make Environmental Management 4.0 disruptive for businesses operating at version 3.0. Industry 4.0 is a new manufacturing paradigm characterized by superior efficiency in all areas, including production, processes, and the environment. This emerging industry is held up as a model of environmentally responsible production practices. Therefore, it is possible to understand how related technologies work together to place industry 4.0 in a green and sustainable light across all sectors.

Furthermore, children were used as workers, and everyone in the factories was disciplined severely (Oke & Fernandes, 2020). The transportation industry also made significant strides during this time. Changes were made to the road and rail networks during the industrial revolution. Steam engines and advances in road-building technology made these transformations possible. Improved infrastructure contributed to shorter travel times. Improvements in communication efficiency can be traced back to the development of telegraphy and railroad signaling (Subramanian, 2022). The industrial revolution is represented in Figure 1.

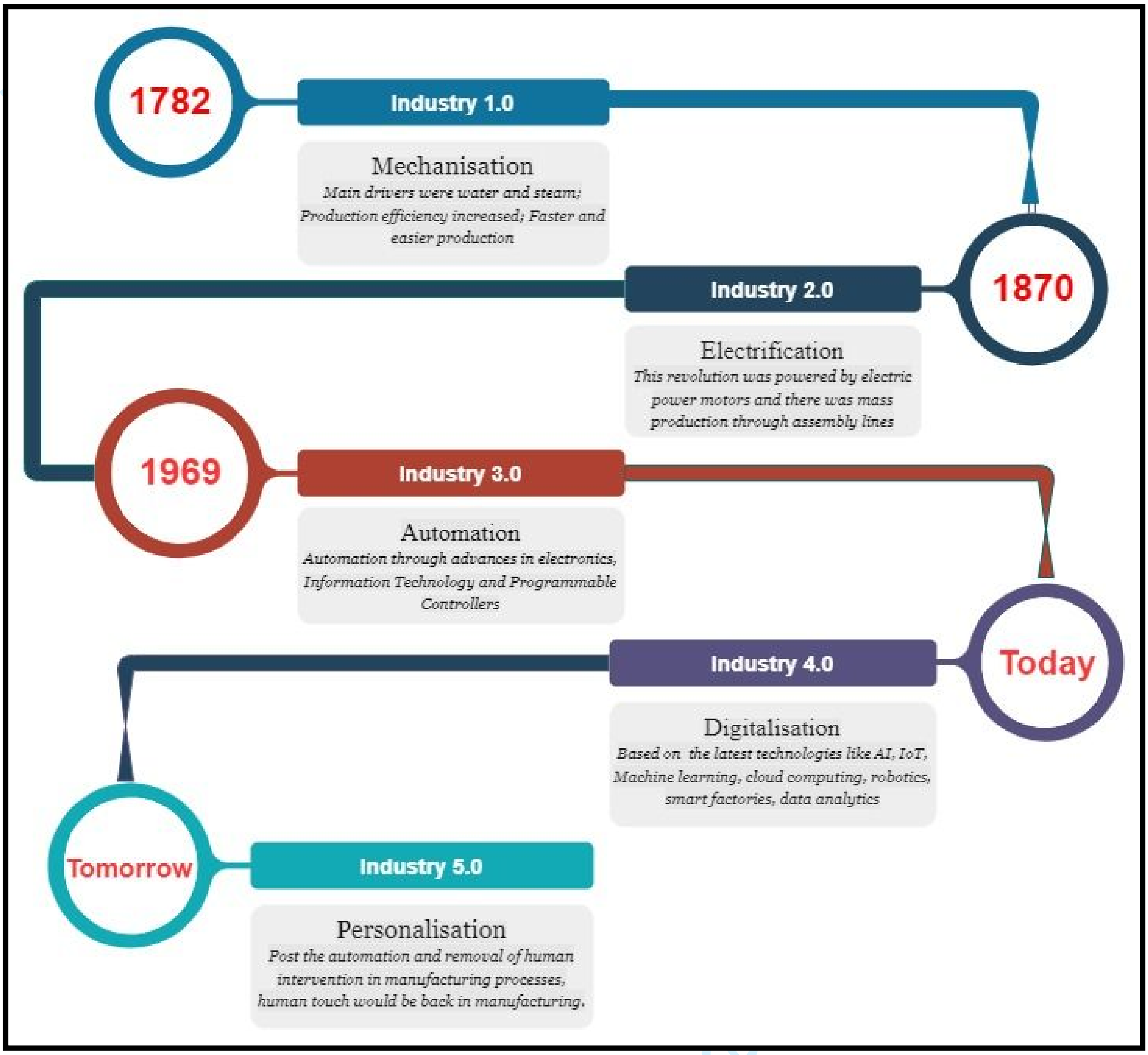

Figure 1: Industrial Revolution- Mechanisation to Personalisation

Today, there is growing concerned about the need for environmental sustainability as the consequences of industrialization continue to be felt. This has led to efforts to reduce greenhouse gas emissions, conserve natural resources, and improve waste management practices. The shift towards renewable energy sources and adopting sustainable manufacturing practices are some of how industry and society are working towards a more sustainable future.

There is no doubt that the fourth industrial revolution can make environmental sustainability better. "Industry 4.0" refers to incorporating advanced digital technologies into manufacturing and other industries (Yadav, Kumar, et al., 2020). Some examples of these technologies include artificial intelligence, robotics, the Internet of Things (IoT), and big data analytics. These technologies can assist businesses in optimizing their operations and lowering their influence on the environment in several ways, and some areas of implications are represented in Table 2.

Table 2: Areas of Implication

Areas of Implication	**Description**
Energy efficiency	Industry 4.0 technology can assist businesses in lowering their overall energy consumption by detecting areas of waste and optimizing operations to make better use of energy. For instance, Internet of Things (IoT) sensors can monitor energy usage and locate regions with high consumption. At the same time, artificial intelligence (AI) algorithms can analyze data to determine ways to reduce energy waste.
Waste reduction	Waste can be minimized with the use of Industry 4.0 technologies, which help businesses streamline their manufacturing procedures and make better use of raw materials. Robotics and AI, for instance, can assist manufacturers in cutting down on the raw materials needed to make a product. At the same time, 3D printing can let businesses make things with minimal waste.
Sustainable supply chains	By analyzing and managing suppliers' environmental effects, Industry 4.0 technology can assist businesses in developing more sustainable supply chains. IoT sensors, for instance, can monitor the transit and storage of commodities to ensure that they are handled in an environmentally responsible manner. At the same time, big data analytics can assist businesses in identifying suppliers with superior sustainability standards (Yadav, Luthra, et al., 2020).
Circular economy	Industry 4.0 technology can assist businesses in transitioning towards a circular economy by making it easier to reuse and recycle resources. IoT sensors, for example, can measure the lifecycle of items and materials, and 3D printing enables firms to produce new products from recycled materials. Likewise, IoT sensors can measure the lifecycle of products and materials (Bag et al., 2021).

This research is carried out to help the academicians, current and future researchers, Industry, and all the stakeholders by providing ten important research areas which are in trend or need more attention shortly. This research contributes to framing and exploring three research questions that deal with the current and future research constituents' relationship between industrialization and environmental sustainability.

The following research questions were framed and explored in the current study:

Research Question 1: What are current research constituents regarding publications, keywords, contributing authors, and their countries?

Research Question 2: How did the industrial revolution affect Environmental Sustainability?

Research Question 3: What are the future aspects of Industry 4.0 leading to the next revolution, 5.0?

The structure used in this study to experiment is represented in Figure 2.

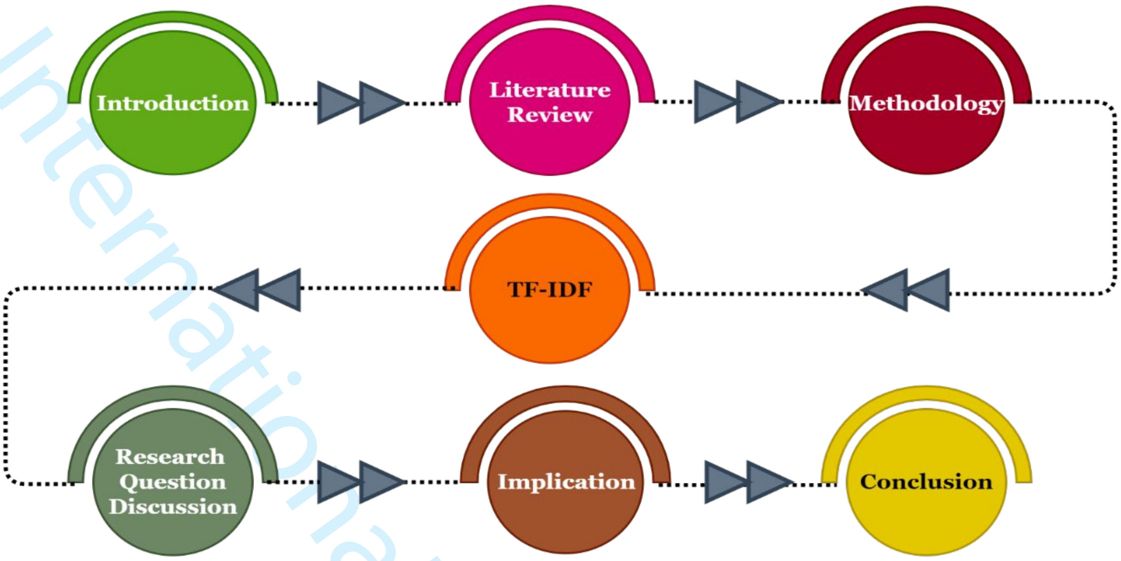

Figure 2: Paper Structure used for Experiment

The rest of the article is organized as follows. Section 2 demonstrates literature about different aspects of industry 4.0 and environmental sustainability. The methodology followed is presented in section 3 of the manuscript. Section 4 illustrates Term Frequency-Inverse Document Frequency. Section 5 discusses the key aspects and implications derived from the study are presented in section 6 of the article. Finally, the conclusion and future aspects are presented in the article's final section.

2. Literature Review

The earliest mechanization of manufacturing was accomplished through water and steam power during the first industrial revolution. However, extensive usage of electricity during the second phase of the industrial revolution, often known as the era of mass production, was significantly responsible for the creation of mass manufacturing. The information technologies in the fourth industrial revolution collect the physical and digital worlds (Ajah & Chigozie-Okwum, 2019). It is anticipated that humans will again be at the center of operations due to the fifth industrial revolution, which will use a human-cyber-physical system to generate value (Virmani & Ravindra Salve, 2021). Two points are worthy of being mentioned. The first one is that the time that elapses between each successive industrial revolution is getting much shorter, which indicates how quickly technology has progressed in the modern period (Yang & Gu, 2021). The second one is that even though there was a significant development in theoretically new technology between the second and the fourth industrial revolution, the subsequent industrial revolution will still be founded on the one that came before it (Rymarczyk & others, 2020). According to projections based on historical observations, a hu-man-cyber-physical system will most likely be the focus of the fifth industrial revolution in the next two to two decades. These projections predict that this will be the case.

The current era is the fourth industrial revolution, which focuses on industry digitalization. Industry 4.0 is still seen by many organizations as the "next thing" they should be working on or as the trend to which they are currently modifying their business strategies in response (Shashi et al., 2022). This demonstrates how advances in information technology kicked off the fourth industrial revolution and how those advancements enabled it. Essential components include virtualization, intelligent systems, automation, robots, big data analytics, artificial intelligence, machine learning, and the Internet of Things. The researchers in this study applied topic modeling, a statistical model for unearthing the underlying themes in large bodies of text. It automatically groups related terms and infers patterns without requiring the user to enter predefined subject tags. Topic Modelling is synonymous with Topic Detection, Topic Extraction, and Topic Analysis. Topic modeling can be done by using various techniques like bibliometric analysis, Latent Dirichlet Allocation (LDA), Latent Semantic Analysis (LSA), Parallel Latent Dirichlet Allocation (PLDA), and a couple more methods (K. Sharma et al., 2022) since Latent Semantic Analysis (LSA) is a powerful method for deciphering text and unearthing concealed topics via contextual analysis, which authors in this research study use. Latent Semantic Analysis is a method for deducing the latent meanings of a text. After being kept under wraps, these topics are used to group papers with similar content. Several studies and reviews have been undertaken to explore the fields of Industry 4.0 and Environmental Sustainability individually using bibliometric analysis (Balasubramanian et al., 2021). The lack of a framework and comprehensive definition of the research topic Industry 4.0 hinders the creation of new business areas and research methods. Therefore, a research study in 2021 intends to provide a completely objective definition based on a statistical review without limiting the selection of publications to a particular research or business field (Rupp et al., 2021). One more study exhibits the relevance of Industry 4.0 in the Logistic Field using bibliometric analysis. Researchers studied and evaluated the existing research on Industry 4.0's potential for use in logistics. The quality of 131 research papers was determined by searching for them in Scopus (Bigliardi et al., 2021). This research used bibliometrics to choose the best papers, authors, keywords, countries, and journals. There is also a large body of work in this area, considering bibliometric analysis to be carried out in 2022 focusing on Industry 4.0 technologies on lean management tools (Nedjwa et al., 2022). Researchers thoroughly studied the link between 38 Lean tools and 15 Industry 4.0 technologies, which a few authors have only briefly looked at. The plan describes Lean 4.0 technologies and tools that are useful for businesses in many different industries, focusing on interactive engineering and simulation for the future factory. Within the literature, much research has been surrounding data-based experimental analysis using bibliometric analysis in environmental sustainability. Using bibliometric analysis, the authors of one of the most recent investigations into environmental sustainability concluded that many Q-methodology articles fail to disclose effectively or justify the use of subjective decision-making at any point in the investigation (Sneegas et al., 2021). After further research into the relevant literature, it was discovered that bibliometric analysis had also been performed on Industry 4.0 and Environmental Sustainability.

Based on the literature, it is concluded that there are six significant critical aspects of integrating Industry 4.0 with environmental sustainability: resource efficiency, circular economy, Renewable energy, Sustainable Manufacturing, Life cycle assessment, and collaborations between companies, government agencies, and other stakeholders (Bag et al., 2020; Kaswan et al., 2023a). Integrating Industry 4.0 with environmental sustainability depends on resource effectiveness. This integration can assist in optimizing resource utilization, decreasing waste and emissions, and enhancing environmental sustainability (Bag & Pretorius, 2020). Industry 4.0's ability to collect and analyze enormous amounts of data in real time is one of its primary advantages. This information can optimize energy and material use in industrial processes. In addition to improving resource utilization, Industry 4.0 can promote circular economy principles, in which waste is reduced and resources are reused or recycled (Bag & Pretorius, 2020). First, Industry 4.0 technologies, such as the Internet of Things (IoT), can facilitate better supply chain transparency and traceability, making tracking and tracing inputs and products simpler. This can permit closed-loop systems that minimize waste and reuse or recycle materials (Mastos et al., 2021). Second, Industry 4.0 technology can facilitate a more sustainable and efficient use of resources. For example, advanced analytics and machine learning can maximize the utilization of resources such as electricity, water, and raw materials (Bonilla et al., 2018).

Reducing waste and emissions can help minimize manufacturing processes' environmental effects (Kaswan et al., 2023b; Rathi et al., 2022). In addition, industry 4.0 technologies can facilitate the development of new business models that promote the circular economy. For instance, manufacturers may offer services such as leasing or renting as an alternative to selling them altogether. This can encourage longer product lives, encourage manufacturers to design for durability and repairability, and decrease waste production. Incorporating Industry 4.0 with environmental sustainability requires cooperation between businesses, government agencies, and other stakeholders (Awan et al., 2021). Working together, the industry can reduce the adverse effects that manufacturing and supply chains have on the environment and still get the full benefits of Industry 4.0. Companies, government agencies, and other interested parties can work together in several important ways, including creating and adopting common standards, disseminating best practices, funding research and development, offering incentives, and involving interested parties.

Furthermore, it was discovered that this research contributed to the Sustainable Industry 4.0 reference framework with application procedures. This aims to demonstrate how sustainability concepts may be supported by Industry 4.0 technologies (Ejsmont et al., 2020). Another study published in 2020 that contributed to a similar scenario noted that much of the scientific community's attention is focused on enhancing economic and environmental factors, with less emphasis on social sphere issues. The paper concludes by discussing the challenges, perspectives, and recommendations associated with further research into the connections between industry 4.0 and sustainability (Furstenau et al., 2020). A topic modeling technique using Latent Dirichlet Allocation (LDA) has been applied to industry 4.0, in which 685 papers were analyzed on industry 4.0 from 2016 to 2019 in Korea Journal Index (KCI). In addition, researchers collected papers using Python-based web scraping software and analyzed them using LDA in R (Cho & Woo, 2019). A variant of this popular technique on the same research topic was carried out some time back, which presents the pillars of Industry 4.0 that have advanced the area and then analyzed the publications and citation structure, most referenced articles, most productive and influential authors, organizations, and nations in Web of Science (Janmaijaya et al., 2021).

Studies have demonstrated a strong and consistent link between Industry 4.0 and Environmental Sustainability; taking a reference from very recent research on Smart Cities conducted in the year 2022 (C. Sharma, Batra, et al., 2022), in this paper, authors have applied another method, Latent Semantic Analysis (LSA) to predict the research trends in the field of Industry 4.0 and Environmental Sustainability. However, by studying the literature thoroughly, the authors concluded that Latent Semantic Analysis (LSA) was not applied to the topics separately or collectively.

3. Methodology

In this study, the authors conduct a systematic literature review by following the guidelines provided by Kitchenham & Charters (Kitchenham & S. Charters, 2007). The study methodology is divided into three phases: data collection, experimental, and analysis.

Firstly the data collection phase is in which data is collected from the Scopus database for an experiment. A string is formulated to extract the data to make a corpus that includes the title of the papers, year, Source, and abstract of the article. The authors identify essential keywords related to the study and derive them with the help of the AND and OR operation strings. Identified keywords that are used to collect the corpus are “industry 4.0”, “environment”, “ecological”. The following string is derived from the keywords which are passed on the title, abstract, and keywords of the published articles included in the Scopus database:-

(TITLE-ABS-KEY(("industry 4.0") AND ("environment" OR "ecological")))

A string is run on the Scopus database as it is considered the most extensive and reliable database among all the databases (Tseng et al., 2019). In the first pass string provided, 4,827 results were extracted on running the string. The step-wise procedure to experiment is shown in Figure 3.

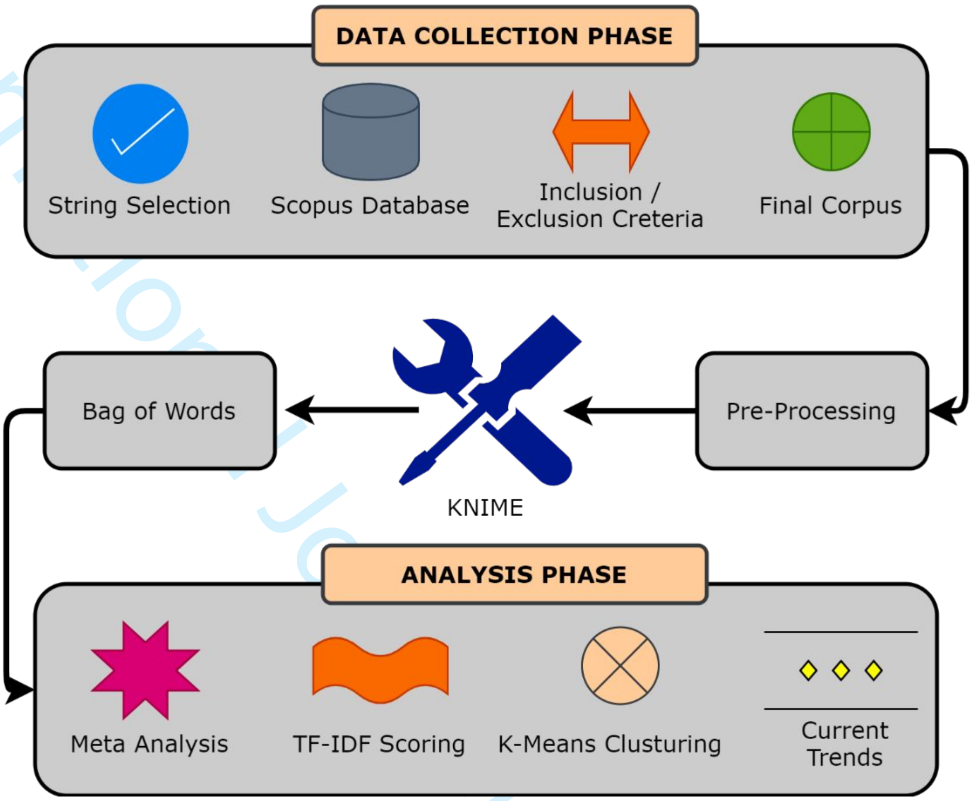

Figure 3: Step-wise Process of Experiment

Once the data was extracted, the author applied inclusion and exclusion criteria to the extracted corpus. First, articles published in the English language are considered for the Experiment, and in addition to this, an article published in journals and conferences are considered. Next, all articles from the corpus are removed with missing information like authors, year, title, and abstract information. Finally, 4,364 published articles were selected for the Experiment. A sample of the uploaded corpus is shown in Table 3.

Table 3: Corpus Sample

Unique ID	Title	Year	Source Title	Abstract
Doc 1	Title 1	2013	Journal 1	“Industry 4.0 has become the most significant subject of the emerging fields in manufacturing and industrial practices over the decade. It leverages the new smart technologies, including Artificial Intelligence, the Internet of Things, Autonomous Vehicles, Advanced Robots, etc., for the high involvement of automation."

Doc 2	Title 2	2013	Journal 2	"Industry 4.0 refers to digitized and connected industrial value creation. Future value creation is in digitized, intelligent, and connected factories and production networks. This development yields extensive and industry-spanning opportunities, e.g., increased efficiency, quality, and flexibility, which affect human beings' work environment, leading to new forms of human-machine collaboration."
Doc 3	Title 3	2014	Conference 1	"Industry 4.0 refers to digitized and interconnected industrial value creation. In this new industrial paradigm, value creation is located in digital, intelligent, connected supply chains and production networks. Research indicates that Industry 4.0 poses economic potentials and addresses sustainability's social and ecological dimensions."
Doc 4	Title 4	2014	Conference 2	"3D printing constructs physical objects by building and stacking layers according to the CAD (Computer-aided Design) information. Attackers target a printing object by manipulating the printing parameters such as nozzle movement and temperature."
Doc 5	Title 5	2014	Journal 3	"3D printing has drawn tremendous attention in Industry 4.0. However, with the ever-increasing consumers' requests for 3D printing services, there lies a big challenge to eliminate the unbalanced demands and supplies of 3D printing resources in a geographically distributed environment."

In the second phase, collected data is required to pre-process so that noisy data can be removed from the corpus. To perform this Experiment, Konstanz Information Miner (KNIME), an open-source platform, is used for its text mining feature (Fillbrunn et al., 2017). It is easy to use and has many features that help researchers perform their experiments. For example, researchers can share their workflow for better insight (Dietz & Berthold, 2016)(C. Sharma, Sakhuja, et al., 2022). Vosviewer, an open-source software, is used for network analysis (Singh et al., 2023) (Xie et al., 2020). In addition to KNIME and Vosviewer, authors have extensively used Excel to create graphs and analyze.

In pre-processing the corpus with the help of KNIME following steps are followed, which are represented in Figure 3 (Evangelopoulos et al., 2012)(Tseng et al., 2019):

Step 1: Part of Speech (POS Tagging) assigns the token to each word from the corpus.

Step 2: To make the data normalized, each token is converted to either uppercase or lowercase.

Step 3: All the punctuation marks are erased using the punctuation eraser module, as it does not draw any meaning. It is just used to complete the sentence or distinguish the sentences.

Step 4: Individually number does not provide any information, so all numbers should be removed from the corpus.

Step 5: Once all numbers are removed, then it is also required to remove the stop words (is, am, are). Individually stop words do not draw any knowledge.

Step 6: It is required to convert all words to their root word, so stemming is performed using porter stemmer (Feldman & Sanger, 2006).

Step 7: Finally, all stem words are converted to

After pre-processing the data, the bag of words (BOW) is created. BOW is also known to be the dictionary of the word. On this BOW further, the latent semantic analysis model is implemented, and the KNIME workflow used to conduct document pre-processing has been shown in Figure 4. Latent semantic analysis is a subdomain of text mining under the umbrella of natural language processing. Once the BOW is created, the author calculates the term frequency (TF) and inverse document frequency (IDF) for each word of BOW. Then, the TF value is multiplied with IDF to find the TF-IDF score for each word, and K-Mean clustering is applied to the TF-IDF score for predicting the current research areas, which are discussed later section as a research question discussion.

Figure 4: KNIME Workflow to Conduct Experiment

4. Term Frequency-Inverse Document Frequency (TF-IDF)

In natural language processing, text mining is a very emerging field to provide information from unstructured data. Researchers from text mining implement various techniques, but in this study, the author implemented LSA, which is based on the TF-IDF score (Jones, 1972) (Wu et al., 2008) (Ramos, 2003). From the BOW, the TF and IDF score is calculated, and further, the TF-IDF score is calculated. TF refers to the term frequency and is used to calculate the frequency of a specific word in the document. It is estimated as the number of times the term appears in the document divided by the total times in the document (Artama et al., 2020)(Kim et al., 2020). On the other hand, IDF is used to calculate inverse document frequency. The mathematical formula for TF-IDF is shown in equations (1) and (2).

$$TF = \frac{\mathit{Number\ of\ times\ word\ appears\ in\ document}}{\mathit{Total\ number\ of\ terms\ in\ the\ document}} \qquad (1)$$

$$IDF(i,j) = \log\left(\frac{\mathit{Total\ number\ of\ document}}{\mathit{Number\ of\ documents\ with\ term\ 'i'\ inside\ it}}\right) \qquad (2)$$

The TF-IDF score calculates the word's weight in the document and corpus (Yalcinkaya & Singh, 2015).

TF-IDF values for the corpus used in this study have been shown in Table 3, which have been computed automatically by KNIME workflow using Equations 1 and 2. There are 19,092 unique tokens extracted from the corpus, and from these tokens, the top 20 frequent words, along with their count, have been represented graphically in Figure 5.

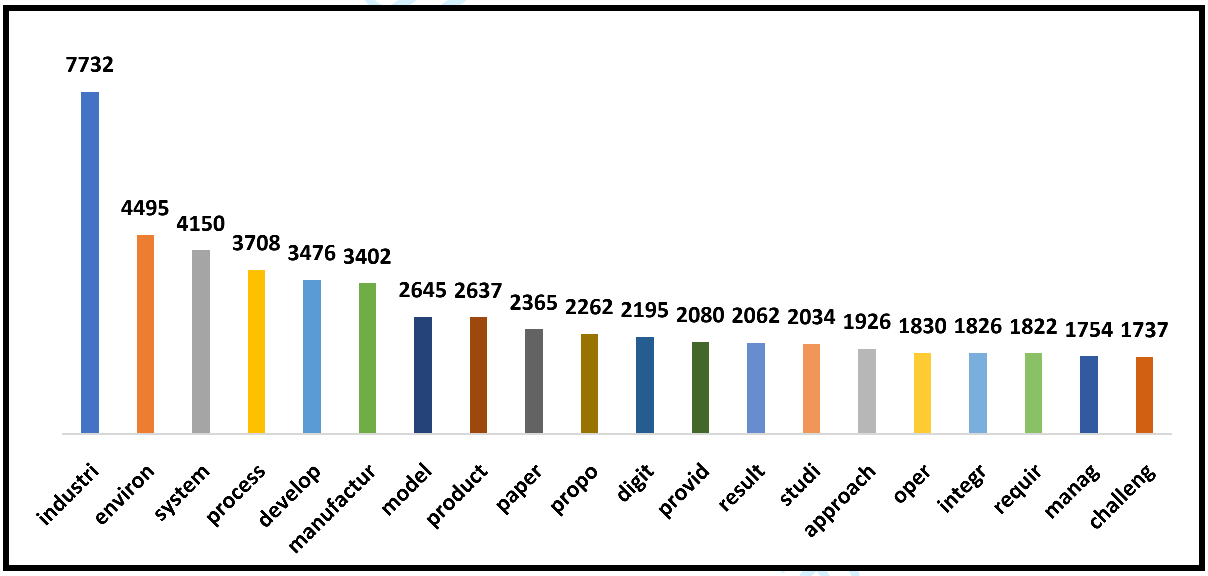

Figure 5: Top 20 Frequent Terms

After calculating the TF-IDF score, the matrix of 19092 terms X 4364 documents has been created. As the data is enormous and it is impossible to represent the data in the document, the top 20 terms have been selected, and the matrix of 20 terms X 4364 documents is shown in Table 4.

Table 4: Representation of 20 terms X 4364 document for TF-IDF Score

Term	**Doc1**	**Doc2**	**Doc3**	**Doc4**	**Doc5**	**Doc6**		**Doc4364**
manufactur	0.0054	0.0034	0.0000	0.0000	0.0177	0.0000	……	0.0084
environ	0.0034	0.0069	0.0069	0.0028	0.0105	0.0000	……	0.0032
industri	0.0015	0.0036	0.0000	0.0025	0.0093	0.0112	……	0.0126
system	0.0049	0.0061	0.0059	0.0041	0.0766	0.0000	……	0.0046

approach	0.0076	0.0000	0.0000	0.0000	0.0000	0.0000	……	0.0000
requir	0.0098	0.0000	0.0000	0.0000	0.0000	0.0000	……	0.0000
paper	0.0041	0.0049	0.0049	0.0034	0.0000	0.0103	……	0.0000
product	0.0093	0.0000	0.0000	0.0000	0.0146	0.0000	……	0.0000
develop	0.0057	0.0000	0.0072	0.0000	0.0000	0.0076	……	0.0057
process	0.0000	0.0032	0.0000	0.0000	0.0000	0.0000	……	0.0064
propo	0.0000	0.0118	0.0073	0.0051	0.0095	0.0000	……	0.0000
oper	0.0000	0.0173	0.0000	0.0000	0.0000	0.0000	……	0.0000
provid	0.0000	0.0108	0.0099	0.0000	0.0000	0.0140	……	0.0000
model	0.0000	0.0072	0.0000	0.0000	0.0000	0.0000	……	0.0000
result	0.0000	0.0152	0.0000	0.0000	0.0000	0.0000	……	0.0000
integr	0.0000	0.0000	0.0000	0.0063	0.0000	0.0000	……	0.0071
manag	0.0000	0.0000	0.0000	0.0000	0.0000	0.0178	……	0.0185
digit	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	……	0.0000
challeng	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	……	0.0138
studi	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	……	0.0201

There are 19092 unique terms identified from the corpus, and the top 20 terms are represented through the matrix. In transformation, the weight is assigned to each term according to its importance in the document. Once the TF-IDF score is calculated based on these scores, making the groups of words is required. Finally, k-Means clustering is implemented on the TF-IDF score to cluster the BOW. There is no such optimal solution provided by previous researchers to find the optimal number of topics from the corpus, but Deerwester (Deerwester et al., 1990) provided facts through which 10 clusters were identified for 4364 documents. The ten clusters identified using K-Means clustering with their high-loading terms are shown in Table 5. These ten clusters are considered the current trends.

Table 5: Ideal Topic Label with High Loading Terms

Cluster	Topic Label	High Loading	Relevant

Value		**Terms**	**Article**
Cluster 1	industry, datum, system, paper, develop, product, technologi, base, manufactur, applic, environ, social, technologus, robot, digit, author, research, engin, specif, manag	State of industry 4.0 in Society	(Carvalho et al., 2020) (Zhang et al., 2021) (Kern & Scholz, 2020)
Cluster 2	industry, environ, digit, base, product, system, us, future, process, technologus, paper, studi, datum, analysi, control, real, power, stakehold, knowledge, research	Industry 4.0 and sustainable Environment	(Konstantinidis et al., 2020) (Basavanna et al., 2021) (Settanni et al., 2018)
Cluster 3	health, Design, service, wast, risk, economi, secur, blockchain, iot, cultur, oee, barrier, capit, lead, growth, measur, ceram, strategi, flexibl, circular, construct, artificial, iot	Industry 4.0 Technologies	(Lüers et al., 2018) (Panda et al., 2020) (Koch et al., 2021)
Cluster 4	product, datum, model, robot, industry, system, technologi, level, determine, inform, path, iot, enterpri, logistic, transform, knowledge, suppl Design, comput, smart, applic, digit, chain	Industry 4.0 for supply chain management	(Trochimczuk et al., 2019) (Tang et al., 2023) (Gazzaneo et al., 2020)
Cluster 5	qual, model, Design, industry, product, datum,	Industry 4.0 and	(Tovar et

	profession, circula, adopt, resource, iot, optim, digit, manufactur, cloud, perform, learn, economi, intellig, factori, system, solute, sensor, process	circular economy	al., 2020) (Zia et al., 2021) (Iradier et al., 2019)
Cluster 6	industry, system, product, manufactur, datum, Design, process, environ, technologus, research, require, public, inform, internet, people, citi, model, learn, paper, busi, train, manag, applic, solute, role	Smart Cities	(Cortés et al., 2020) (Tovar et al., 2020) (Wahler & Oriol, 2014)
Cluster 7	product, industry, digit, model, manag, applic, iot, system, human, chapter, research, studi, datum, smart, inform, right, technologus, engin, process, manufactur, propo, environ	Smart Manufacturing	(Egger et al., 2020) (Eriksson et al., 2021) (Trigo et al., 2021)
Cluster 8	destin, tourism, audit, career, cach, adopt, leadership, poultry, laser, print, bcdt, translat, a-ugv, ammunit, shipbuild, fish, ppc, smme, propuls, item, oil, mcen, reshor, oa, cppss	Sustainable Tourism	(Ramalho et al., 2020) (Grote et al., 2021) (Shubyn et al., 2022)
Cluster 9	model, product, field, real, datum, industry, research, process, simul, network, system, resource, manufactur, robot, applic, social, human, smart, iot, companus	IoT based Smart Applications	(Trigo et al., 2021) (Rädler & Rigger, 2020) (Lundgren

			et al., 2022)
Cluster 10	innov, cloud, rfid, iot, ethic, assembli, energi, perform, safety, space, datum, sensor, data, service, dimen, engin, reader, control, intellig, line, chain, educ, mainten Technologi, digit	RFID and IoT in Smart Healthcare	(Sofiah & Susim, 2020) (Stojanovic et al., 2018) (Kommadi, 2020)

Once the clusters are extracted based on their TF-IDF score ao, they need to be labeled with the help of experts and authors' discussion. Clusters are labeled based on the key terms and against each cluster's high-loading articles provided in Table 2.

5. Research Questions and Discussion

5.1. Research Question 1: What are current research constituents regarding publications, keywords, contributing authors, and their countries?

The descriptive statistics of the articles in the corpus are the primary subject of meta-analysis. Different metadata can be generated for each article, year, subject area, author, etc., since the corpus includes information on Year, Author, Countries, Subject area, etc.

5.1.1. Publications by Year

The first article was published in 2013 on industry 4.0 and environmental sustainability per the data from Scopus. This area increases with time, as represented in Figure 6. The leading publication encountered in 2021 is 998, 22.86% of the total publication. Year-wise analysis shows that industry 4.0 is increased with time, but researchers also relate or raise the issues in terms of environmental sustainability.

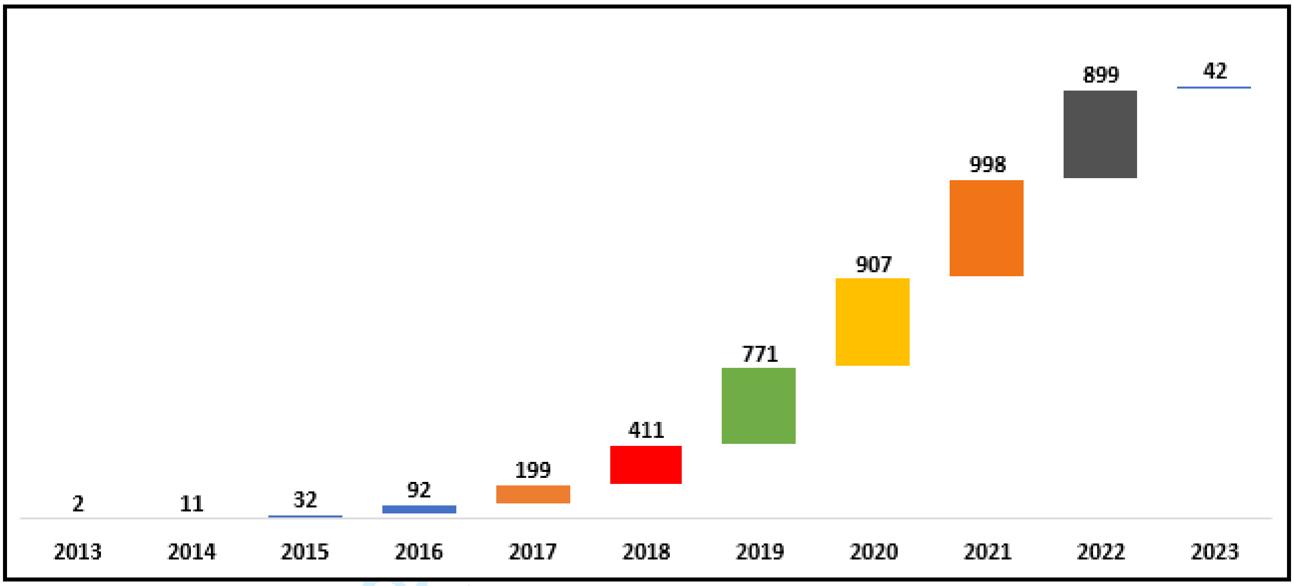

Figure 6: Year-Wise Publication Analysis

5.1.2. Leading Authors

There are 4364 published articles analyzed in this study as it is difficult to discuss every author, so here author detailed the top 10 authors in Table 6. Table 6 includes the author's name and publication with citations according to the considered data.

Table 6: Leading Researchers

Name of Author	Articles	Citation
Rauch e.	25	215
Zharinov i.o.	18	16
Matt d.t.	17	192
Kumar a.	16	303
Mourtzis d.	16	270
Xu x.	16	2084
Li y.	15	156
Shukalov a.v.	15	16
Liu y.	14	430
Chen y.	13	100

Author Erwin Rauch is affiliated with Industrial Engineering and Automation (IEA), the Free University of Bozen-Bolzano, Piazza Università 1, Bolzano, Italy. In the considered data, he has 25 documents which are 0.5% of contribution and a citation of 215, but on Google scholar, the author has 4495 and 37 H-Index as of December 2022. Igor O. Zharinov, Faculty of Information Security and Computer Technologies, ITMO University, Kronverksky Av., Saint Petersburg, 197101, Russia, leads the board after Erwin Rauch with 18 articles and 16 citations. On the other hand, based on citation, author Xun Xu, Department of Mechanical Engineering, The University of Auckland, New Zealand, is leading with 2084 citations and 16 articles, but on Google Scholar author has 20961 citations and 71 H-index.

5.1.3. Publications by Journals

Journals are essential in publishing the articles, so the top 10 journals are represented in Figure 7. Procedia Manufacturing is leading the board with the highest publication (114), which is 2.6% of the contribution. The journal has the 55 H-Index, but unfortunately, the journal will be discontinued in 2022. Procedia Computer Science has 111 articles published, 2.5% of the contribution. The journal's h-Index is 92, and 3.6 is its cite score.

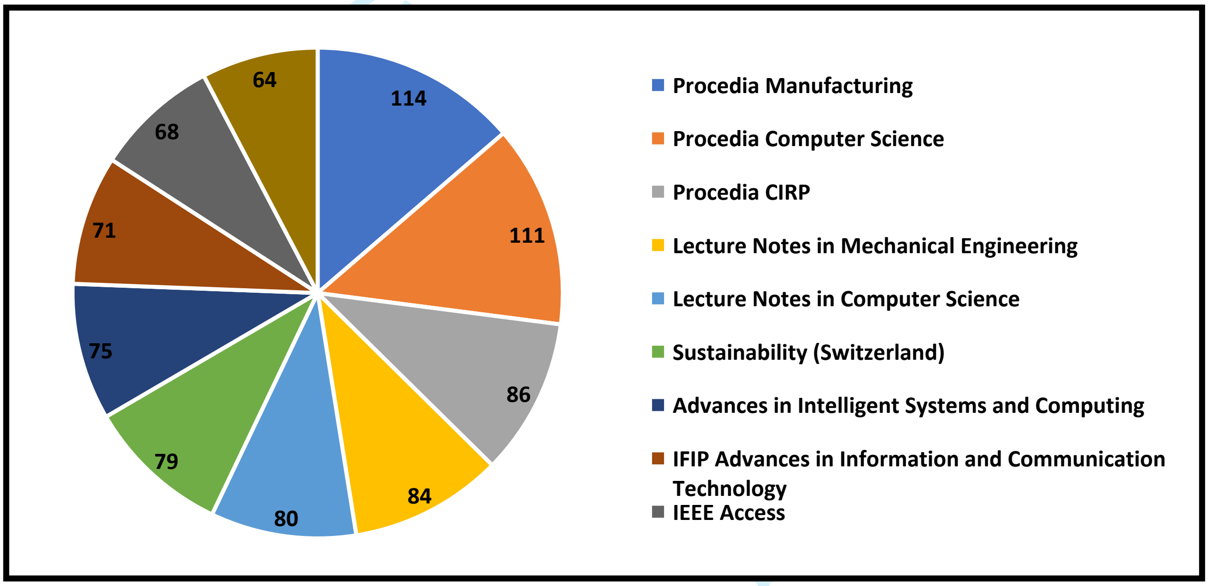

Figure 7: Leading Journals

5.1.4. Network Analysis

Network analysis represents the network between the authors, countries, institutes, keywords, etc., so the author used the Vosviewer tool in this study to present various network analyses of the corpus (Morel et al., 2009). Firstly the coauthorship analysis is given in Figure 8, which shows the link between the leading authors and their networks. Each node color represents one network of authors.

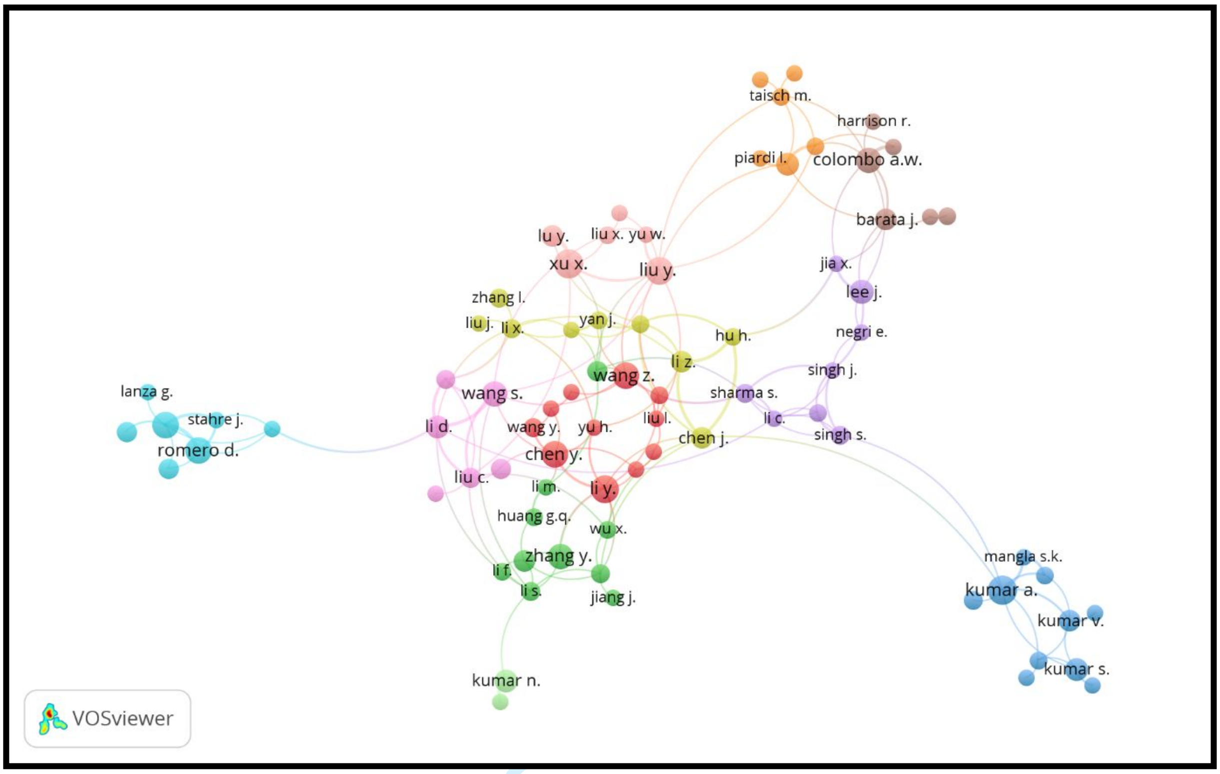

Figure 8: Researcher Network

The author's coauthorship network analysis shows that Erwin Rauch from Itlay is the leading author having 25 publications with 215 citations. His link strength with other authors is 14. Zharinov i.o.is at number 2 on the publication board, with 18 articles having 16 citations. His link strength with other authors is 9. Regarding citations, Xun Xu from New Zealand leads the board with 16 articles and 2084 citations. The author's link strength with other authors is 80. Author Ju Yeon Lee from South Korea is behind Xun Xu with 11 articles and 1546 citations.

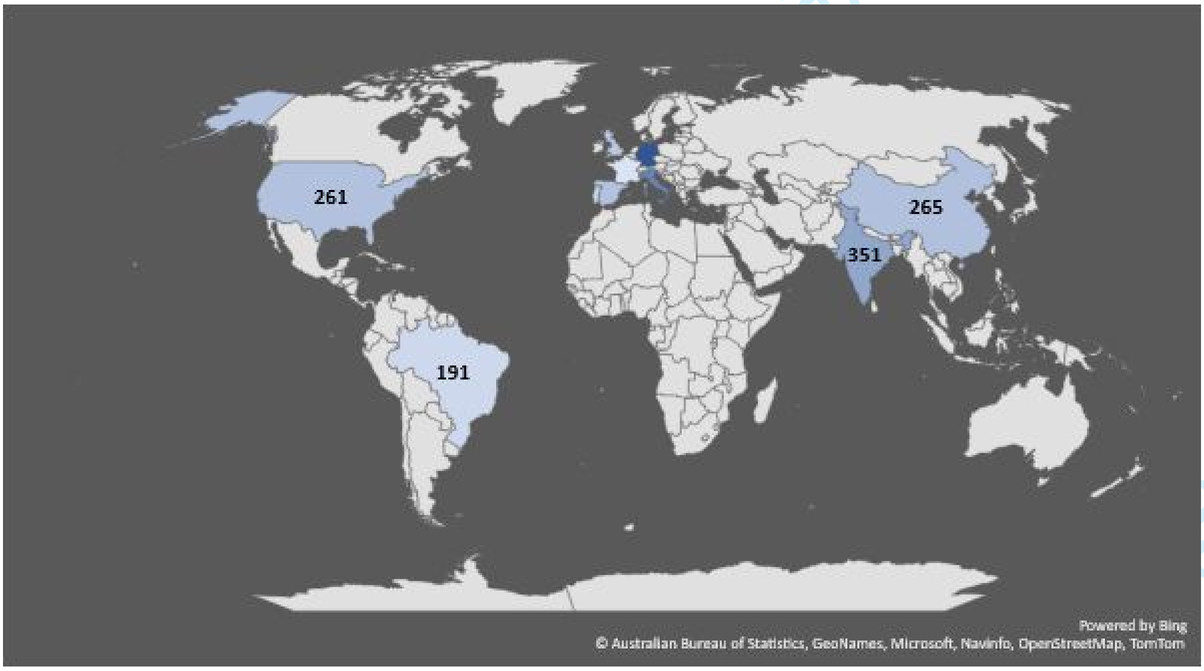

Figure 9: Ten Leading Countries with Article Count

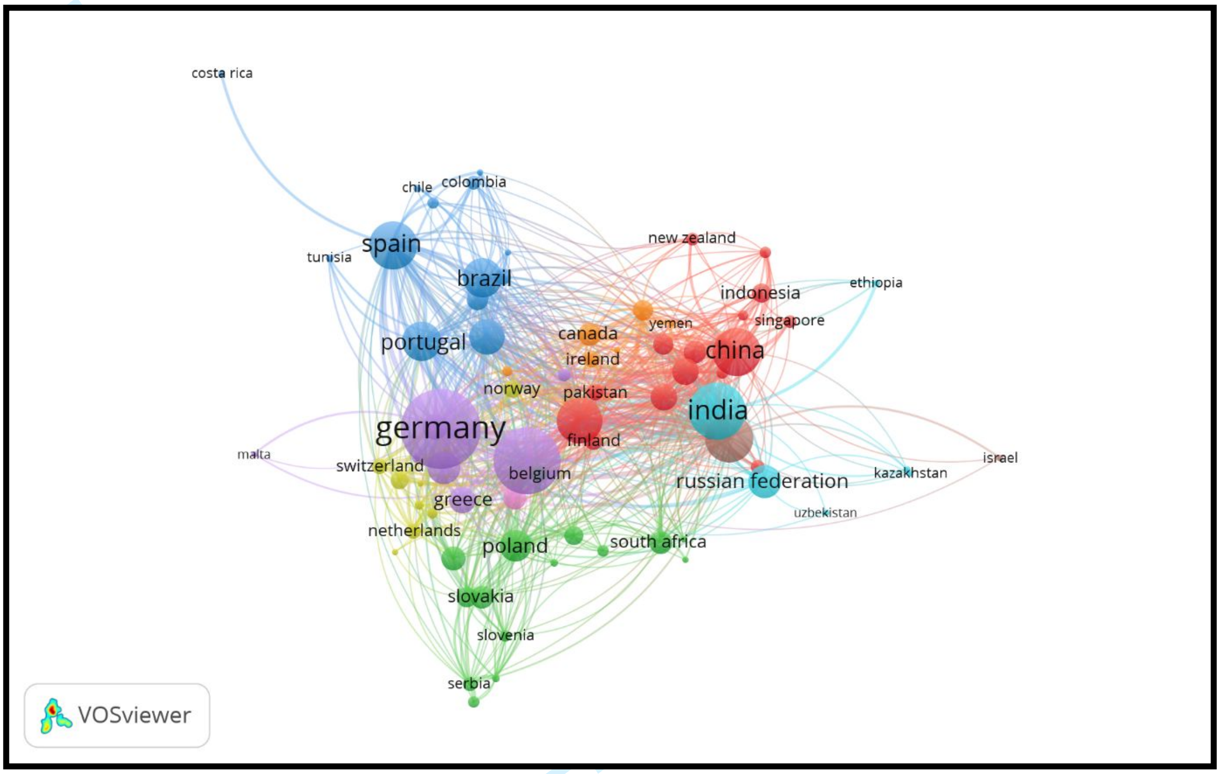

Figure 10: Countries Network

The leading countries contributing to environmental sustainability in industry 4.0 are represented in Figure 9. The network between the countries is shown in Figure 10. The analysis indicates that Germany leads the board with 606 documents and 9035 citations of these articles. Italy is following Germany with 462 and 5237 citations. India is in the third position with 351 and 4320 citations. This shows that Germany is leading in terms of the document count. However, regarding citations, Germany is leading with 9035 citations, the United Kingdom is in 2nd position with 6008 citations, and the United States is in the third position with 5686 citations.

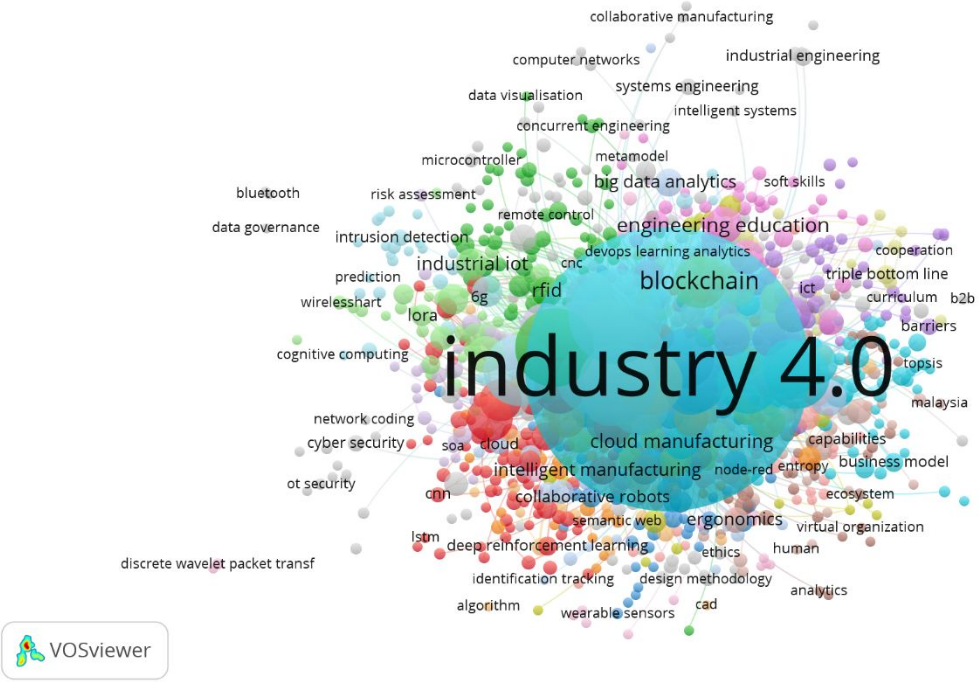

Figure 11: Network Analysis of Keywords

Keywords play a critical role when research is discussed, so authors provide the keyword analysis represented in Figure 11 and Figure 12. In Figure 11 relationship among the various keywords is described, and analysis shows that industry 4.0 is the leading keyword, and it occurs 2207 times in the corpus. Figure 12 is the cloud analysis of the keywords, highlighting the keywords with many occurrences. The analysis represents that “industry 4.0”, “internet of things”, and “digital twin” are the author keyword which has the highest number of occurrences, 2207, 250, and 173, respectively. The link strength represents the relationship between the author's keywords, so “industry 4.0” has a link strength of 4680, 666 for “internet of things and 464 for “digital twin”. On the other hand, some authors' keywords like adaptive control, wirelesshart, and industrial revolution 4.0 have low occurrence and minimum link strength.

Figure 12: Word Cloud based on Frequency of Words in BOW

5.2. Research Question 2: How did the industrial revolution affect Environmental Sustainability?

The results of the Industrial Revolution were far-reaching and beneficial. However, destroying local ecosystems was one of the significant drawbacks of industrialization. Oil and trash clogged U.S. waterways, and the air in industrial areas became thick with pollution as natural resources were used up (Felsberger et al., 2022). As industrialization progressed after the Industrial Revolution, so did evidence of its damaging environmental effects. The globe has experienced several ecological catastrophes due to the rapid rise of urbanization and the pollution brought on by the industrial revolution. During the early stages of the Industrial Revolution, it wasn't easy to see how the pollutants would eventually affect the environment (Jiang et al., 2022). Following the second Industrial Revolution, it became clear that industrialization had several adverse effects on the surrounding ecosystem. In the 1980s, scientists concluded that the ozone layer had been damaged, which served as the planet's natural defense against ultraviolet radiation (Vasileva-Tcankova, 2022).

Industrial cities were engulfed in a blanket of pollution caused by factory haze. Consequently, many people developed respiratory diseases, while wildlife suffered damage. The impact of industrialization on water systems led to increased water quality issues. Untreated sewage, waste, oil, and other forms of junk pollute water supplies (Khan et al., 2022). The first indications of deteriorating water quality occurred in the second half of the nineteenth century. The release of harmful chemicals into rivers, streams, lakes, and oceans caused widespread illness and disease epidemics. Waterways are essential to the health of ecosystems, which are home to numerous animal species and provide them with food. Due to exposure to oil spills and other poisons in these oceans, numerous marine creatures perished. Coal was an essential resource in the early days of industrialization (Thanigaivel et al., 2022). As soon as the commercial coal mining sector began to take off in the 19th century, the technologies used to heat homes, make iron, and newer, more efficient methods quickly supplanted power factories. In the past, wood charcoal was required to produce iron, and wood fires were used to generate heat for homes and power for industries dependent on water flow. As the coal mining industry expanded, these other resources were gradually phased out and replaced by coal (C. Wang & Cheng, 2023)—an increase in consumer demand for these goods brought on the overexploitation of coal and other natural resources. Because it was commonly used in the workplace and private homes, it significantly contributed to the air pollution plaguing industrial cities. Incorrect mining techniques were also responsible for releasing potentially harmful compounds into the oceans in the area. It began a careless and wasteful lifestyle that would have long-lasting effects on the natural world. Human migration and settlement altered landscapes and local fauna as people relocated to other parts of the globe. Most of the world's population lacked advanced infrastructure until the start of the industrial revolution in the 19th century. There was a rise in mobility as a result of the Industrial Revolution. As a direct result of the increase in population, urban areas, including suburbs, villages, and cities, were increased.

Even though the population and the use of resources are growing exponentially, there is still ignorance towards technology (Industry 4.0) that can help us regulate the situation at a meaningful rate and promote sustainability. People have prioritized making a profit over considering how their actions may impact others or the environment. Concentrating on simply one of sustainability's three bottom lines is ineffective. Industry 4.0 is a potent tool that may be used to eliminate barriers; nevertheless, poor integration may have catastrophic outcomes (Han et al., 2022). However, it can be utilized to eliminate the difficulties if it is not correctly implemented. This innovative industrial model is recognized for its virtual and digital placement and excellent technological standing. The technologies that are now in use in Industry 4.0 are not necessarily brand new; what is revolutionary is the integration of various technologies, which enables the industry to behave dynamically and respond swiftly to the needs of the internal and external environment (Eswaran & Bahubalendruni, 2022). These technologies make it possible to conduct leaner and more efficient production processes. The technologies, as mentioned earlier, which are a part of the fourth industrial revolution, will serve as pillars for the fourth generation of environmental management. The technological potential of the new industrial model contributes to the sustainability of Industry 4.0. This is primarily because Industry 4.0 is a new industrial model (Mourtzis et al., 2022). The combined use of these technologies improves the efficiency with which environmental management can be conducted and the industrial activity itself. Their production process is enhanced when virtualized, streamlined, manufactured precisely when required, and produced on demand (Corallo et al., 2023).

5.3. **Research Question 3:** What are the future aspects of Industry 4.0 leading to the next revolution, 5.0?

The objective of Industry 4.0 is to acquire the crucial insights and knowledge required to make manufacturing processes more efficient than they were in the past. Industry 4.0, the Fourth Industrial Revolution, has allowed us to alter the structure of the globally networked market over the previous decade. The tools and technology that enable us to rapidly adapt and respond to fluctuations in market demand are driving the sector to rely less on traditional mass manufacturing techniques (Aoun et al., 2021). Human labor and animal traction became obsolete during the industrial revolution. At the same time, innovative work methods emerged, permitting employees to complete their jobs in less time on the clock (Sloane & Zakrzewski, 2022). Worker incomes rose as a result. It is essential to remember that this new government did not come into being overnight but rather represented the conclusion of a protracted and notorious process that amounted to more than a revolution. Industry 4.0 is, in a nutshell, the use of cutting-edge technologies like artificial intelligence (AI), robotics, quantum computing, additive manufacturing, and the Internet of Things (IoT) in traditional production methods. Industry 4.0 and other ideas about smart manufacturing are becoming more and more critical in all areas of research and development (Heidari et al., 2022). Industry 4.0 allows focusing on essential functional pillars like technological progress, integration and collaboration, and process optimization. These megatrends include the cloud, big data, and cyber security (Sajadieh et al., 2022). They are expected to play a big part in making smart manufacturing a reality (Bhatia & Kumar, 2022). For autonomous solutions to work, there needs to be a dynamic interaction between technologies, ecosystems, and business models that work together and complement each other (Kohtamäki et al., 2022). So that short-term needs can be met without sacrificing long-term goals, a plan that can be carried out must be made and followed.

It would appear that no obstacles are standing in the way of developing Industry 4.0. It may anticipate a quick acceleration in the growth and refining of autonomous and intelligent methods for interfacing with various systems and tools in the future (Mourtzis et al., 2022). Businesses will have access to an endless supply of actionable insights about their operations for as long as data-gathering technologies exist (Sunder M. et al., 2023). These conclusions can be deduced from the data if one looks closely enough (Madhav & Tyagi, 2022). The concept of intelligent robots working side by side with people in the workplace is what is meant to be referred to by the term "Industry 5.0." It investigates how humans could benefit from the assistance of robots in completing complex tasks with greater ease and accuracy by utilizing the expertise and access to cutting-edge technology that currently exists among people. A new focus on the person is one of the hallmarks of the fourth industrial revolution, which also ushers in increased productivity and the accumulation of more data (Leng et al., 2022). Because it follows closely on the heels of the two most recent industrial revolutions, "Industry 5.0" is notoriously difficult to characterize. Anyone thinking about transitioning to the practices of Industry 5.0 should first investigate the compatibility of these methods with the instruments and ideas of earlier revolutions (Maddikunta et al., 2022). Since the introduction of automation and AI, there has been a growing fear that computers could one day substitute trustworthy humans in the workforce. This anxiety has been compounded by the fact that automation and AI are becoming more widespread. Recently, there has been a rise in this problem. As described in the blog article titled "How to Build Manufacturing Skills in the Face of Automation," Industry 5.0 is not to eliminate the need for humans and replace them with robots. There will be no need for any of the four prior industrial revolutions to make room for the fifth industrial revolution. Consider the frequency with which people still bring up the rapidly expanding use of automation in conversation. Since approximately fifty years ago, this has been happening regularly. In addition, standard instruments used during the start of the industrial revolution, such as lathes and milling machines, are still utilized in modern manufacturing, albeit in conjunction with more sophisticated processes and technical advancements.

6. Implications

Industry 4.0's goal is to keep developing due to various factors such as location, the availability of technical employees, staff opposition to the 4.0, and the backing of all stakeholders. A large part of this technology is devoted to improving the efficiency of processes by equipping machines with a wide range of sensors that allow them to communicate with one another. With the help of AI and cloud computing, the concept of automation is disseminated across the economy and refined. Recent technological advances will increase industrial facilities' productivity and efficiency by over 15% (Rüßmann et al., 2015). As a result, workers' and those businesses' earnings become more marketable to employers. The study aims to learn how Industry 4.0 will affect economic, industrial, and ecological sustainability. Both managers and politicians can utilize the results to determine which technologies should be adopted or encouraged through policy initiatives and which sustainability priorities should be prioritized. This is why economic, environmental, and social sustainability factors are considered. Sustainable development and mitigating the adverse effects of industrialization on the environment appear to be receiving increased focus from industry experts, researchers, and academicians (Sartal et al., 2020). The global impact of the industry's supply networks, goods, and processes on sustainability means this focus will only grow (Ali et al., 2021). Understanding the difficulties of achieving the Paris Agreement's environmental goals can be aided by studying the Industrial Revolution and Environmental Sustainability. Significant technological improvements by the Industrial Revolution have tremendously boosted human productivity and quality of life and devastated the environment. The causes of today's environmental problems and viable solutions to those problems can be better understood by looking back at the Industrial Revolution. Likewise, we can learn valuable lessons about approaching sustainability in the present by looking back at the technological, economic, and social transformations during the Industrial Revolution. That policy interventions are crucial is another valuable lesson. Government regulations during the Industrial Revolution were crucial in guiding industry growth and softening its toll on the environment. Carbon pricing, renewable energy mandates, and limits on polluting sectors are just a few examples of the policies we need now to help us shift to a more sustainable economy.

Studying the Industrial Revolution and Environmental Sustainability can provide helpful information for formulating public policy about creating environmentally friendly technologies. The following are a few ways such studies can help understand the relationship between economic growth and environmental protection, recognize effective policies, and find areas for improvement. The Industrial Revolution was a period of considerable innovation, and governments should draw lessons from this time to encourage the development of environmentally friendly technologies. Furthermore, by providing incentives for research and development, policymakers can encourage the development of new technologies that are both commercially viable and environmentally friendly.

7. Conclusion and future research agenda

The environmental devastation caused by the industrial revolution cannot be eradicated. Still, its lingering impacts on our world may be observed in our reliance on machinery and technology, which are the leading contributors to pollution and climate change. Therefore, the need for research in these areas becomes more vital. Environmentally friendly practices are at a crossroads in the future. The possibilities and realities of achieving sustainability have never been greater, nor have the obstacles been more significant. The 2020s have been identified as a pivotal decade for establishing and institutionalizing environmental sustainability and minimizing the escalating concerns of climate change, biodiversity loss, environmental pollution, and disease outbreaks. This is because the 2020s are expected to be the decade in which most of the world's population will be alive. The literature on environmental sustainability and industrial revolutions contains many increasingly complicated and linked topics. Once-obscure subfields have grown into thriving academic communities and more varied research and engagement contexts. This expansion is expected as the field develops; however, it raises the question of what constitutes the core of environmental sustainability research and what should be the emphasis of future work in this area. Although this expansion is expected, it raises the question of what should be the focus of future work in this area. This research investigates ten essential research areas that need more attention shortly. The Industrial Revolution had a profound impact on both human civilization and the natural world. While it did result in significant economic development and scientific improvement, it also caused extensive pollution and environmental degradation. Our current understanding and attitude to environmental issues owe a great lot to the effects of the Industrial Revolution on environmental sustainability. Climate change, loss of natural resources, stricter environmental legislation, and sustainable development are only a few of the significant environmental concerns resulting from the Industrial Revolution.

Moreover, three research questions are answered based on these research areas. These three questions move around the current research constituents, the impact of the industrial revolution on Environmental Sustainability, and prospects in this field. The limitation of the current study may be compromised, notwithstanding the size of the sample used. Poor retrieval of the literature corpus can be attributed to the limitations imposed by the search words, synonyms, string construction, and variety of search engines used, as well as to the accurate exclusion of results for which the search string is insufficient. Articles' usefulness is rated in two stages. Initially, it's important to note that keywords and search strings may rule out relevant functional research. As a next step, authors used those terms to determine how best to categorize our topics for scholars and practitioners. As data is increasing daily, authors may include more data and compare more techniques in the future.

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