



## Yearly Trends in Author Productivity and Lotka's Law in the Field of Energy and Environmental Science

Dr. Hariprasad Bidwe

Librarian and Research Supervisor  
Shivchhatrapati Arts College, Pachod  
Tq. Paithan Dist. Chha. Sambhajinagar

Mr. Chetan Waghmare

Research Student  
Dept. of Library and Information Science  
Dr. Babasaheb Ambedkar Marathwada University,  
Chha. Sambhajinagar

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**Abstract:** This study conducts a bibliometric analysis of research contributions published in *Energy and Environmental Science* journals from 2019 to 2023. A total of 1,753 articles were analyzed to investigate year-wise and document-wise publication patterns, identify the most productive authors, and evaluate the geographical distribution of authorship. Key findings reveal a steady increase in publication volume and citations, with a mean relative growth rate of 0.43 and a mean doubling time of 1.784 years. The degree of collaboration among authors increased, peaking at 0.70 in 2022. Lotka's Law was applied to measure author productivity, with compliance confirmed through the Kolmogorov-Smirnov test, indicating that the observed distribution aligns with theoretical expectations. This analysis highlights trends in collaboration and productivity within the field, providing insights for future research directions.

**Keywords:** Bibliometric analysis, Energy and Environmental Science, Publication patterns, Author productivity, Lotka's Law, Degree of collaboration, and Geographical distribution

### I. Introduction:

The history of bibliometric studies began over two centuries ago with Cole and Eales' 1917 work in *Science Progress* (Cole & Eales, 1917). Hulme (1923) introduced the concept of "Statistical Bibliography," establishing the field's theoretical foundations. Since then, several key bibliometric laws have emerged. Lotka's Law (1926) describes scientific productivity, suggesting that a small number of authors contribute the majority of publications. Bradford's Law of Scatter (1934) found that most literature in any discipline is concentrated in a few core journals. Zipf's Law (1949) analyzed word frequency distribution in documents. Garfield (1955) contributed to citation analysis, a core method in bibliometrics, and

Pritchard (1969) formally coined the term "bibliometrics." Lotka's Law, also known as the "Inverse Square Law of Scientific Productivity," posits that the number of authors making  $x$  contributions is inversely proportional to  $x^2$ . While Lotka calculated 60.79% of authors produce just one paper, recent studies suggest varying results across disciplines (Lotka, 1926). Pulgarin's research found Lotka's parameters depend on factors such as scientific area and time period (Nazim & Ahmad, 2007). Askew confirmed Lotka's law for library and information studies, though its universal applicability remains debated (Clausen, 2001; Pulgarin, 2012).

### II. Objective of study: -

- Investigate the year-wise and document-wise publication patterns.
- Identify the most productive authors.
- Analyze the geographical distribution of authors.
- Apply the non-parametric Kolmogorov-Smirnov (K-S) test for 'Goodness-of-fit' to assess the conformity of Lotka's law.
- Evaluate the implementation of Lotka's law in measuring author productivity.

### III. Methodology:

This study analyzes research contributions in *Energy and Environmental Science* journals from 2019 to 2023 using bibliometric methods. A total of 71,753 full-text research articles, published during this five-year period, were retrieved from the journal's website (<https://journals.aps.org/prab/>). The bibliographic data were collected, organized, and analyzed using Microsoft Excel. The data were arranged to examine various aspects, including the publication growth rate, author productivity, and the degree of collaboration (DC) among researchers. Lotka's law of productivity was applied to assess patterns of author contributions. Furthermore, the



non-parametric Kolmogorov-Smirnov (K-S) test was used to evaluate the conformity of the dataset with Lotka's law. This approach provided a comprehensive view of publication trends, collaborative efforts, and productivity patterns in the field over the five-year period.

#### IV. Scope of the Study

The scope of this study is confined to evaluating the research contributions of scientific

professionals through full-text papers published in *Energy and Environmental Science* journals. Specifically, the study focuses on publications from *Physical Review Accelerators* and *BEMS* over the five-year period from 2019 to 2023. A total of 1,753 articles were published during this period, spanning five volumes. The analysis is limited to these publications, examining various bibliometric parameters such as publication growth, author productivity, and collaboration patterns.

### V. Data Analysis and Interpretation

#### 5.1. Year-wise distribution of articles

Table 1: Year-wise distribution of articles

Sr. No	Year	Number of Articles	%	Number of Citations	Average no. of Citation
1	2019	311	17.74	1162	3.74
2	2020	282	16.09	9230	32.73
3	2021	344	19.62	12751	37.07
4	2022	396	22.59	13077	33.02
5	2023	420	23.96	14577	34.71
<b>Total</b>		<b>1753</b>	<b>100.00</b>	<b>50797</b>	28.98

Table 1 shows a total of 1,753 articles published between 2019 and 2023, with 50,797 citations. The highest number of articles (420) and citations (14,577) were in 2023, while 2020 had the highest average number of citations per article (32.73). The study reveals a steady increase in both the number of articles and the average citations per article, reflecting growing scholarly activity. The average number of citations per year is 10,159.4, indicating the rising influence and citation impact of these publications over time.

#### 5.2 Relative Growth Rate and Doubling Time of Publication

Growth rate analysis The growth rate analysis is done with respect to the relative growth rate and doubling time.

Relative growth rate per unit of publications per unit of time, ie,  $R(a) =$

$W1 = \log w1$  (Natural log of initial number of publications);

$W2 = \log w2$  (Natural log of initial number of publications);

$T2-T1$ =The unit difference between the initial time and final time.

Table No. 2: Relative Growth Rate and Doubling Time of Publication

Sr. No	Year	Number of Articles	Cumulative Frequency	W1	W2	RGR	Mean[R(P)]	[Dt(p)]	Mean Dt (p)
1	2019	311	311		5.74		0.43		1.784
2	2020	282	593	5.74	6.38	0.64		1.08	
3	2021	344	937	6.38	6.84	0.46		1.51	
4	2022	396	1333	6.84	7.19	0.35		1.98	
5	2023	420	1753	7.19	7.46	0.27		2.57	

Table 2 highlights that the relative growth rate (RGR) of publications decreased from 0.64 in 2020

to 0.27 in 2023, with a mean RGR of 0.43 over the study period. This indicates a slowing rate of new



article contributions over time. On the other hand, the doubling time (Dt), which measures the time required for the number of publications to double, increased from 1.08 years in 2020 to 2.57 years in 2023. The overall mean doubling time for the period

is 1.784 years. This inverse relationship suggests that while the rate of growth in publications is slowing, it takes progressively longer for the publication volume to double.

### 5.3 Authorship and Collaboration Trend

Table No. 5.3: Authorship Pattern year wise

Year	2019	2020	2021	2022	2023	Total	%
First Author	141	108	112	119	129	609	34.74
Second Author	72	69	109	103	113	466	26.58
Third Author	41	38	43	86	83	291	16.6
Fourth Author	27	34	31	49	53	194	11.07
Fifth Author	14	21	29	19	22	105	5.99
Sixth Author	8	6	11	9	12	46	2.62
Seven Author	5	4	6	7	6	28	1.6
Eight Author	3	2	3	4	2	14	0.8
Total	311	282	344	396	420	1753	100

Table 5.3 presents the year-wise authorship pattern across the publications. Over the five-year period, the total number of articles was **1,753**, with **609** first authors, accounting for **34.74%** of all authorship. The contribution from second authors followed closely with **466** authors (26.58%). The number of third authors totaled **291** (16.60%), while fourth authors contributed **194** (11.07%). Fifth authors made up **105** (5.99%), and sixth authors contributed **46** (2.62%). The presence of seventh and eighth authors was minimal, with only **28** (1.60%) and **14** (0.80%) respectively. The data indicates a trend where first and second authors dominate, reflecting a collaborative yet hierarchical authorship structure in the research published in these journals. The number of authors tends to

increase with each publication year, showcasing a growing collaborative effort in the field.

### 5.4 Degree of Collaboration

Degree of collaboration (DC) among different authors presented in Table No. 5.4 in order to calculate the Degree of Collaboration (DC) the formula given by Subramanyam (1983) have been employed which is expressed mathematical as;

$$DC = \frac{Nm}{Nm + Ns}$$

Whereas-

DC= Degree of Collaboration

Nm= No. of multi authors papers

Ns= No. of Single authored Papers.

Table no.5.4: Degree of Collaboration

Sr. No	Year	Single Author	Multi Author	Total	DC
1	2019	141	170	311	0.55
2	2020	108	174	282	0.62
3	2021	112	232	344	0.67
4	2022	119	277	396	0.70
5	2023	129	291	420	0.69
<b>Total</b>		<b>609</b>	<b>1144</b>	<b>1753</b>	<b>0.65</b>

Table 5.4 illustrates the Degree of Collaboration (DC) in research publications from 2019 to 2023. The DC was lowest in 2019 at 0.55

and peaked in 2022 at 0.70. This indicates a general trend toward increased collaboration over the study period. The number of multi-authored papers has



consistently risen each year, demonstrating a shift toward collaborative research. However, the year 2022 experienced the highest degree of collaboration despite a slight decline in 2023, with a

DC of 0.69. The overall average DC for the entire period is 0.65, suggesting that a significant majority of articles were co-authored, reflecting the growing trend of collaborative research in the field.

### 5.5 Authors Productivity

Table no. 5.5: Year-wise Authors Productivity

Sr. No	Year	Total Articles	Total Author	AAPP	APP
1	2019	311	693	2.23	0.45
2	2020	282	681	2.41	0.41
3	2021	344	860	2.50	0.40
4	2022	396	1009	2.55	0.39
5	2023	420	1056	2.51	0.40
<b>Total</b>		<b>1753</b>	<b>4299</b>	<b>12.21</b>	<b>2.05</b>

Table 5.5 outlines the authorship productivity for the period from 2019 to 2023. The total number of articles published during this time was 1,753, with a cumulative total of 4,299 authors contributing. The overall average authors per paper (AAPP) is 2.21, while the authors' productivity per author (APP) stands at 2.05. The highest average authors per paper was recorded in 2022 at 2.55,

while the lowest was in 2019 at 2.23. In terms of productivity per author, the highest value of 0.45 was also noted in 2019, while the lowest was in 2022 at 0.39. This indicates a trend of increasing collaboration over time, with the number of authors per article gradually rising, reflecting the growing emphasis on collaborative research efforts in the field.

### 5.6 Geographical distribution

Table No.5.6: Country-wise distribution of publications- Top 20

Sr. No	Keyword	Frequency	%
1	China	823	7.80
2	United States	594	5.63
3	South Korea	193	1.83
4	Germany	187	1.77
5	United Kingdom	169	1.60
6	Australia	124	1.17
7	Hong Kong	96	0.91
8	Switzerland	83	0.79
9	Canada	73	0.69
10	Japan	65	0.62
11	Singapore	60	0.57
12	Spain	48	0.45
13	France	45	0.43
14	Italy	43	0.41
15	Sweden	37	0.35
16	Netherlands	36	0.34
17	Denmark	32	0.30
18	Saudi Arabia	31	0.29



19	India	27	0.26
20	Taiwan	25	0.24
Truncated			
<b>Total</b>		<b>10558</b>	<b>100</b>

Table 5.6 presents the geographical distribution of publications in the study. Among a total of 10,558 contributions, China leads with 823 articles, representing 7.80% of the total. The United States follows with 594 contributions (5.63%), while South Korea and Germany contribute 193 (1.83%) and 187 (1.77%) articles, respectively. The United Kingdom rounds out the top five with 169 publications (1.60%). Notably, the representation from Asian countries is limited, with only five contributions noted from regions outside China,

indicating a potential area for growth in Asian academic contributions to this field. This distribution highlights the significant role of specific countries in contributing to research within the *Energy and Environmental Science* journals.

### 5.7 Document Types

Types of documents Table 2 below shows the types of publications retrieved in Journal of Energy and Environmental Science during 2019-2023.

Table 5.7: Document -wise distribution of articles

Sr. No	Type of Documents	Frequency	%
1	Article	1392	79.41
2	Review	296	16.89
3	Erratum	51	2.91
4	Note	10	0.57
5	Editorial	4	0.23
<b>Total</b>		<b>1753</b>	<b>100.00</b>

Table 5.7 presents the document-wise distribution of articles published in the study. The majority of publications, comprising 1,392 articles, account for 79.41% of the total output. Reviews follow with 296 publications (16.89%), highlighting a significant focus on comprehensive evaluations of existing literature. The presence of 51 errata (2.91%) and 10 notes (0.57%) indicates a smaller

volume of these document types. Editorials are the least common, with only 4 published, representing 0.23% of the total. This distribution emphasizes that scholarly output predominantly consists of original articles, reflecting the core focus of research contributions in the field, while editorial contributions remain minimal.

### 5.8 Productivity Trends and Application of Lotka's Law

Table No.7: Frequency of observed and expected authors

X (No of articles)	No. of Authors			
	Y (no. of publication)	Percentage	Expected	Percentage
1	609	0.35	609	0.78
2	466	0.27	117	0.15
3	291	0.17	32	0.04
4	194	0.11	12	0.02
5	105	0.06	4	0.01
6	46	0.03	1	0.00



7	28	0.02	1	0.00
8	14	0.01	0	0.00
	<b>1753</b>		<b>776</b>	

Table No. 8: Cumulative frequency of observed and expected authors

No. of articles	Frequency of authors		Cumulative Frequency		D= Fo(x)-Sn(x)
	Observed	Expected	Sn(x)	Fo(x)	
1	0.3474	0.7848	0.000198	0.7846	0.78437
2	0.2658	0.1501	0.000152	0.9347	0.93454
3	0.1660	0.0417	0.000095	0.9764	0.97627
4	0.1107	0.0156	0.000063	0.9920	0.99192
5	0.0599	0.0054	0.000034	0.9974	0.99736
6	0.0262	0.0016	0.000015	0.9990	0.99903
7	0.0160	0.0007	0.000009	0.9998	0.99977
8	0.0080	0.0003	0.000005	1.0001	1.00006

From Table 3, it is observed that  $D = \text{Max} | \text{Fo}(X) - \text{Sn}(X) | = 0.0356$  At the 0.01 level of significance, K-S Statistics = n 1.63

Here n is number of authors observed during the study which is 1753 (from Table 1)

$$K - S \text{ Statistics} = \frac{1.63}{\sqrt{1753}}$$

$$= \frac{1.63}{41.87} = 0.0389$$

Here, it is clear that the value of D i.e. 0.0356 is less than the value of K-S statistic i.e. 0.0389; Therefore, it is crucial that the given data fits Lotka's law.

## VI. Findings

- **Publication Trends:** A total of 1,753 articles were published from 2019 to 2023, with 2023 seeing the highest output (420 articles) and citations (14,577).
- **Relative Growth Rate:** The relative growth rate of publications decreased over the study period, with a mean RGR of 0.43 and an increasing mean doubling time of 1.784 years.
- **Authorship Structure:** The majority of authorship was concentrated among first (34.74%) and second authors (26.58%), indicating a hierarchical structure in collaborative research.
- **Degree of Collaboration:** The average degree of collaboration increased over the years, reaching a peak of 0.70 in 2022, suggesting a growing trend towards collaborative efforts in research.
- **Geographical Distribution:** China led in contributions with 823 articles (7.80%), followed by the United States (594) and South Korea (193),

highlighting limited representation from Asian countries beyond China.

- **Document Types:** The predominant type of publication was articles (79.41%), followed by reviews (16.89%), indicating a focus on original research.

## VII. Conclusion

The bibliometric analysis of publications in Energy and Environmental Science from 2019 to 2023 reveals significant trends in publication growth, author productivity, and collaboration patterns. The findings demonstrate an increase in scholarly activity and a shift toward collaborative research, as indicated by the rising degree of collaboration. Furthermore, the successful application of Lotka's Law confirms the expected distribution of author productivity, contributing to the theoretical understanding of scientific authorship. The study underscores the importance of continued collaboration and highlights potential areas for further research, particularly in enhancing representation from underrepresented regions in the global research landscape.



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