Sustainable Marine Structures
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REVIEW ARTICLE

Knowledge Maps from Scientometric Review on Composite Marine Risers

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ABSTRACT

With the increasing exploration of oil and gas into deep waters, the necessity for material development increases for lighter conduits such as composite marine risers, in the oil and gas industry. To understand the research knowledge on this novel area, there is a need to have a bibliometric analysis on composite marine risers. A research methodology was developed whereby the data retrieval was from SCOPUS database from 1977–2023.

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ARTICLE INFO
Received: 9 January 2025 | Revised: 12 February 2025 | Accepted: 25 February 2025 | Published Online: 4 March 2025
DOI: https://doi.org/10.36956/sms.v7i1.1067

CITATION
Amaechi, C.V., Reda, A., Beddu, S.B., et al., 2025. Knowledge Maps from Scientometric Review on Composite Marine Risers. Sustainable Marine Structures. 7(1): 1–20. DOI: https://doi.org/10.36956/sms.v7i1.1067

Then, VOSviewer was used to visualize the knowledge maps. This study focuses on the progress made by conducting knowledge mapping and scientometric review on composite marine risers. This scientometric analysis on the subject shows current advances, geographical activities by countries, authorship records, collaborations, funders, affiliations, co-occurrences, and future research areas. It was observed that the research trends recorded the highest publication volume in the U.S.A., but less cluster affiliated, as it was followed by countries like the U.K., China, Nigeria, Australia and Singapore. Also, this field has more conference papers than journal papers due to the challenge of adaptability, acceptance, qualification, and application of composite marine risers in the marine industry. Hence, there is a need for more collaborations on composite marine risers and more funding to enhance the research trend.

Keywords: Composite Risers; Marine Risers; Marine Structure; Scientometric Review; Bibliometric Analysis; Composite Material; Knowledge Map

1. Introduction

Over the past few years, there have been major developments in research regarding marine risers and drill strings, which play an essential part in the production of oil and gas offshore installations [1, 2]. Various scholars have reported that marine risers have great importance but also with issues related to vortex-induced vibration (VIV) [3, 4], fatigue performance [5–7], composite riser on offshore platform [8, 9], composite riser testing [10, 11], and weight ratio [12–14] as such the need for lighter conduits, like composite marine risers. Composite marine risers are tubular constructions that connect offshore platforms to subsea wells [6, 7, 15, 16]. On the other hand, in comparison to typical steel risers, composite marine risers offer significant advantages as floating platforms require less platform loads [2, 17–19]. Due to the increased resistance of composites to fatigue and corrosion, as well as their reduced weight, they are particularly appealing for applications that take place in severe environments and deep aquatic environments. With the increasing intensity of research and development efforts, it is becoming increasingly important to have a full awareness of the existing knowledge environment to make future breakthroughs on composite risers [16, 20–23]. In the past 20 years, there has been a significant rise in the interest in hybrid polymers. This has resulted in the creation of a wealth of information that may be utilised by companies involved in design as well as relevant enterprises. The development of materials for composite manufacturing is still evolving. It offers unique applications that have been utilised within the oil and gas industry such as composite marine risers [24–28]. The latter development is characterised by an increase in material development for offshore composites. Also, there is an increased demand for energy derived from fossil fuels, which has resulted in an increase in the activities of exploration, drilling, and production within the oil and gas industry [3, 4, 29–31]. In general, marine risers can be engineered in such a way that they can have a variety of configurations, as shown in **Figure 1**.

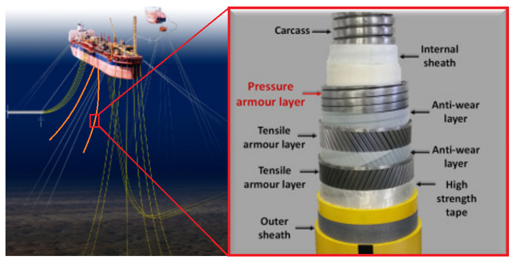

Figure 1. A typical application with arrangement of FPSO with marine risers can be engineered in such with a variety of configuration and showing different layers of the flexible marine riser.

In addition, these activities have resulted in the invention of novel processes, technologies, and materials [32–35]. Additionally, they have led to novel modifications in a variety of fields. In the latter scenario, some materials, such as high-grade steel, have been utilised over the course of time in a variety of offshore constructions. These materials used on the marine risers are characterised by their high reliability along with extended lifespan [12, 13, 36–39]. Conversely, in order to lessen the weight of offshore structures such as deck loads, there has been a surge in utilising marine composites in establishing components such as marine risers [14, 40–43]. The technologies called SURF (subsea umbilicals, risers, and flowlines), have been identified as conduits that provide several advantages in the field of ocean engineering such as excellent resistance to harsh marine environment [36, 44–46]. As a result, in both the business world and the academic world, there is a growing amount of research being conducted on composite risers for use in deep waters. On the academic aspect, there are increasing studies on composite risers covering both research [8–14, 19, 24–27, 31] and reviews [1, 19, 23, 32–35], but there is the need for further work on composite risers using research approaches like scientometrics to identify the gaps in the research [1, 47–55]. The recent study of Amaechi et al. [1] was undertaken using bibliometrics and meta-analysis to identify the research trend on composite marine risers. However, that study had gaps in literature necessitating the present paper, including the knowledge maps, visualisation plots, keywords analysis, word cloud and emerging trends on composite marine risers. On the business aspect, composite marine risers are a unique application of hybrid polymer composites that are utilised in the process of developing marine risers for offshore platforms in the oil and gas sector. When compared to the size of the marine industry, offshore composites are not nearly as widespread as they possibly should be. Whilst there is an expanding consumer and commercial interest in employing composites as a replacement to steel in an array of technical designs, there is still a significant distance to go in the field. Composites are already being used in several engineering designs. In the present day, composites are utilised for a variety of purposes, including industrial, aviation, maritime, and domestic/household applications. Tubulars, such as composite marine risers and composite marine hoses, are examples of places where these applications can be found. Composite risers, which are a subsea riser type, provide the offshore industry with a variety of uses and advantages that are unique to themselves. Both drilling and production are processes that require transporting oil products from oil wells to subsea pipelines and marine risers. Several advantages, such as low weight and cost savings, have been demonstrated by studies that composite risers have gains in weight reduction [1, 36, 44–46]. Composite risers offer a number of advantages. Due to this need, these marine risers need to be constructed with great precision, taking into consideration aspects such as safe operation and resistance to corrosion, in addition to deep water settings. In order to facilitate the movement of fluids on oil platforms, multi-layered conduits such as marine risers have been developed.

In this work, knowledge maps were presented from a scientometric review on composite marine risers. These maps were developed using a novel tool together via a visualisation mapping approach. In Section 1, an introduction to this research was offered, and the methodology of the research was presented in Section 2 using data from Scopus. Following that, the scientometric study on composite marine risers is performed in order to carry out an initial analysis based on the contents of the reviewed publications, as presented in Section 3. In Section 4, the emerging trends on this area are given whilst Section 5 draws conclusions on the investigation.

2. Methods and Materials

In this section, the materials used and the approach taken for the data analysis of the study are detailed.

2.1. Research Methodology

To address the research methodology, some understanding of the research framework, as shown in **Figure 2** which was considered as well as the research questions addressed is necessary. The research questions addressed in this investigation include:

- What are the current trends in research on composite risers?
- What types of partnerships have been established in developing composite risers, and where?
- What knowledge maps can be obtained from the scientometric review on composite marine risers?

Within the scope of this systematic review, the publications evaluated were limited to empirical research, theoretical analyses, and advancements deemed state-of-the-art. The selected articles for investigation were required to meet the following criteria: (a) a clearly defined methodology; (b) specified outcomes; and (c) an interpretation that includes explanations of the research limitations. In the process, the conceptual papers were required to meet several prerequisites, including: (a) an organized benchmark selection process; (b) a properly established timeline; and (c) an analytical procedure that involved a critical review. Details on the inclusion/exclusion criteria used is available in recent meta-analysis study conducted on composite risers [1]. The findings from the various publications reviewed showed that there are advances made in composite risers. A concise visual documentation of selected papers was created, encompassing research publications, attribution data, co-authorship, and publication year. Additionally, this tabulated bibliography featured a thematic classification of key components. Lastly, the research methodology also included the exclusion of resources that were deemed superfluous. As depicted in **Figure 3**, the methodology for the scientometric review involved the use of an online academic database to extract data relevant to the topic area.

Figure 2. Research framework for the scientometric review on Composite Risers.

2.2. Article Synthesis

The selection process for scholarly articles is a crucial component of the meta-scientific analysis conducted in this literature review. A primary goal of this review is to uncover research threads, trends, and advancements related to composite risers. To this end, a public database named Scopus, accessed via Lancaster University UK, was utilized, as illustrated in **Figure 4**. A total of 139 publications with the term "composite risers" and 576 publications with the keywords 'composite AND risers' were included in the scientometric analysis. This selection was made after careful consideration and exclusion of irrelevant material to ensure the data's relevance to the study's focus on composite risers. The Scopus database was utilized, with descriptors in the English language. All articles included in the review were in English, as non-English papers were excluded. Keywords were sourced from internet search engines, with "composite risers" being the primary focus of the research. However, comparisons were also drawn with "marine risers" and "steel risers" to ascertain developmental trends in other types of marine risers relative to composite risers.

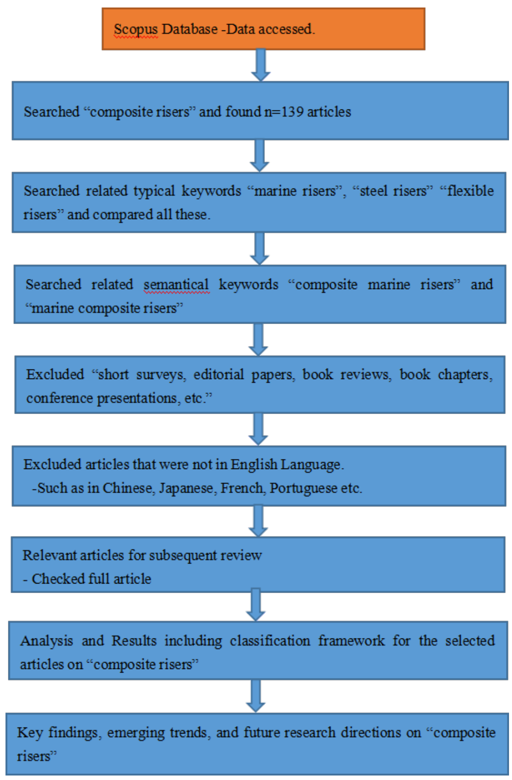

Figure 3. Research methodology for the scientometric review on composite risers.

2.3. Scientometric Analysis' Tools

Regarding this research, the scientometric review utilized data retrieved from Scopus. This data underwent further post-processing, incorporating specific variables and networks, and was then exported. The visualization for the knowledge maps was created using VOSviewer, which is well-validated for scientometric studies [47–50]. The model was designed with a resolution of 1.0, applying various normalization methods through VOSviewer [51–55]. The outcomes of the scientometric analysis are detailed in Section 3. The study developed both the keywords co-occurrence network and the co-citation network, as they appeared in publications, using the extrapolated data.

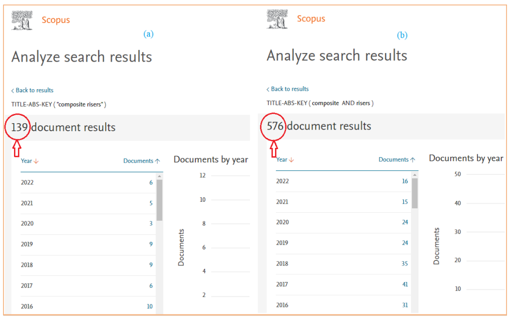

Figure 4. Scopus database screenshots on the keyword "composite riser", showing (**a**) 139 publications using "composite risers" and (**b**) 576 publications using 'composite AND risers'.

3. Scientometric Review and Visualization Mapping

The scientometric review and visualization mapping of composite risers are presented in this section, utilizing VOSviewer for the knowledge mapping and data sourced from the Scopus database.

3.1. Mapped Network by All Keywords

The post-processed analysis of the keyword-mapped network was performed using VOSviewer. The analysis employed the full counting method for co-occurrence. Three main types of keyword analysis were conducted: all keywords, author keywords, and index keywords. For this section's investigation, "all keywords" were used to extract data from the Scopus database. A total of 1,091 different keywords related to "composite risers" research were identified. The initial analysis determined the minimum number of keyword re-occurrences. The thresholds were set as follows:

- 5 keywords: 59 keywords met the threshold.
- 4 keywords: 86 keywords met the threshold.
- 3 keywords: 145 keywords met the threshold.
- 2 keywords: 282 keywords met the threshold.

For the 282 keywords with at least two occurrences, the total strength of the co-occurrence links with other keywords was calculated. The mapped network was then developed by selecting the keywords with the highest total link strength, as illustrated in **Figures 5** and **6**.

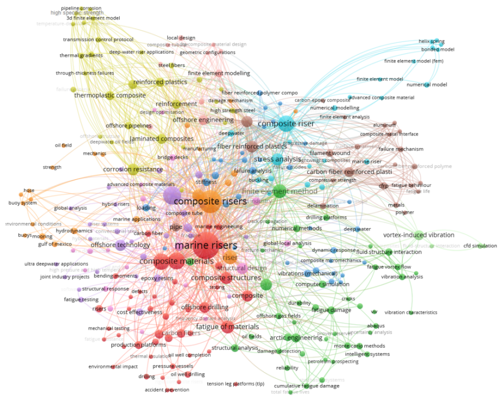

Figure 5. Mapping of all keywords on "composite risers" research showing the network visualization. It was generated using the VOSviewer tool.

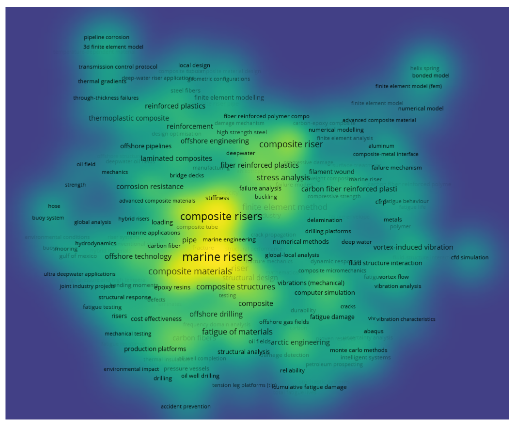

Figure 6. Mapping of all keywords on "composite risers" research showing the density visualization. It was generated using the VOSviewer tool.

Further analysis disregarded smaller data sets, leading to the generation of 11 clusters, although some contained only a small number of items. The clusters are as follows:

- Cluster 1: 46 items
- Cluster 2: 43 items
- Cluster 3: 33 items
- Cluster 4: 29 items
- Cluster 5: 29 items
- Cluster 6: 23 items
- Cluster 7: 23 items
- Cluster 8: 23 items
- Cluster 9: 19 items
- Cluster 10: 10 items
- Cluster 11: 4 item

The most dominant cluster, Cluster 1, is represented by an ox-blood red node for 'marine risers' in **Figure 5**, with 246 links, 69 occurrences, and a total link strength of 681. Following this is Cluster 7, the orange node for 'composite risers' in **Figure 5**, with 225 links, 48 occurrences, and a total link strength of 529. Cluster 6, depicted as a sky-blue node for 'composite riser' in **Figure 5**, has 159 links, 25 occurrences, and a total link strength of 305. This indicates a higher volume of research publications on marine risers compared to composite risers. Cluster 3, a red node in **Figure 5**, represents 'composite materials', while Cluster 5, a purple node for 'offshore oil well production', has 181 links, 31 occurrences, and a total link strength of 365. Cluster 1 also signifies 'composite structures', with 74 links, 14 occurrences, and a total link strength of 114. Keywords with fewer linkages include 'accident prevention', 'vibration characteristics', 'oil field', 'tension leg platform', among others. The keyword occurrences are fully displayed using the density visualization in **Figure 6**.

3.2. Mapped Network by Author Keywords

The post-processed analysis of the keyword-mapped network was conducted using VOSviewer. This analysis, based on co-occurrence and employing the full counting method, focused on author keywords. From the Scopus database, 202 author keywords associated with "composite risers" research were identified. The initial data analysis established the minimum number of keyword re-occurrences required. The thresholds were set as follows:

- 5 keywords: 6 out of 202 keywords met the threshold.
- 4 keywords: 7 keywords met the threshold.
- 3 keywords: 18 keywords met the threshold.
- 2 keywords: 49 keywords met the threshold.

For keywords with at least two occurrences, the total strength of the co-occurrence links with other keywords was calculated. The mapped network was then developed by selecting the keywords with the highest total link strength, as depicted in **Figure 7**.

Further analysis was conducted by ignoring smaller data sets as they were used to generate 7 clusters, but some were also small quantities. Cluster 1 had 10 items, cluster 2 had 9 items, cluster 3 had 7 items, cluster 4 had 7 items, cluster 5 had 5 items, cluster 6 had 4 items, and cluster 7 had 2 items. The most dominant cluster is cluster 7 which is seen as the node with orange colour representing the research on 'composite riser' in **Figure 7**. It has 36 links, 24 occurrences and a total link strength of 76. The next dominant cluster is cluster 3 which is seen as the blue node representing 'offshore engineering' in **Figure 7**. It has 10 links, 7 occurrences and a total link strength of 26. The next dominant cluster is cluster 4 which is seen as the yellow node representing 'numerical modelling' in **Figure 7**. It has 8 links, 3 occurrences and a total link strength of 10. This shows that there are more research publications on marine risers than on composite risers. The fourth cluster is cluster 3 which is a red node in **Figure 7** for 'finite element modelling'. It is represented with 7 links, 5 occurrences and a total link strength of 19. Cluster 2 representing 'stress analysis' is represented with a purple node with 9 links, 3 occurrences and a total link strength of 17. Cluster 1 representing 'marine riser' is represented with a red node with 3 links, 3 occurrences and a total link strength of 3. Some other author keywords, such as 'mechanics,' had the least linkages. A full display of the occurrence of the keyword can be visualised using the density visualization in **Figure 8**.

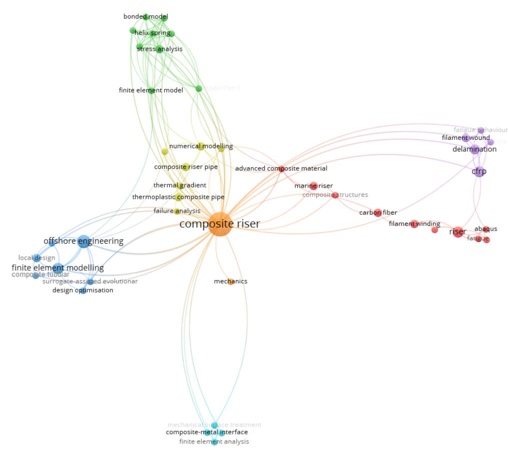

Figure 7. Mapping of author keywords on "composite risers" research showing the network visualization. It was generated using the VOSviewer tool.

3.3. Mapped Network by Index Keywords

The post-processed analysis of the mapped network by keywords was carried out using VOSviewer. The analysis was conducted by co-occurrence via the full counting method for these different keywords that were identified as index keywords. From the data retrieved from the Scopus database, there are 977 index keywords on "composite risers" research. The data was first analysed to determine the minimum number of times that each keyword appeared. Using 28–31 keywords as the minimum limits, 3 keywords met the threshold. Using 26–27 keywords as minimum limits, 4 keywords met the threshold. Using 19–25 keywords as the minimum limits, 5 keywords met the threshold. Using 17–18 keywords as the minimum limits, 7 keywords met the threshold. Using 15–16 keywords as the minimum limits, 8 keywords met the threshold. Using 14 keywords as the minimum limits, 9 keywords met the threshold. Using 13 keywords as the minimum limits, 12 keywords met the threshold. Using 12 keywords as the minimum limits, 17 keywords met the threshold. Using 10–11 keywords as the minimum limits, 19 keywords met the threshold. Using 9 keywords as the minimum limits, 21 keywords met the threshold. Using 8 keywords as the minimum limits, 27 keywords met the threshold. Using 7 keywords as the minimum limits, 32 keywords met the threshold. Using 6 keywords as the minimum limits, 40 keywords met the threshold. Using 5 keywords as the minimum limits, 55 keywords met the threshold. Using 4 keywords as the minimum limits, 80 keywords met the threshold. Using 3 keywords as the minimum limits, 132 keywords met the threshold. Using 2 keywords as the minimum limits, 248 keywords met the threshold. Some limits were put on the re-occurrence of keywords using 2 keywords. It was calculated on each of the 977 keywords by using the total strength of the co-occurrence links with other keywords. The mapped network was developed by selecting the keywords with the greatest total link strength, as extrapolated in **Figures 9** and **10**.

Further analysis was conducted by using all the data sets to generate 31 clusters. Some of these clusters had large items, such as Cluster 1 had 67 items, cluster 2 had 49 items, cluster 3 had 49 items, cluster 4 had 48 items, and cluster 5 had 57 items. The most dominant cluster is cluster 31, which is represented as the node with greyish colour, signifying 'marine risers' in **Figure 9**. It has 576 links, 69 occurrences and a total link strength of 989. The next dominant cluster is cluster 5, which is represented as the purple node, signifying 'composite risers' in **Figure 9**. It has 483 links, 48 occurrences and a total link strength of 756. The next dominant cluster is cluster 12, which is represented as the sky-blue node, signifying 'offshore structure' in **Figure 9**. It has 272 links, 25 occurrences and a total link strength of 368. Cluster 5 signifying 'offshore oil well production' is represented with a green node with 351 links, 31 occurrences and a total link strength of 530. This shows that there are more research publications on marine risers than on composite risers. There are also other clusters representing other index keywords like 'composite structures', 'offshore technology', 'Fiber reinforced plastics', etc. A full display of the occurrence of the index keyword is represented via the density visualization in **Figure 10**.

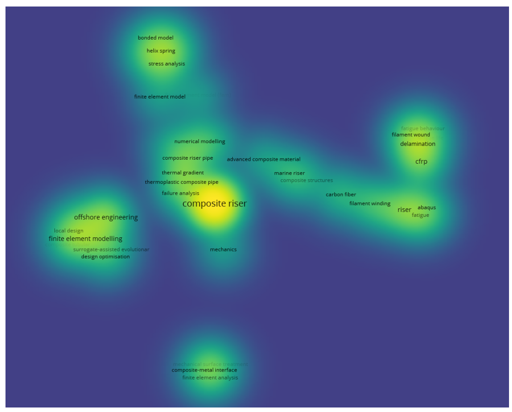

Figure 8. Mapping of author keywords on "composite risers" research showing the density visualization. It was generated using the VOSviewer tool.

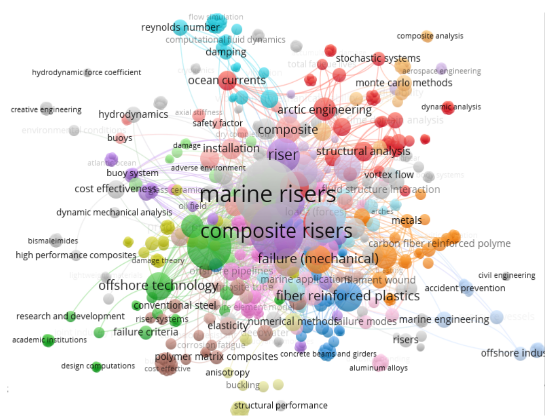

Figure 9. Mapping of index keywords on "composite risers" research showing the network visualization. It was generated using the VOSviewer tool.

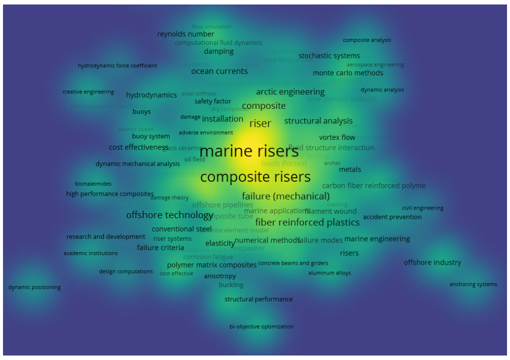

Figure 10. Mapping of index keywords on "composite risers" research showing the density visualization. It was generated using the VOSviewer tool.

3.4. Mapped Network by Citations

The relevance of publications in the academic sphere is gauged by the citations received by the papers, which consider several factors. These citations can serve as indicators of the progress achieved by authors and the impact made by researchers in their field. Various databases, such as Scopus, Google Scholar, and ResearchGate, utilize metrics like the h-index and citation counts. To present a clearer view on the authorship impact, the citations are classified using Google Scholar. It was done by considering the number of citations in the subject as a form of classification for top 15 authors. The citation analysis was conducted by classifying research works using the h-index and number of citations for selected authors in **Table 1**. Using the citation analysis, it was observed that the authors with the highest h-index had the highest citations, as noticed to be Tan, V.B.C in **Table 1**, followed by Tay, T.E, then Ye, J, followed by Morozov, E.V., then Jaiman, R.K. down to the last author- Singh, M.

Table 1. The number of citations in the subject for top 10 authors.

Authors	h-Index	Citations
Tan, V.B.C.	68	10679
Tay, T.E.	50	8098
Ye, J.	45	6541
Morozov, E.V.	34	4939
Jaiman, R.K.	36	3996
Qian, X.	34	3440
Ochoa, O.O.	23	2425
Sobey, A.	20	1388
Ashraf, M.A.	17	1231
Toh, W.	15	1003
Amaechi, C.V.	20	887
Pham, D.C.	12	812
Wang, C.	10	272
Ragheb, H.A.	7	79
Singh, M.	4	49

In this study, citations are employed to investigate the global impact of research on 'composite risers'. The visualizations in **Figures 11** and **12** illustrate that the mapping of citations in 'composite risers' research presents varying cluster densities. This knowledge mapping was conducted using a normalization method based on association strength. The data was grouped into 11 clusters with a resolution of 1.0, and a minimum cluster size of 1.0. Similarly, the clusters were also designed to be rotated by 90 degrees and the small clusters were merged. Hence, 85 items were used to generate the 11 clusters. The other small items were clustered separately but could not be merged into the association as they fell outside the network of clusters. Cluster 1 contained 19 items, cluster 2 had 17 items, cluster 3 had 9 items, cluster 4 had 9 items, cluster 5 had 7 items, cluster 6 had 5 items, cluster 7 had 4 items, cluster 8 had 4 items, cluster 9 had 4 items, cluster 10 had 4 items, and cluster 11 had 3 items. However, there is need to have a further analysis of the authorship trend in Section 3.5.

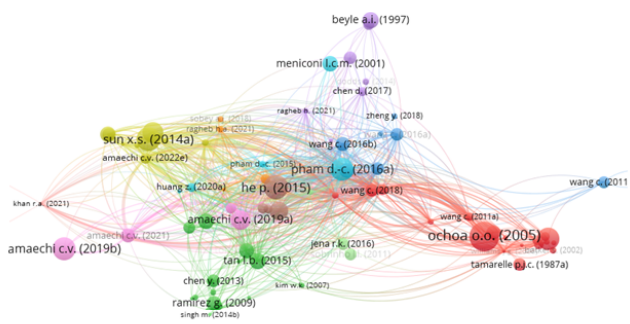

Figure 11. Mapping of citations on "composite risers" research showing the network visualization. It was generated using the VOSviewer tool.

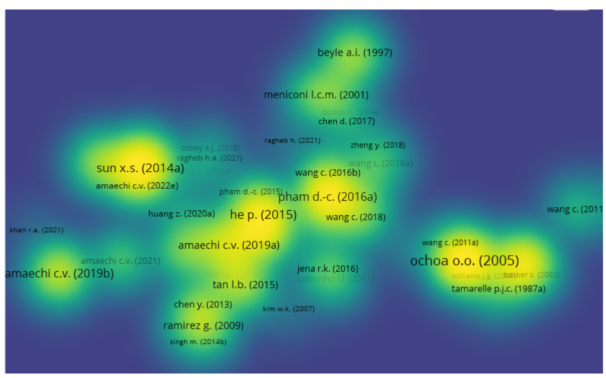

Figure 12. Mapping of citations on "composite risers" research showing the density visualization normalized using the association strength method of normalization via the VOSviewer tool.

3.5. Mapped Network by Authors

As seen in the visualizations in **Figures 13** and **14**, the mapping of the authors on 'composite risers' research reveals varying cluster densities. The mapping indicates that only a few countries have high research densities in the field of composite risers. This data was post-processed in VOSviewer using the co-occurrence node of the network and was conducted with a normalization method based on association strength. The data were grouped into 11 clusters with a resolution of 1.0 and a minimum cluster size of 1.0. The clusters were designed to be rotated by 90 degrees, and the smaller clusters were merged, resulting in a total of 189 items used to generate the 11 clusters. The other small items were clustered into small clusters but could not be merged into the association as they fell outside the network of clusters. Cluster 1 contained 44 items, cluster 2 had 25 items, cluster 3 had 25 items, cluster 4 had 21 items, cluster 5 had 18 items, cluster 6 had 15 items, cluster 7 had 13 items, cluster 8 had 11 items, cluster 9 had 8 items, cluster 10 had 5 items, and cluster 11 had 4 items. It was observed that the affiliation with the highest number of research works did not have the publications with the most co-authorship relations, as seen in **Figures 13** and **14**. However, this scientometric analysis revealed that the main co-authors primarily focused on composite marine risers and related subjects. Different nodes are coloured to show the interactions and research timelines for developments in composite risers. The authors in the red node made significant contributions to the development of composite materials as they collaborated with various Joint Industry Projects (JIPs) on composite marine risers, particularly between 1986-2005, predominantly in the United States of America (U.S.A.) and Norway. The authors on the purple nodes conducted extensive research from 2011–2022, mainly in Australia and China.

3.6. Mapped Network by Countries

As seen in the visualizations in **Figures 15** and **16**, the knowledge mapping of research countries on 'composite risers' research reveals varying cluster densities. The mapping indicates that only a few countries have high research densities in the field of composite risers. This data was post-processed in VOSviewer using the co-occurrence node of the network and was conducted with a normalization method based on association strength. The data were grouped into 2 clusters with a resolution of 1.0 and a minimum cluster size of 1.0. The clusters were designed to be rotated by 90 degrees, and the smaller clusters were merged, resulting in a total of 11 items used to generate the 2 clusters. The other small items were clustered separately but could not be merged into the association as they fell outside the network of clusters. Cluster 1 comprised 6 items (Brazil, France, India, Norway, Singapore, and the United States), while cluster 2 consisted of 5 items (Australia, China, Denmark, Nigeria, and the United Kingdom). In conclusion, the U.S.A. recorded the highest publication volume but less co-occurrence with other affiliations outside the cluster, which was strongly followed by countries like the UK, China, Nigeria, Australia and Singapore.

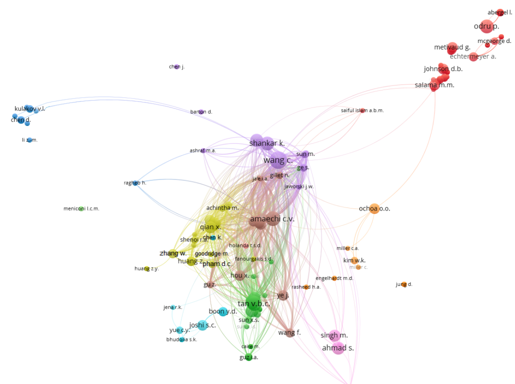

Figure 13. Mapping of authorship on "composite risers" research showing the network visualization. It was generated using the VOSviewer tool.

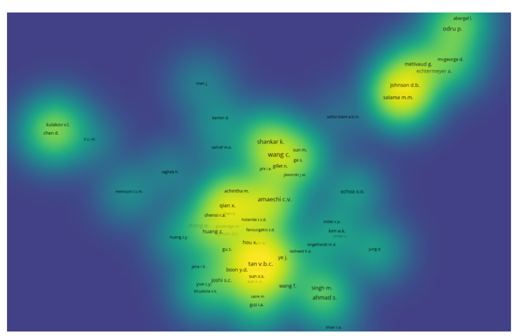

Figure 14. Main authors with more than 5 co-authorship research publications on "composite risers", the density (size and red colour) accordingly to co-authorship importance (number of co-authorships). It was generated using the VOSviewer tool.

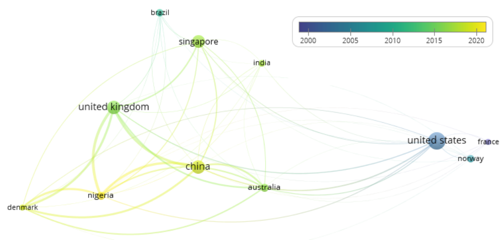

Figure 15. Mapping of publication countries on "composite risers" research showing the overlay visualization. It was generated using the VOSviewer tool.

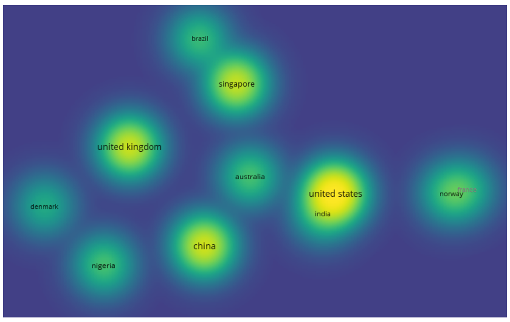

Figure 16. Mapping of publication countries on "composite risers" research showing the density visualization. It was generated using the VOSviewer tool.

3.7. Mapped Network by Co-Authorship

As seen in the visualizations in **Figure 17**, the mapping of co-authorship impact on 'composite risers' research revealed varying cluster densities. The study included data from 269 authors working on composite risers. The full counting method was used, setting the maximum number of authors per publication at 25. Thresholds were established based on the minimum number of authors, with 3 items meeting the threshold for 8 authors, 6 items for 7 authors, 9 items for 6 authors, 14 items for 5 authors, 27 items for 4 authors, 35 items for 3 authors, and 81 items for 2 authors. Limits were imposed on the recurrence of authors, calculated for each of the 269 authors by using the total strength of the co-occurrence links with other keywords. The network map was developed by selecting the keywords with the highest total link strength, as shown in **Figures 17** and **18**.

The mapping indicates that fewer countries exhibited heavy research densities in the bibliometric output obtained on composite marine risers. These data were post-processed in VOSviewer using the co-authorship node of the network and were analyzed with a normalization method based on association strength. The data were organized into 4 clusters with a resolution of 1.0 and a minimum cluster size of 1.0. The clusters were designed to be rotated by 90 degrees, and the smaller clusters were merged. As a result, 26 co-authorship items were utilized to generate the 4 clusters. Cluster 1 contained 9 items, cluster 2 also had 9 items, cluster 3 had 4 items, and cluster 4 had 4 items. It was observed that there is a significant relationship of co-authorship within composite riser research. The highest co-authorship density indicates that the research works with the most co-authorship relations, as seen in **Figures 17** and **18**.

However, this scientometric analysis has revealed that the main co-authors primarily focused on composite risers. Different nodes are color-coded to display the interactions and research timelines for developments in composite risers. The authors associated with the red node have made significant contributions to the development of composite risers and composite materials for marine risers, originating from Amaechi C.V. (identified as Cluster 1), such as Ref[1]. Similarly, the authors linked to the green node have heavily contributed to the development of composite materials, with the major starting point for a research path seen from Wang C. (identified as Cluster 2), as depicted in **Figures 17** and **18**. Therefore, this study demonstrates that both authors, among others, invested considerable time working on composite risers, resulting in doctoral research with high-quality publication outputs and co-authorships. Nonetheless, this does not imply that other researchers or doctoral studies on composite risers were not conducted, as we identified few doctoral theses that were conducted on composite risers showing the evolving trend in the subject[1, 56–62].

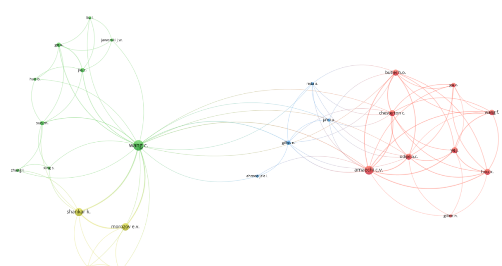

Figure 17. Mapping of co-authorship on "composite risers" research showing the overlay visualization. It was generated using the VOSviewer tool.

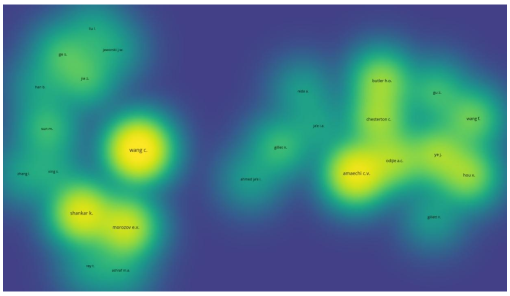

Figure 18. Mapping of co-authorship on "composite risers" research showing the density visualization. It was generated using the VOSviewer tool.

3.8. Mapped Network by Organisations (or Affiliations)

The post-processed analysis of the mapped network by organizations (or affiliations) was carried out using VOSviewer, as shown in **Figure 19**. The analysis was conducted using the full counting method, setting the maximum number of organizations per document at 25, ignoring documents co-authored by a large number of organizations, with the minimum number of organizations set at 1 and a minimum number of citation for an organization at 0. There were 197 organizations in the affiliation list, determined by using the total strength of the bibliographic coupling links with other organizations. Out of the 197 affiliations, the largest set of connected items consisted of 152 items. These were used to generate 11 clusters, although some contained only small quantities. Cluster 1 had 51 items, cluster 2 had 33 items, cluster 3 had 15 items, cluster 4 had 11 items, cluster 5 had 10 items, cluster 6 had 8 items, cluster 7 had 7 items, cluster 8 had 7 items, cluster 9 had 5 items, cluster 10 had 3 items, and cluster 11 had 2 items. **Figure 19** illustrates the extensive networking of various affiliations and international networks established through the research works on composite risers.

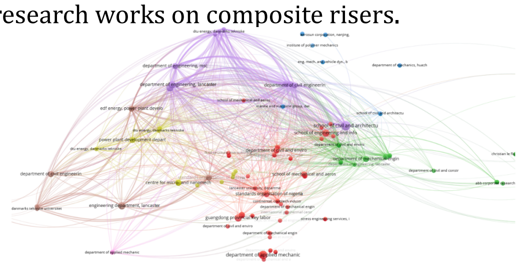

Figure 19. Mapping of affiliations on organisations that research on "composite risers" showing the network visualization normalized using the association strength method of normalization. It was generated using the VOSviewer tool.

3.9. Word Cloud on Publication Keywords

The scientometric analysis of the search terms used in this study, along with the publication keywords, was conducted by post-processing the keywords to form word clouds. Using a word cloud generator, the keywords are displayed in descending order of prominence, from the most to the least bold, and from the highest to the lowest frequency. Voyant Tools, an open-source web-based application for text analysis, is utilized to analyse the keywords. It provides a web-based reading and analysis environment for digital texts, promoting meticulous reading and analysis of texts or corpora. This tool is particularly useful for academics in the fields of engineering, information technology, data analysis, and the humanities, as well as for librarians, researchers, students, and the public.

Voyant Tools can be used to examine user-uploaded texts, internet texts, or other online texts like author keywords and publication keywords. The publication keywords for this study were obtained from the top 85 articles on 'composite riser' sourced from Google Scholar. The extracted publication keywords yielded a total of 1,390 keywords and 415 unique keyword forms. However, the most frequent keywords in the corpus were: composite (88 occurrences); riser (72); risers (50); design (24); and engineering (20), as illustrated in **Figure 20**.

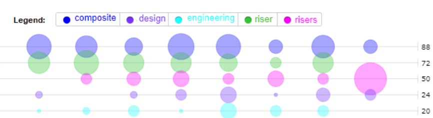

Figure 20. Bubblelines on the frequencies for 5 top keywords on composite riser research.

The keywords identified include thermoplastic composite pipe, composite riser, thermal gradient, flexible riser, tensile armor, carbon fiber, composite tensile armor, deep sea oil riser, marine composites, composite materials, computational fluid dynamics, ocean waves, vibrations, vortices, composite structure, strength, configuration, axial tension, CPR design, prediction, failure mode, requirement, composite production riser, unbonded flexible riser, finite element model, composite tube, offshore engineering, numerical modeling, stress distribution, choke, marine system, drilling riser, and others. The analysis of these keywords was conducted using the Cirrus reader in Voyant Tools. The trends in the words, correlations from word frequencies, and segment inter-connectivity between the words demonstrate a strong correlation among the keywords, as depicted in **Tables 2** and **3**. Further analysis of the correlation and significance of composite riser research is presented in **Figure 21**.

Table 2. Parameters for publication keywords.

Parameters	Values
Total keywords	1,390
Unique keyword forms	415
Vocabulary Density	0.299
Readability Index	26.494
Average Words Per Sentence	1390.0

Table 3. Keyword Correlation and Significance on composite riser research.

Keyword Term1	Keyword Term2	Correlation	Significance
Composites	Fibers	0.49236596	0.1482661
Composite	TCP/Installation	0.48819634	0.15226409
CFRP	Structure	0.49099028	0.14957803
CFRP	Finite	0.51214755	0.13017447
Structure	TCP	0.49099028	0.14957803
Local	Pipe	0.46974897	0.17072928
Finite	Model	0.47043753	0.17001721
Finite	Optimization	0.51214755	0.13017447
Numerical	Tailored	0.5	0.14111328
Numerical	TCP/Polymers	0.5	0.14111328
Pipe	Thermal	0.5021624	0.13912636
Pipe	Wall	0.50529116	0.13628195
Homogenization	Materials	0.5069794	0.13476211
Pipes	Platforms	0.5063697	0.13530977
Marine	Tensile	0.50676763	0.13495219
Risers	Weight	0.50034325	0.14079669
Failure	Properties	0.5048268	0.13670182
End	Joint	0.5039527	0.13749437
Flexible	Thermoplastic	0.49455026	0.14619748
Reliability	Stress	0.49009803	0.15043268
Pipeline	Stress	0.49055243	0.14999706
Fiber	Glass	0.48412293	0.15623225
CPR	Flexible	0.48173594	0.15623225
CPR	Joint	0.8409599	0.0022994
Buckling	CPR	0.51915985	0.124105975
Buckling	Collapse	0.81483537	0.0040860
Delamination	Risers	0.5547002	0.09607159
Laminate	Liner	0.8179178	0.0038358
Fatigue	Life	0.84953594	0.0018623

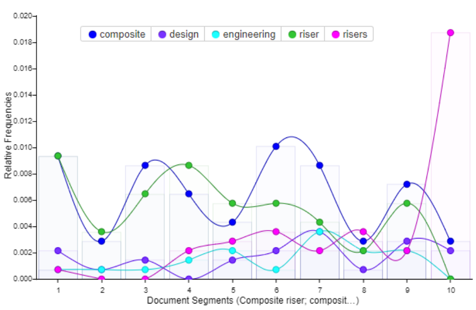

Figure 21. Trend on relative frequencies and document segments for 5 top keywords.

Figure 21 illustrates that some keywords are compound words, formed by combining multiple words. The analysis shows that 'composite riser' has the highest relative frequency at 0.093660, while 'engineering risers' have the lowest relative frequencies. A comprehensive analysis of the keywords resulted in the creation of word clouds for the publication keywords. The word cloud analysis revealed that certain words have higher densities than others, as depicted in **Figure 22**. The keywords that were occurring most frequently are displayed in larger font sizes and distinct font colours. Additionally, it was noted that the term 'risers' appeared more frequently in the publications than other keywords.

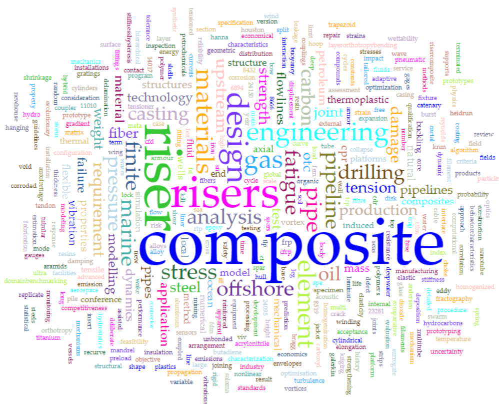

Figure 22. Word cloud on publication keywords on the composite riser research.

4. Emerging Trends and Future Directions

Composite marine risers are a one-of-a-kind application of hybrid polymer composites that are utilised in the process of producing marine risers for offshore platforms within the oil and gas sector. In addition to that, this study demonstrates how cutting-edge techniques can be utilised for conducting scientific literature evaluations. This paper also provides an overview of the research that has been conducted on composite risers [1], as well as the application of scientific literature review in this industry and other relevant fields. However, there are limitations in this scientometric review as it did not consider the doctoral research works and did not consider non-English publications. It was found that there are various related doctoral works on composite risers [56–62]. The processes that were conducted in this scientometric review are centred on the published data that was gathered from the Scopus database [1]. Within the framework of the study design, the utilisation of recent scholarly publications from the Scopus database as well as high-impact journal papers and conference papers pertaining to the topic matter was incorporated. Although some sorting was done because it was observed that certain linked articles on marine composites were captured and reviewed by taking into consideration the current state of the art on composite risers, some sorting and evaluation was done. Furthermore, future research can examine various composite riser industry requirements and standards, including those from ABS, BSI, DNV, NIS, ISO, and API, encompassing current regulations. Lastly, there should be more numerical models on the thermal conductivity, structural integrity, and verification studies on composite risers as well as full-scale experimental testing on composite risers.

The analysis reveals that the research in composite marine riser has several emerging trends, like:

- Smart Risers: Implementing sensors and data analytics to provide real-time monitoring and intelligent control of composite risers.
- Multi-Scale Modelling: Integrating different modelling scales (microscopic, mesoscopic, and macroscopic) to accurately predict the behaviour of composite risers under complex loading conditions.
- Full-scale experimental testing: There is the need to have more work on full-scale experimental testing of composite risers [1], as current publications are not recent which shows a gap in this area. The current full-scale experimental testing works are other tubular composite pipes, but there is the need for those on composite risers. This is further confirmed by the findings of this study that there is the need for more industry and JIP collaborations.
- Bio-inspired Design: Utilizing principles from nature to develop novel composite materials and structures with enhanced performance.
- Optimization and Machine Learning: Utilizing optimization approaches and machine learning for designing composite marine risers are also emerging areas on composite marine risers' research.
- Sustainable Marine Structures: Recent scientometric works that cover developments in sustainable marine structures [1, 63–66] exist, but further developments should include composite marine risers. While the procedure in the present study was carried out by first extracting the data using the Scopus database prior to correlating it with an-

other data source -Web of Science (WoS) database, the use of other academic databases are recommended for future study. Similar instance with trends is the recent study on composite marine risers' bibliometric review and meta-analysis [1].

- Integration with Offshore Renewable Energy: Adapting composite riser technologies for applications in offshore wind energy systems and wave energy systems [66].
- Qualification Requirements: The investigation also determined various studies on the composite risers [1] that met the necessary qualification requirements such as VIV [3, 4], fatigue [5–7], qualification [18], layer configuration [12, 37] and response-based reliability [67]. However, a systematic review is required for investigating these requirements, as well as other aspects of composite riser reliability.
- Guidelines and Design Codes: There is the need for more guidelines on composite riser which will enable the structural design [13, 31], mechanical responses [39, 40], reliability [67], subsea pipeline decommissioning [68] and monitoring [69, 70]. Further works on standardisation can be conducted which will enhance standards elaboration. Further research can examine composite riser industry requirements and standards, like ABS, BSI, DNV, NIS, ISO, and API, with current regulations.

In summary, the discussion on the emerging trend will be incomplete without a tabulated list on some research themes. Thus, the research theme from this scientometric review is given in **Table 4**.

5. Conclusions

This study is presented on the scientometric review that have been conducted on composite marine risers. In this paper, the research methodology taken is also described. The knowledge maps are developed by providing the SCOPUS data and post-processing it in VOSviewer with detailed description of the visualization mapping. This is crucial because a significant amount of information gained from research on composite marine risers can be obscured by the sheer volume of articles published annually. Consequently, it is important to analyze the trends using bibliographic output of research on composite marine risers, as in earlier CPR bibliometric review [1]. To conduct a comprehensive evaluation of the research landscape of composite marine risers, this work utilizes knowledge maps and scientometric analysis. We have identified major research issues, significant authors, institutions, and emerging trends in the field using bibliometric data and visualization tools. The aim of this study is to provide a valuable resource for researchers, engineers, and other stakeholders interested in the development and implementation of composite marine risers. The knowledge maps obtained from the scientometric review on composite risers present a novel contribution to marine engineering.

Table 4. The research theme on the emerging areas from this scientometric review.

Research Theme	References
Marine Riser	[1, 2, 71]
Vortex-induced vibration (VIV)	[3, 4]
Fatigue damage	[5–7, 72–74]
Composite riser	[1, 8, 9, 31, 37–39]
Composite riser testing	[10, 11, 44, 46]
Weight ratio	[12–14]
Composite material	[1, 15, 16, 42]
Qualification	[10, 11, 18, 25]
Structural design	[13, 31, 47]
VOSviewer	[1, 47–55]
Composite Marine Risers	[1, 56–62]
Sustainable Marine Structures	[1, 63–66, 71]
Scientometric Analysis	[1, 47–55, 63–66]
Marine Structure	[63–70]
Reliability	[67, 74]
Subsea pipeline decommissioning	[68]
Flexible riser	[17, 18, 27]
Coupling	[28, 29, 36]
Composite pipe	[31, 38]
doctoral thesis on composite risers	[56–62]
Composite riser end-fitting	[24–26]
Composite riser review	[1, 23, 32, 34, 35, 43]
Mechanical responses	[39, 44, 71]
Monitoring	[18, 33, 69]
Guideline	[69, 70]
Offshore platform	[2, 8, 9, 18, 19, 72]
Global design	[3, 13, 72–74]
Local design	[3, 12, 14, 71, 75–77]

Some of the most important findings from this study are as follows: firstly, it was observed that the research trends recorded the highest publication volume in the U.S.A. but less cluster affiliated, as it was followed by countries like the U.K., China, Nigeria, Australia and Singapore. Secondly, this field has more conference papers than journal papers due to the challenge of adaptability, acceptance, qualification, and application of composite marine risers in the marine industry. Hence, there is a need for more collaborations on composite marine risers and more funding to enhance the research trend. Although this is a scientometric study, it did not examine the research conducted on composite risers for use in marine environments as there is need for further work with tabulated data to compare the designs. Also, a comprehensive analysis of composite risers was carried out using the SCOPUS database, comparing results from two distinct retrieval periods could be also done aside from 1977–2023, as a closer timeframe may present different trends. Thirdly, the result of the analysis based on the available literature on composite risers showed that annotated bibliography can be performed in future work on this area. Fourthly, to visualize the presented results, this study has successfully given knowledge maps through the comprehensive data analysis which was conducted with the aid of cutting-edge technologies like VOSviewer to develop knowledge maps.

Finally, the impact of the research and this scientific analysis on composite risers were presented. The data retrieved from publications span fields such as science, engineering, and general research. This includes journal articles, review articles, conference papers, and notes. Due to the challenges of adaptation, acceptance, qualification, and application of composite risers in the industry, more conference papers were found in the area than journal publications. This analysis also highlights the efforts made in producing publications, patents, and design codes or standards relevant to the topic. Furthermore, this scientometric study on the subject showcases recent developments, geographical activity by countries, authorship records, collaborations, funding organizations, connections, co-occurrences, and areas requiring further investigation. Thus, another systematic review is required to comprehensively investigate the necessary qualification requirements that were met by composite risers. Further research can examine various composite riser industry requirements and standards, like ABS, BSI, DNV, NIS, ISO, and API, with current regulations.

Author Contributions

Conceptualization, C.V.A.; methodology, C.V.A., S.B.B., A.R., D.B.M., I.A.J., A.S., B.H., C.W., X.J., J.C., and A.K.O.; software, C.V.A., S.B.B., A.R., D.B.M., I.A.J., A.S., B.H., C.W., X.J., J.C., and A.K.O.; validation, C.V.A., S.B.B., A.R., and A.K.O.; formal analysis, C.V.A., S.B.B., A.R., and A.K.O.; investigation, C.V.A.; resources, C.V.A., S.B.B., A.R., D.B.M., I.A.J., A.S., B.H., C.W., X.J., J.C., and A.K.O.; data curation, C.V.A., S.B.B., A.R., D.B.M., I.A.J., A.S., B.H., C.W., X.J., J.C., and A.K.O.; writing—original draft preparation, C.V.A.; writing—review and editing, C.V.A., S.B.B., A.R., D.B.M., I.A.J., A.S., B.H., C.W., X.J., J.C., and A.K.O.; visualization, C.V.A., S.B.B., A.R., D.B.M., I.A.J., A.S., B.H., C.W., X.J., J.C., and A.K.O.; supervision, C.V.A., and S.B.B.; project administration, C.V.A., S.B.B., A.R., D.B.M., I.A.J., A.S., B.H., C.W., X.J., J.C., and A.K.O.; funding acquisition, C.V.A., S.B.B., D.B.M., I.A.J., A.S., and B.H. All authors have read and agreed to the published version of the manuscript.

Funding

The funding support of the School of Engineering, Lancaster University, UK, for the Engineering Department Studentship as well as the Engineering and Physical Sciences Research Council (EPSRC)'s Doctoral Training Centre (DTC), UK is highly appreciated. In addition, the funding of Foreign Postgraduate Scholarship by Niger Delta Development Commission (NDDC), Port Harcourt, Nigeria, as well as the support of Tertiary Education Trust Fund, Nigeria (TETFUND), Abuja, Nigeria are both appreciated. This research also acknowledges the BOLD25 Initiative of Universiti Tenaga Nasional (UNITEN), Malaysia. The authors would like to express their gratitude to the Higher Institution Centre of Excellence (HICoE), Ministry of Higher Education (MOHE), Malaysia under the project code 2024001HICOE as referenced in JPT(BPKI)1000/016/018/ 34(5). The financial support received for this doctoral research is highly appreciated.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable

Data Availability Statement

The supplementary data is also made available herewith. The link for the supplementary data used is https://data.mendeley.com/datasets/zftxt2p8b6/2.

The data citation is "Amaechi, Chiemela Victor (2022), "Supplementary Dataset on Scientometrics of Composite Risers", Mendeley Data, V2, doi: 10.17632/zftxt2p8b6.2".

Acknowledgements

The authors applaud the support of both Lancaster University's School of Engineering and Universiti Tenaga Nasional (UNITEN), Malaysia for providing the research platform. We also acknowledge using Scopus, and VOSviewer in this study. The comments from industry colleagues, the journal editor and the reviewers on this manuscript are much appreciated in improving the manuscript's quality.

Conflicts of Interest

All authors disclosed no conflict of interest.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Abbreviations

CFRP – Carbon Fibre Reinforced Plastic
CPR – Composite Production Risers
ABS – American Bureau of Shipping
API – American Petroleum Institute
BSI – British Standards Institution
DNVGL – Det Norske Veritas
FPSO – Floating Production Storage and Offloading
ISO – International Organization for Standardization
JIPs – Joint Industry Projects
SURF – subsea umbilicals, risers, and flowlines
TCP – Thermoplastic Composite Pipe
U.K. – United Kingdom
U.S.A. – United States of America
VIV – Vortex-induced vibration
WoS – Web of Science

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