



# Evolution of Mission-Oriented Unmanned Aerial Vehicle Networks: A Comprehensive Review

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## Abstract

Since the inception of sustainable green unmanned aerial vehicles (UAV), energy efficiency and mission-oriented intentions are the emerging turns in the UAV sector. This study aims to examine the energy efficiency and network performance of mission-based UAVs by conducting a bibliometric analysis of 1391 publications between 2005 and 2023 from the Web of Science (WoS). For a total of 383 records extracted from the Web of Science (WoS), bibliometric analysis was conducted using two techniques: performance analysis, which finds the various research elements (*i.e.*, publication statistics, citation statistics, top publishing countries, top publishing journals, top publishing institutions, and top publishers), and science mapping, which includes relationships among the above-found research elements (*i.e.*, citations by country, citations by journals, keyword co-occurrences, co-authorship, co-citations, and bibliographic coupling) using the open source VOS viewer and Biblioshiny. The findings showed that the China, India, and the USA are the most productive countries in UAV research. Future research on the use of UAVs for a variety of missions was also identified as having potential active areas of study, taking into account network performance and energy consumption in the developing mission-based UAV sector. Indian research contribution on energy in UAVs and their network performance are feeble.

**Keywords:** Bibliometric analysis; Unmanned aerial vehicle (UAV); Energy Efficiency; Network performance; Mission orientation; Deep learning.

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## 1. Introduction

Today, rapid developments in unmanned aerial vehicles (UAV) sustain highly spatial remote sensing in short spans of time at a low cost. Based on real-time applications, remote monitoring missions such as reconnaissance missions are being deployed increasingly with the strong investment and support of various governments.<sup>[1]</sup> Past COVID-19 pandemics witnessed the expansion of UAV reconnaissance applications for various mission-critical uses like information dissemination and surveillance, forecasting of temperature in a particular area *etc.* Most of the manufacturing and radioactive industries are reflecting the fast evolution of such UAVs. The underlying use of UAV in civil engineering to create and estimate the long bridges map in minimum time and cost with aerial surveying

roadmaps, which is another context of data acquisition technology where it not only captures the many stresses such as pests, nutrition deficiencies, and diseases information in farming but also helps in spraying proper liquor medicine in the competing areas efficiently without any losses to human lives or crops. Promoting invaluable help in environmental perception with cross-multidisciplinary technology creates a great significance in the field of various engineering and technology fields. Therefore, it is much more important now to explore UAV research in various applications where it could be significantly used. Further, the fierce competition and ever-growing expectations of a green environment have transformed this industry to the next level, where innovative platforms are integrated with schemes of UAV network performance that exist in 3D space.<sup>[2-4]</sup> Since the small UAVs are designed to survive for 30 minutes in the air. But this was an influence when deployed in particular missions where it drifted in particular surroundings. Present-day UAV design is more complex, dynamic, challenging, and highly competitive with the huge demands for long existing flight in air. Government and other users aspire to exuberant energy efficient schemes with quality of service (QoS) deployed in

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particular missions where it drifted in particular surroundings and elongate the mission for an elongated time without degrading the network performances. Present-day UAV design is more complex, dynamic, challenging, and highly competitive with the huge demands of long flight time.

Surveyed papers traditionally focus on the content of the publications,<sup>[5]</sup> while bibliometric method provides a novel approach which pays attention to the characteristics of the countries, disciplines and how the papers in this emerging research area have evolved.

The main objective of the present performed bibliometric analysis is to highlight and understand the significant research trends in the context of the use of green UAVs for mission-oriented mapping and detection activities, network performances, *etc.* Among VOS viewer,<sup>[6]</sup> BibExcel,<sup>[7]</sup> CiteSpace,<sup>[8]</sup> Bibliometrix is one of the highlighted software tools used by the researchers to perform the bibliometric analysis. To achieve this objective, this paper presents performance analysis<sup>[9]</sup> (*i.e.*, publication statistics, citation statistics, top publishing countries, top publishing journals, top publishing institutions, top publishers, top Web of Science (WoS) categories) and science mapping<sup>[10]</sup> (*i.e.*, citations by country, citations by journals, keyword co-occurrences, co-authorship, co-citations, bibliographic coupling) for relevant bibliographic records extracted from the WoS database. The article is organized as follows: Section 2 provides information about the research approach, materials, and methods used to conduct the bibliometric analysis. Section 3 is the core of this manuscript, which presents the detailed bibliometric analysis in terms of performance analysis and science mapping, outlines the important insights that emerged from the bibliometric analysis, and includes subjective discussions on the results. Finally, Section 4 concludes the study and summarizes the outcomes of the study. Furthermore, potential limitations and future research directions are also highlighted.

## 2. Material and methods

Chen *et al.*<sup>[11]</sup> suggested a method for discerning and mapping the cumulative scientific knowledge and evolutionary nuances of established fields by making sense of vast amounts of unstructured data in rigorous ways, which paves the way in business, provided the basis for performing the presented bibliometric analysis based on the pertinent literature methods. The meta-analysis of journal retrospectives to determine the overall degree and direction of effects or associations is another tool suggested in Ref. [12]. Bibliometric analysis and meta-analysis rely on quantitative procedures as opposed to systematic literature reviews, which frequently use qualitative techniques and may be tainted by interpretation bias from academics with various backgrounds. This bias can be avoided or reduced because bibliometric analysis and meta-analysis use quantitative techniques. One important essential stated by Danvila-del-Valle *et al.*<sup>[13]</sup> is that the research can be developed by looking at various intellectual frameworks and selecting the pertinent references, authors, themes, and journals. Identify

the essential impacts and get an organized assessment of the traits and advancements in the research domains by using the conclusion provided in Ref. [14]. We created a three-stage common strategy (see Fig. 1, which gives the methodology to drive the bibliometric analysis using the WoS database) from these four baseline methodologies. Keywords and search criteria (stage 1), database search and export (stage 2), and bibliometric analysis (stage 3) are the three steps that make up the procedure. Below is a detailed discussion of each stage:

### Stage I: Keyword and search criteria

To fulfill the requirements for further explorations; the authors put forward a comprehensive information set of systematic literature reviews, references, citations, and a bibliography. The study on network performance in mission oriented UAVs for green sustainable environment with its application in all schemes (traditional to innovative) would provide holistic learning to all concerned.<sup>[15–17]</sup> Regarding the employment of green UAVs for missions involving energy-efficient communication, a number of research questions (RQ) have been developed. A search query was created to extract the pertinent literature from the database using a variety of keywords based on the questions studied that had been prepared, as shown in Fig. 1. In order to specify the scope of the study, search criteria were also established in the first stage. Only works published in English between 2014 and 2022 were taken into account for the bibliometric analysis that was conducted. The present study encompasses following research queries (RQs):

RQ1: How have drones and UAVs been used for mission-oriented activities?

RQ2: Which is the most influential research articles (MIRA) and most influential references (MIR)?

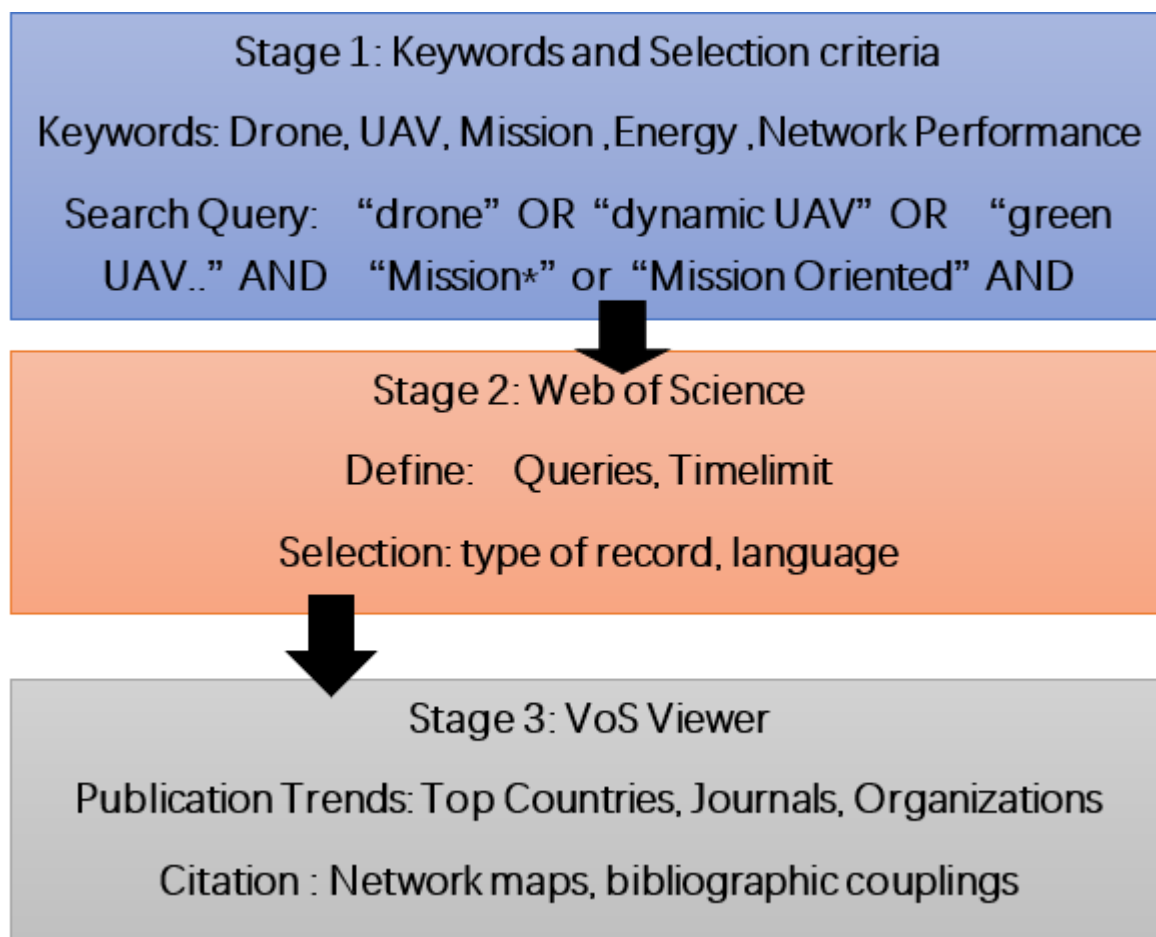
RQ3: How foundations of research domain developed?

RQ4: What are the prominent themes in the extant literature?

RQ5: How evolution of concepts developed in the research domain?

RQ6: What is the future scope of study?

**Stage II: Database search and export:** The second stage involved in finding a database and doing a keyword search against it. We used the one and only WoS database—one of the largest in the sciences and engineering—for this study. WoS contains a carefully chosen collection of excellent, peer-reviewed literature, whereas Scopus also contains publications that are not pertinent. Additionally, the WoS offers tools for examining the connections between articles, authors, and institutions as well as a variety of measures based on citations, including the impact factor and the h-index. So, in order to obtain the most important trends in this field, we chose to use WoS for the subject bibliometric analysis with the goal of only analyzing high-quality, peer-reviewed literature. As a result of the specified research query, a total of 383 literature records (dated March 11, 2023) were extracted and exported for bibliometric analysis.



**Fig. 1** Research methodology to derive the bibliometric analysis.

### Stage III: Bibliometric analysis

The exported literature records from the WoS were statistically and graphically examined in the third and last stages. The analysis involved performance analysis, science mapping and network analysis. Contrary to journal distribution analysis, which preserves the insights of the preeminent journals and the intellectual foundation of the subject, performance analysis covered the most prominent authors, sources, institutions, nations, and cited references as presented in Ref. [17]. The focus on research themes based on the words used in papers and a co-citation analysis that offers the evolution of research fronts and significant documents is another parameter of thematic clusters and temporal evolution. Such a thorough outcome demonstrates the exponential growth of research in a given field, with the vast majority of contributions coming from other nations. The author provides a different type of analysis utilizing VOS Viewer in Ref. [16], where it is possible to determine the current state of development and the top trends in terms of influence, major journals, articles, subjects, authors, institutions, and nations. The analysis and graphical presentations are important because they can aid the researchers and professionals in understanding the current condition of the field in which they are working.

Although science mapping covered bibliographic coupling, co-citation analysis, and citation analysis. RStudio 4.2.2

Packages and VOS viewer 1.6.18 were used to analyze both of them (Bibliometrix – Biblioshiny). Using Biblioshiny,<sup>[18]</sup> network analysis utilizing co-occurrence analysis, thematic progression, and topic trends were investigated.

## 3. Results and discussion

### 3.1 Performance analysis of network performance/energy in research articles related to mission-oriented UAV

#### Article publication activity

The trend of research articles' publication on network performance and energy in mission UAVs marked its beginning in 2005 (as seen in Fig. 2). Work in this field could be traced back to the development of drone and UAV concepts during the latter half of the 21st century. It is evident that a single article was written in 2005, when Harmon *et al.*<sup>[19]</sup> came out with energy optimization behavioral outcomes of UAVs, suggesting energy efficiency aspects towards UAVs. However, aggressive research in this field started in 2018 with eight articles. The most prolific years were 2022 (93 articles each), 2021 (90 articles), 2020 (70 articles), 2019 (56 articles), and 2018 (30 articles). An increase in research articles was observed during 2019–2020 due to the COVID-19 pandemic and its effects on the economy and emergency conditions, including transportation, medical facilities, emergency monitoring, and providing networks over disaster areas, as

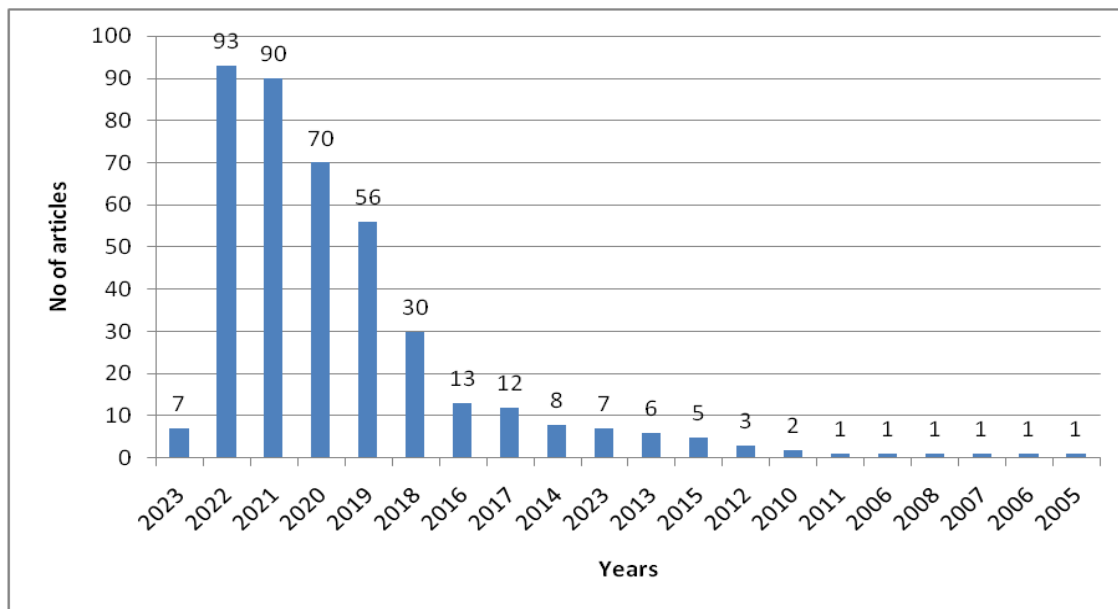


Fig. 2 Publication trend on Network Performance and Energy Research in Mission-Oriented UAV from 2005-23.

well as research and academic works, which seem to be the new research area for the future world to work on for promoting various engineering purposes. Also, a rising trend was noticed during 2023, with seven articles in two months.

**Most influential authors, institutions, and countries**

With the help of bibliometric analysis, the statistical evaluation of published research articles was categorized into influential and productive categories: authors, institutions, and countries (Table 1). The most influential author (MIA) in network performance and energy research in mission UAVs with 1357 citations was Y. Zeng. However, the most productive author (MPA) in this field was Zhang, with 12 articles and 189 citations. Nati University Singapore leads with 1171 citations from 6 articles and was preceded by Southeast University with 945 citations from 14 articles. Amongst countries, China stood at the top with 2254 citations

from 146 research articles in energy and network performance.

**Most influential journals**

Table 2 presents the leading nine journals that published articles in the field of energy and network performance in mission UAVs. The most influential articles were from the IEEE Transactions on Wireless Communications, which scored the highest in total citations from 8 articles, whereas the IEEE Access and Sensors led in the maximum number of publications (54 and 41 articles), with a very good record of total citations (626 and 353). Other prominent journals were the IEEE Internet of Things Journal (TA = 36; TC = 393), the Journal of Intelligent and Robotic Systems (TA = 33; TC = 1847), and the Journal of Computer Networks (TA = 11; TC = 187). These top 5 journals contributed 175 research articles out of 383, which is almost 45% in the field of energy and performance focusing UAV missions.

Table 1. Article retrieving and collection approach.

Stage	Data retrieval process	Repudiate	Acknowledge
1	Search criteria		
1.1	Article indexing database: WoS		
1.2	Retrieving date: 11 March 2023		
1.3	Search words and terms: ("Drone" OR "Drones" OR "Unmanned Aerial Vehicle" OR "UAV" OR "Unmanned Aerial System" OR "UAS") AND (mission oriented or mission* or reconnaissance mission) AND (network performance OR energy * OR energy efficient)		1391
1.4	Subject area: (telecommunication OR automation and control system OR remote sensing or power system and electric vehicle)	612	779
1.5	Type of document: ("Article")	339	440
1.6	Publication year: 2013-2022	20	420
1.7	Language of document: ("English")	3	417
2	Article selection criteria		
2.1	Erroneous records screening: Include documents with valid author information only	00	417
2.2	Content screening: Include articles if "Titles, abstracts, and keywords" indicate relevance to scope of study (i.e., energy efficient or mission) only	34	383

**Table 2.** Most influential authors – institutions – countries.

TC	Author	TA	TC	Institute/Affiliation	TA	TC	Country	TA
1357	Zeng,Y	9	1171	Nati univ singapore	6	2254	China	146
1163	Zhang,r	7	945	Southeast univ	14	1190	Singapore	10
717	Xu,j	5	929	Univ Sydney	7	1165	Australia	18
195	Wu,q	7	671	Guangdon univ technol	5	837	USA	57
189	Zhang,x	12	186	Nanjing univ aeronaut and astronaut	20	692	Spain	22
169	Li,j	7	165	Purple mt labs	5	612	Italy	25
156	Wang,j	7	128	Chinese acad sci	6	505	England	20

Note: TC = Total Citations. TA = Total Articles.

**Most influential research articles (MIRA)**

Out of all MIRAs, Y. Zeng (2019) led with 595 citations, which encompass the study on energy minimization for wireless communication (Table 3). It is followed by Y. Zeng (2018), with 264 citations, focused on the flight time minimization of UAVs. Both of them came when UAVs were transforming from 2D to 3D while focusing on mission-oriented targets. Detailed analysis of MIRA revealed crucial, impactful, and influential research areas like: Y. Zeng (2017); configuration and specifications of an unmanned aerial vehicle (TORRES-SANCHEZ, 2013); energy-efficient routing collection in UAV intentions (LAKEW DS, 2020); and 5G placement of an unmanned aerial vehicle (ORSINO A., 2017).

**Table 3.** Most influential journals.

Journal Name	TA	TC
IEEE transactions on wireless communications	8	1026
IEEE access	54	626
IEEE internet of things journal	36	393
Sensors	41	353
Journal of intelligent & robotic systems	33	305
IEEE transactions on communications	7	299
IEEE communications magazine	5	258
Computer networks	11	187
IEEE transactions on vehicular technology	10	180

Note: TC = Total Citations. TA = Total Articles

**Most influential references (MIR)**

Table 4 presents details of MIR cited locally (LC) and globally (GC). LC refers to the frequency of a reference cited by others in energy or network performance (UAV mission). GC refers to the frequency of a reference cited by others that may be outside the context of energy or network performance (UAV mission). "Energy Minimization for Wireless Communication with Rotary-Wing UAV" by Y. Zeng, 2019 is the MIR (LC = 41, GC = 595, Ratio = 6.89%), followed by "Trajectory Design for Completion Time Minimization in UAV-Enabled Multicasting" by Y. Zeng, 2018 (L = 22, GC = 264, Ratio = 8.33%). Standing at the top in MIRA and also in MIR, Y. Zeng, 2019, "Energy Minimization for Wireless Communication with Rotary-Wing UAV" had the highest GC (LC = 22, GC = 595, Ratio = 6.89%). Reference "Joint Optimisation on

Trajectory, Altitude, Velocity, and Link Scheduling for Minimum Mission Time in UAV-Aided Data Collection" by LI JX, 2020, had the highest LC/GC ratio (LC = 11, GC = 62, Ratio = 17.74%).

**Table 4.** Top most 5 influential research articles (mira).

Author	Title	TC
Y. Zeng, 2019,	Energy Minimization for Wireless Communication With Rotary-Wing UAV	595
Y. Zeng, 2018,	Trajectory Design for Completion Time Minimization in UAV-Enabled Multicasting	264
ZHANG SW, 2019,	Cellular-Enabled UAV Communication: A Connectivity-Constrained Trajectory Optimization Perspective	198
TORRES-SANCHEZ J, 2013,	Configuration and specifications of an Unmanned Aerial Vehicle (UAV) for early site specific weed management	175
PLOS ONE	Effects of Heterogeneous Mobility on D2D- and Drone-Assisted Mission-Critical MTC in 5G	109
ZHAN C, 2019,	Completion Time Minimization for Multi-UAV-Enabled Data Collection	101
LAKEW DS, 2020,	Routing in Flying Ad Hoc Networks: A Comprehensive Survey	92
GUPTA L, 2016,	Survey of Important Issues in UAV Communication Networks	87
MALAVAR A, 2015,	Development and integration of a solar powered unmanned aerial vehicle and a wireless sensor network to monitor greenhouse gases	85
FRIEDRICH C, 2015,	Hybrid-Electric Propulsion for Aircraft	84

Note: TC = Total Citations.

**3.2 Foundations of research of energy/ Network performance research in UAV through Co-citation analysis**

The data retrieval process in the WoS data base involved filtering through keywords or a broad spectrum (energy or network performance in missions UAVs), which may have some limitations in accessing any important article that does not satisfy both criteria.

Analysis of co-citations in references facilitates access to

and uncovers the foundations and fundamentals of research areas.<sup>[19]</sup> Analysis of reference data by measuring semantic associations by VOS viewer version 1.6.18 (Analysis type: Co-citation, Analysis unit: Cited references, Threshold: 10) on the data set of 383 articles provided useful information about the following four important clusters based on co-citation coupling<sup>[20]</sup> (Fig. 3), which are mentioned as:

- 1 – Influence of collaborative mission control on UAV (Red colored)
- 2 – Air/water search and rescue /Energy conservation in UAV (Green colored)
- 3- Structural modeling/collaborative multi-UAV framework (Blue colored)
- 4 – Enhancing network performance (Yellow colored)

This co-citation in Fig. 3 derives the baseline foundation of research where it finds two publications that are cited together in one article. After tracking the same pair of papers, co-cited papers tend to form a research cluster that shares a common theme. Such common themes are detected in the present analysis given by four different colors: red, green, blue, and yellow.

### 3.3 Thematic clusters of energy/ Network performance research in mission UAV through bibliographic coupling

**Influence of collaborative mission control on UAV (red colored):** Zhao *et al.*<sup>[21]</sup> suggested the influence of multiple UAV collaboratively handle the targeted mission using machine learning models. Another Finger *et al.*<sup>[22]</sup> investigated the effect of UAV aircrafts mobility on the battery. The effect of hello packets on AODV routing elaborated in Ref. [23]. Another author<sup>[24]</sup> developed a design for disaster management

by UAV which percept the utilitarian values. Similarly, Arjomandi-Nezhad and Poudel *et al.*<sup>[25,26]</sup> investigated implications on quality of service metrics towards the mission based environment of UAV in the centre of their studies.

### Air/water mobility and rescue /Energy conservation in UAV (Green colored)

The foundations of motives for UAVs were examined,<sup>[27,28]</sup> where they suggested that people depend on drones not only due to their high mobility but also due to their rescue missions, emergency completeness, and various other economical reasons of power savings. For investigating motives behind UAV performance and targeted mobility, S. Jung *et al.*<sup>[29]</sup> and A. Alioua *et al.*<sup>[30]</sup> provided a meta-analytic perspective for determinants of energy harvesting models. Conservation as a green UAV,<sup>[31,32]</sup> influence of branding the UAV in sustainable developments,<sup>[33]</sup> importance of communication with flight span and battery life evaluations on UAVs,<sup>[34,35]</sup> and motivations of people, industry, and governments in driving new markets while developing green or energy-based UAVs in India<sup>[36]</sup> were also prominently referred to study focusing on reconnaissance missions and UAV mobility influencing energy motives.

### Structural modeling /collaborative multi UAV framework (Blue colored)

Various researchers cited the structural modeling<sup>[37–39]</sup> in their work in collaborative communication and multi-UAV. Similarly,<sup>[40]</sup> was cited for the conceptual framework of multi-agent UAV,<sup>[41]</sup> the unified framework for UAV perceived value, and for the power consumption prognosis.<sup>[42]</sup>

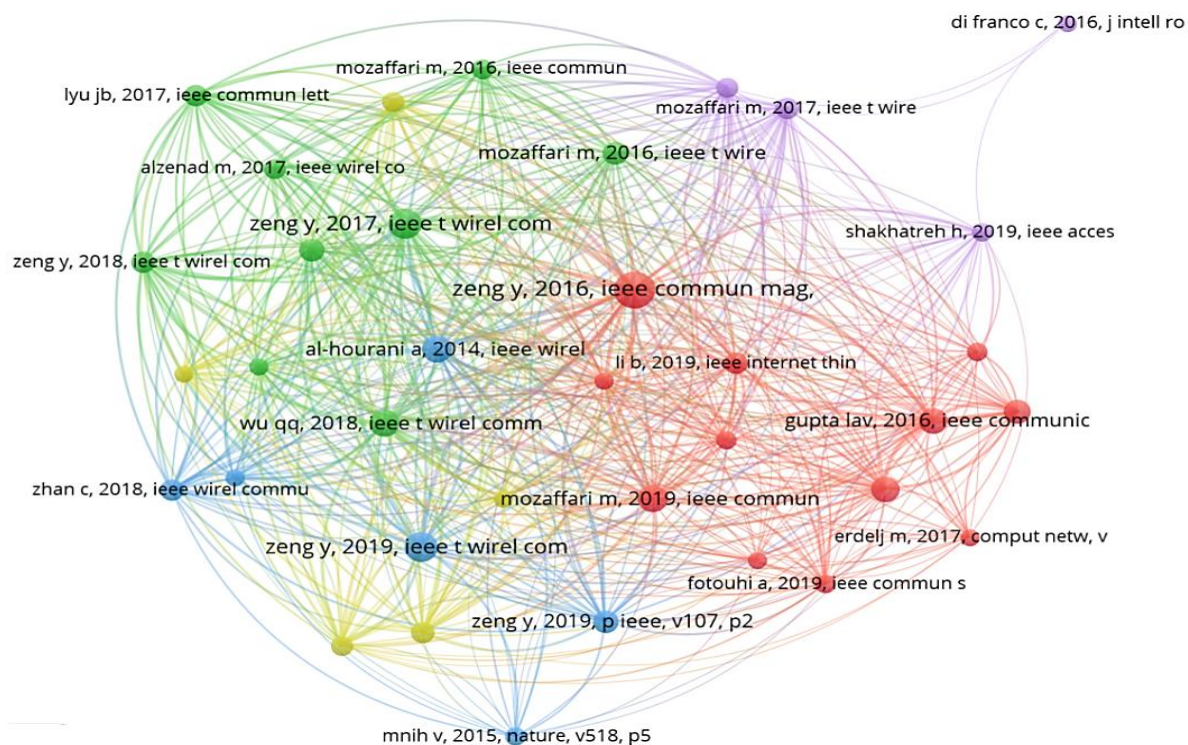


Fig. 3 Co-citation Reference Network with threshold of minimum 10 citations.

**Enhancing network performance (Yellow colored)**

Authors in Refs. [43–46] worked on the foundations of targeted mission attributes, UAV habitat, and recreational throughput. All of these authors were referred in various studies on enhancing network performance metrics such as throughputs in mission-targeted drones.

**3.4 Thematic clusters of energy/ network performance research in mission targeted UAV through co-occurrence analysis**

This analysis provides knowledge to explore thematic clusters in UAV research areas in detail. Here, the co-occurrence of themes and keywords is constructed into a pictorial network to uncover the thematic co-existence of UAV communication topics. The data were analyzed using VOS viewer (Analysis type: co-occurrence, analysis unit: all keywords, minimum number of occurrences of a key word: 15). Out of 2985 keywords, 50 met the threshold, and the top 50 cutoff marks were chosen for calculating the total strength of co-occurrence links with other keywords. Thus, the keywords with the greatest total link strength were selected (Fig. 4).

The results from the VOS viewer application that provided popular themes and keywords in the study are found in Table 4. Along with frequency, clustering of keywords on the basis of coupling can be observed in the network (Fig. 4), establishing the priorities for scientific research as well as for planning and administration in educational institutions. The analysis gives information about the top 30 keywords. The

word "mission unmanned aerial vehicles" obviously topped the list of co-occurrences as it was used in the string to extract information from the WoS database. This way, it establishes the potential relationship between the two words, which enlightens the research trends on which one can work in the future by finding papers on the two connected words with different technologies and using them in his or her work. One such example is the relationship between the design of UAVs and performance, as seen in Fig. 4 with green cluster analysis, where one can find publications related to them and work on implementing new designs that promote the best performances. Thematic co-occurrence analysis revealed the green cluster to have the maximum number of keywords (330 cumulative, or 29.35% of the top 30 keywords) with stronger links with other keywords in the domain of UAV missions with respect to network performance and energy. Further, on observing all the other clusters, it is clear that "UAV", "performance," along with "energy" and "throughput," were key themes in the Red Cluster, comprising a cumulative score of co-occurrences with 19% of the top 30 keywords, indicating some studies done in an Indian context. Also, by observing the yellow cluster, themes namely "energy behaviour", "management", "internet" and "5G" co-occurred cumulatively with 16% of the top 30 keywords, which may have been carried out in the USA.<sup>[47]</sup> Light blue clusters have a smaller number of co-occurring keywords, but keywords like "routings", "coverage", "path planning", *etc.* were prominent in Canada and China and were futuristic in nature.<sup>[48,49]</sup>

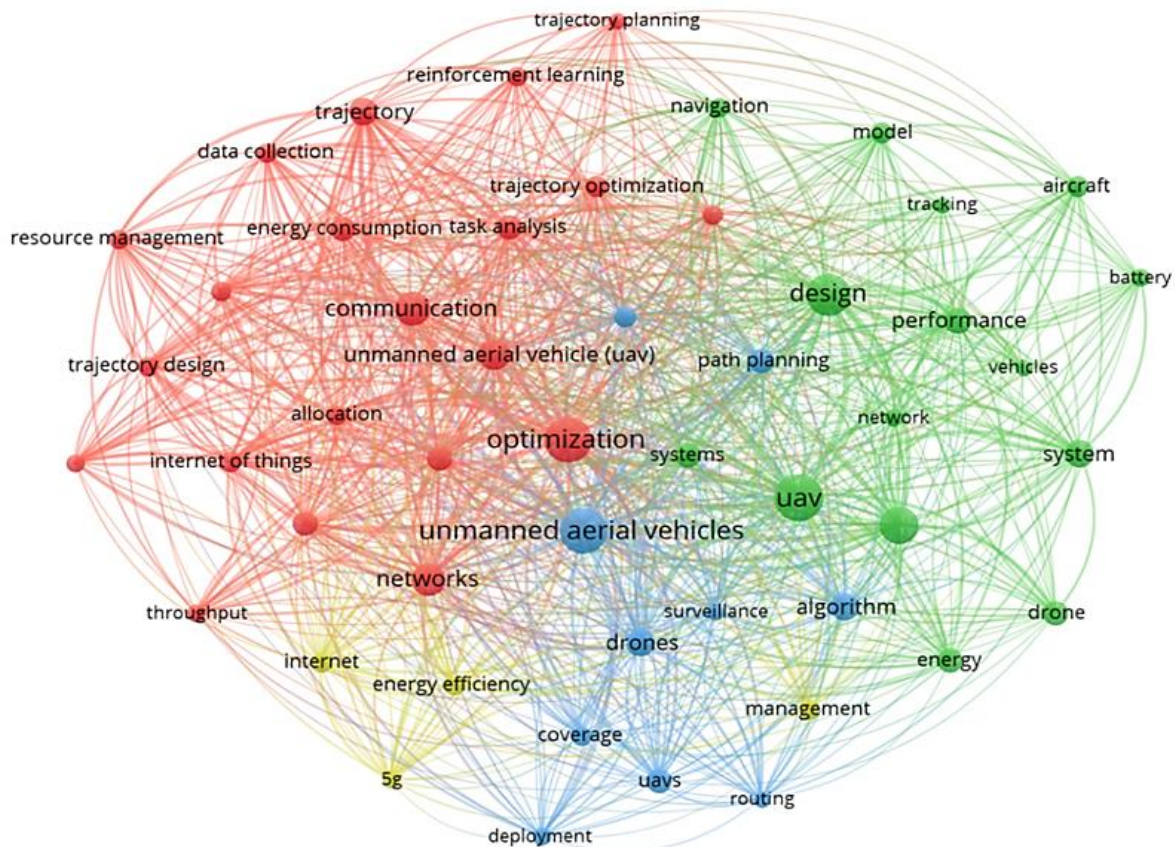


Fig. 4 Co-occurrence connection of top 50 articles between two keywords.

### 3.5 Thematic evolution of network performance/energy in UAV research through co-occurrence analysis

After analyzing the results of "thematic co-occurrence analysis" with VOS viewer, certain limitations were identified, as this tool provides good results for interpreting prominent themes but not their trends. To mitigate this issue, biblioshiny (a network approach) was used to depict the evolution and thematic trends. Option "Author Keywords" was selected rather than "Keyword Plus" to get better insights about themes. Software provided automated four time periods or time slices

(2005–2010; 2011–2015; 2016–2020; and 2021–2023) on selecting cutting points "4".

Table 5 presents the 16 most frequent keywords, indicating the major themes discussed in UAV mission literature. The word "unmanned aerial vehicle" tops the list with 67 occurrences, followed by "energy consumption" (20), "drone" (16), "remote or routing" (11) and "throughput" (9). This indicated that most of the work in the field of energy and throughput was focused on mission-based UAV domains.

**Table 5.** Top Most 5 influential research articles (MIRA).

LC	Authors	Title	GC	LC:GC(%)
41	Y. Zeng, 2019, IEEE T WIREL COMMUN	Energy Minimization for Wireless Communication with Rotary-Wing UAV	595	6.89
22	Y. Zeng, 2018, IEEE T WIREL COMMUN	Trajectory Design for Completion Time Minimization in UAV-Enabled Multicasting	264	8.33
18	ZHANG SW, 2019, IEEE T COMMUN	Cellular-Enabled UAV Communication: A Connectivity-Constrained Trajectory Optimization Perspective	198	9.09
11	LI JX, 2020, IEEE INTERNET THINGS	Joint Optimization on Trajectory, Altitude, Velocity, and Link Scheduling for Minimum Mission Time in UAV-Aided Data Collection	62	17.74
8	ZHAN C, 2019, IEEE T WIREL COMMUN	Completion Time Minimization for Multi-UAV-Enabled Data Collection	101	7.92
8	LAKIEW DS, 2020, IEEE COMMUN SURV TUT	Routing in Flying Ad Hoc Networks: A Comprehensive Survey	92	8.70
7	CABREIRA TM, 2018, IEEE ROBOT AUTOM LET	Energy-Aware Spiral Coverage Path Planning for UAV Photogrammetric Applications	78	8.97
7	ABEYWICKRAMA HV, 2018, IEEE ACCESS	Comprehensive Energy Consumption Model for Unmanned Aerial Vehicles, Based on Empirical Studies of Battery Performance	65	10.77
5	ZHANG JW, 2018, IEEE T SIGNAL PROCES	UAV-Enabled Radio Access Network: Multi-Mode Communication and Trajectory Design	69	7.25
5	ZHANG XH, 2018, INT J HYDROGEN ENERG	Experimental investigation on the online fuzzy energy management of hybrid fuel cell/battery power system for UAVs	48	10.42
5	XIE Y, 2019, AEROSP SCI TECHNOL	Fuzzy logic based equivalent consumption optimization of a hybrid electric propulsion system for unmanned aerial vehicles	38	13.16
5	LIU DX, 2020, IEEE COMMUN MAG	Opportunistic UAV Utilization in Wireless Networks: Motivations, Applications, and Challenges	47	10.64
4	MARDANI A, 2019, IEEE ACCESS	Communication-Aware UAV Path Planning	37	10.81
4	WU FH, 2019, IEEE ACCESS	Energy Consumption and Completion Time Tradeoff in Rotary-Wing UAV Enabled WPCN	29	13.79
4	PRASETIA AS, 2019, IEEE ACCESS	Mission-Based Energy Consumption Prediction of Multirotor UAV	24	16.67

Note: LC = Local Citations. GC = Global Citations

Further, the thematic evolution of the keywords presented in four time scales (2005–2010; 2011–2015; 2016–2020; and 2021–2023) revealed various sub-themes related to UAV behavior in 3D missions, which could be the determinants of energy and throughput. The keyword "deep learning" was also observed at the 15th position in the list, suggesting that authors are also generally contributing to deep learning in UAV research (Table 5).

### 3.6 Trend of topics/ themes of energy/throughput vehicle research in mission-based UAVs

We could get the thematic evolution as explained above. Thematic evolution through co-occurrence analysis could provide prominent themes but not the futuristic and upcoming in-trend themes, and it is suggested to identify broader as well as niche themes. To get better results, the Biblioshiny application was used (analysis type: documents, words, topic trends, with options). Author’s keywords: word minimum frequency = 5, number of words per year = 5. This provides a spatial representation of the connections between the disciplines, fields, and texts as well as the author's discovery of new themes or historical developments. A list of the top 50 words that passed the threshold level is also presented (Fig. 5). This information could enrich the knowledge of researchers in emerging areas of missionary UAVs and aerial vehicles. [Note: F=Frequency. FOY=First Occurrence Year. MOY=Median Year of Occurrence. LOY [Last Occurrence Year]

### Basic topics and themes

Analysis provided results to identify basic topics and themes in the area of energy and network performance in UAV missions. Themes with keywords: unmanned aerial vehicles (F = 67, FOY = 2005, MOY = 2016, LOY = 2023), energy consumption (F = 20, FOY = 2015, MOY = 2018, LOY = 2022), and throughput (F = 9, FOY = 2018, MOY = 2021, LOY = 2023) could be treated as the basic themes.

### Emerging topics and themes

Analysis of Fig. 6 provided results to identify emerging topics and themes in the area of energy and network performance in mission UAVs. Themes with keywords: internet (F = 38, FOY = 2021, MOY = 2022, LOY = 2022), energy efficient (F = 14), energy (F = 38, FOY = 2016), MOY = 2018, LOY = 2020), aerial vehicle (F = 12), 2018 (MOY = 2020), LOY = 2022), and performance (F = 38, FOY = 2018 (MOY = 2020), LOY = 2022) could be treated as emerging themes. Through this given trend, it is found that although most of the research on aerial vehicles started in 2019, it was conducted very little, as seen by their low frequency count. Another frequency of the word "optimization," which seems to be higher since 2020, shows the major contribution of the world in this domain. The emerging demand for network performance, energy, or services for the UAV is still scarce in the world, which can be more explored in the future.

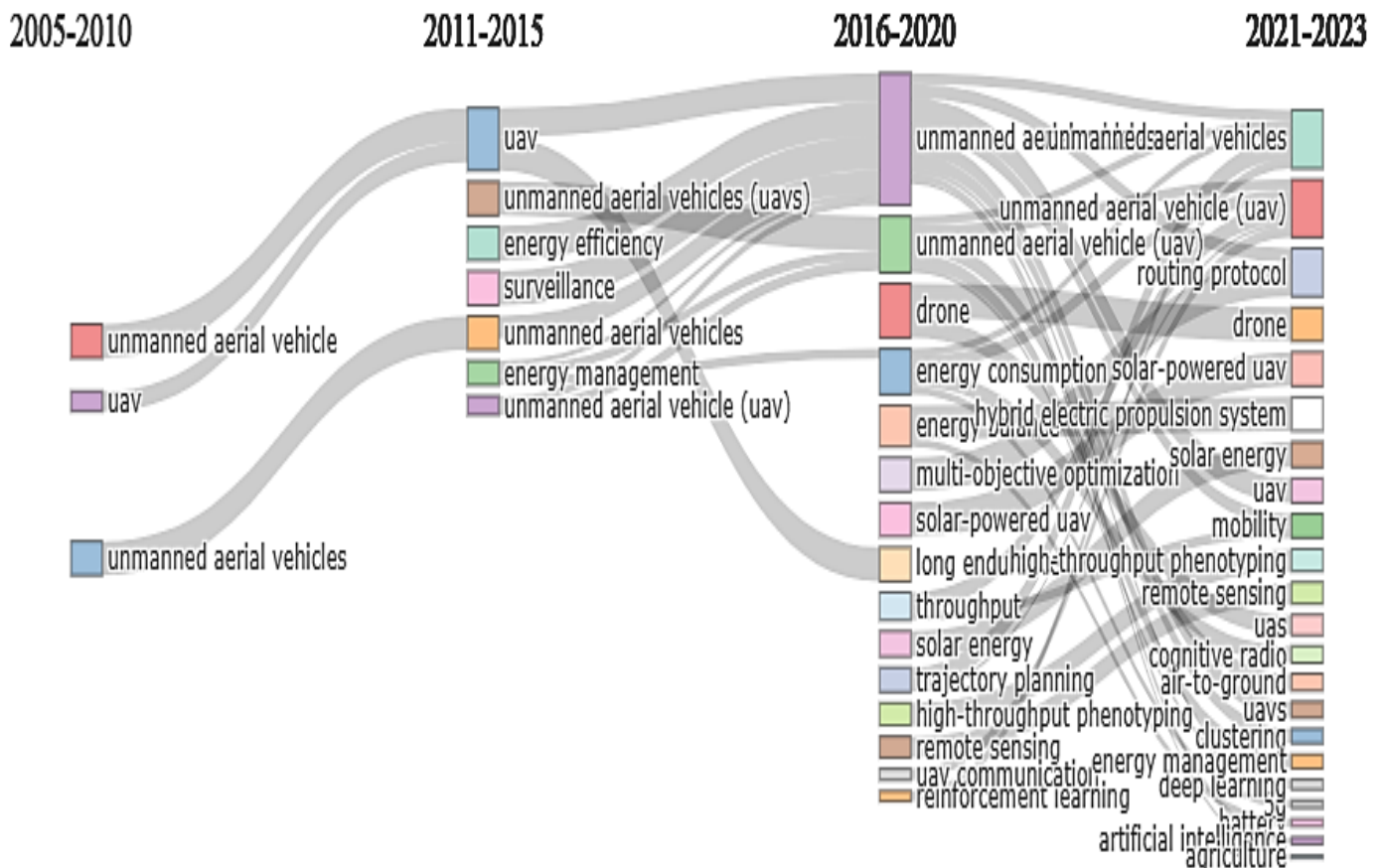


Fig. 5 Thematic Evolution, using R-Biblioshiny (Top 50 Author’s Keywords).

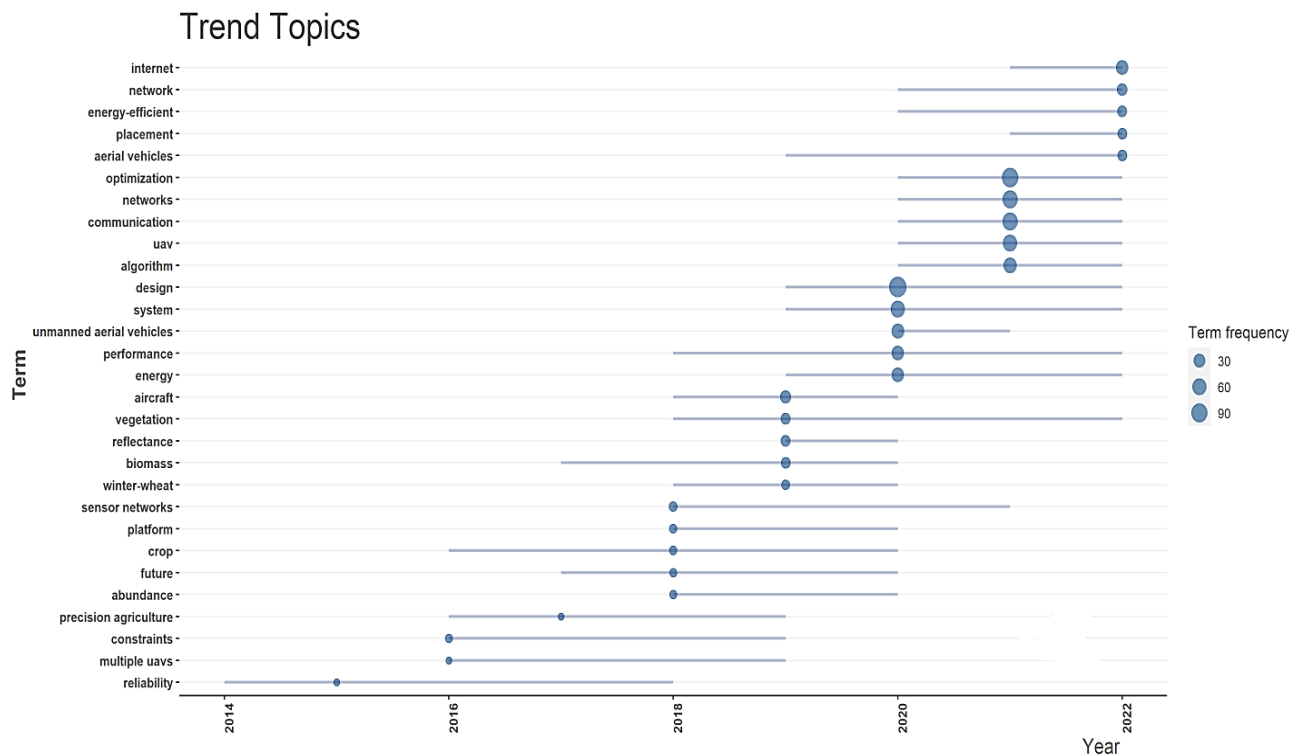


Fig. 6 Trend of Topics – Time Span 2014 to 2022.

Evolution of trends in countries

Analysis from Fig. 7 helped to identify the evolution of themes related to energy and performance in UAVs with country-specific names, viz., China (F = 41, FOY = 2011; MOY = 2020; LOY = 2022); India (F = 24), FOY = 2011; MOY = 2015; LOY = 2022); and the United States of America (F = 32, FOY = 2005; MOY = 2016; LOY = 2022). Italy (F=11, FOY=2014,

MOY=2016, LOY=2018), Korea (F=6, FOY=2011, MOY=2018, LOY=2022). Inference could be drawn that the evolution of studies in this domain could have started in developed countries in West and East Asia, like Korea and the USA, and extended to developing countries in Southeast Asia, like India and China. Hence, UAV research has been a trending domain in India for the past few years.

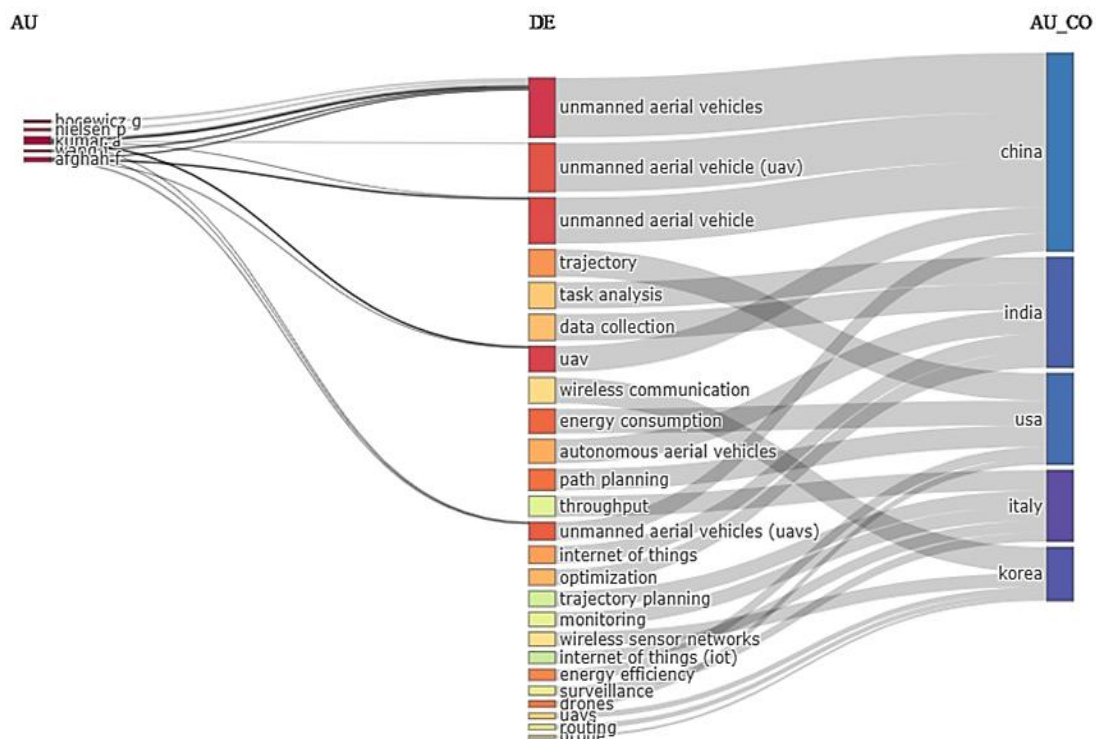


Fig. 7 Three field plotting between author-keyword –country from 2005-2022.

**Countries contribution in UAV research**

Analysis from Fig. 8 helped to identify the evolution of articles related to energy and performance in UAVs with country contribution with specific years in terms of no of articles =NA, first contribution year=FCY, last contribution year=LCY, viz. the world's highest contribution in the research domain by China (NA = 612; FCY = 2010; LCY = 2023), USA (NA = 312), India (NA = 124; FCY = 2011; LCY = 2023) and Italy (NA = 80; FCY = 2005, LCY = 2023) Although China started late in the domain, the researchers explored more and contributed to the world with the highest number of articles. Next, a developing country like India contributed in the same domain with its great efforts, which influenced the mission intentions for the various targeted missions. Next, the developed countries like the USA and Korea, although they started contributing in this domain in 2005, have seen their contributions degrade per year and almost settle on diminishing for the coming years. Through this analysis, it can be predicted that the countries that have contributed in the past few years to publications will give the world a new opportunity to see their publications, and new research will try to find their challenges solved through them by searching papers in the same country.

**Word dynamics**

The words that appear next to "UAV," or unmanned aerial vehicle," in the titles and abstracts of the detected publications are displayed in this section as a word cloud. Words are displayed in the word cloud in varying sizes based on how frequently they appear. The prominent words are positioned in the middle of word clouds, despite the fact that placement is frequently haphazard. In this study, the analysis of document topics was used to produce the word cloud results. According

to Fig. 9, "optimization," "design," "energy," "performance," "throughput," "coverage," and "communication" were the terms most frequently associated with UAVs on which scholars, academicians, or industries can work that are trending in recent years and can contribute in their same domain, which would be easy for one who does not know which research topics are in trend, so through this word "dynamic," a larger density will give more publications, and a less dense word gives the areas that are lacking and have more chances where others are not considered.

**4. Limitation**

The data set used in the current study was taken from articles that were published and indexed in the Web of Science (WoS) database between the years of 2005 and 2022, making it comprehensive in nature. This database only included journal articles; it did not include conference or review papers, which limited the scope of any further research. The data set was further constrained by the subject area, which was restricted to reconnaissance missions and monitoring, sustainable economies, energy, performance, maneuvers, recons, surveillances, aerial surveillance, rejuvenation economies, remote sensing, and social monitoring. Although some research ignites the energy of vehicle-to-vehicle communication, which improves the time gap in platooning systems.<sup>[50]</sup> Wu *et al.*<sup>[51]</sup> solves the limitations in the real time field where the vehicle nodes fail to adapt in drastic acceleration/decelerations losing the battery power. Still Li.<sup>[52]</sup> finds the new limitation on achieving optimal electric vehicle charging using the natural resources which might be the new area for research in future. These restricted locations might be the subject of additional research.

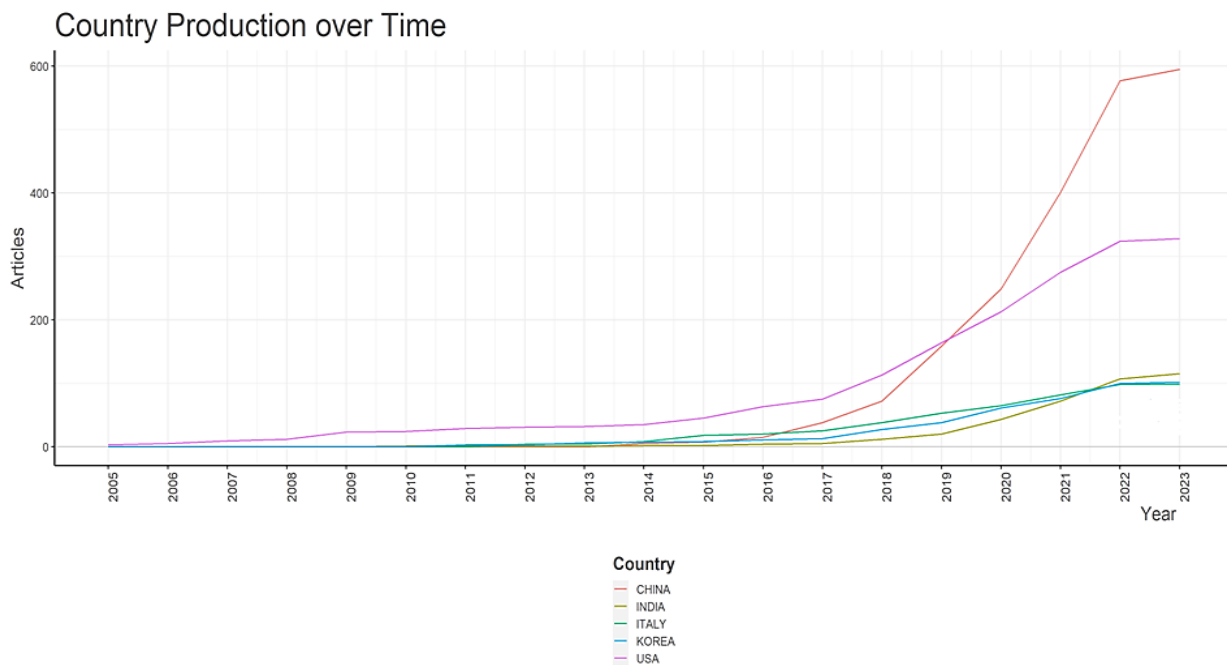


Fig. 8 Countries contribution over time span of 2005-2023 (biblioshiny).



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