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MAPPING THE EVOLUTION TRENDS OF BIOBASED PRODUCTS: A TWENTY-YEAR ANALYSIS

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Abstract- One of the key discussions in the recent decade is sustainability. The biobased product industries have become a priority area with high potential for future growth, reindustrialization, and addressing societal challenges. Biobased products can create a more sustainable economy and lower the dependency on fossil products. This study aims to identify research trends, the most productive journals, and countries using a Bibliographic Network Analysis. A total of 3782 articles published in the Web of Science database from 1993 to 2022 were retrieved. After document and language filtration, there are 2580 articles obtained. The publication related to biobased products is gradually increasing from 1993 to 2021, but the number of publications slightly dropped in 2022. The highest articles published is in 2021 with 420 articles published. The top 3 countries, which published highest number of articles related to biobased products are People's Republic of China, *United States* of America, and Netherlands. People's Republic of China is the highest articles published, meanwhile *United States* of America have the highest citation regarding biobased product. Furthermore, the top 10 most productive journals, highly cited articles, and author's keywords are investigated in this paper.

Index Terms- Bibliographic Network Analysis, Biobased, Biobased product, Fossil, Sustainability

I. INTRODUCTION

The explosion of the human population has gradually increased the need of resources. The demand for conventional products such as conventional plastics, fuel-based products etc are gradually increasing which might leads to pollutions and other environmental hazards such as climate change, food security, resource depletion, and environmental degradation. Herman, Blok and Patel [1] revealed that biobased material could be used to replace dwindling and less sustainable fossil-based products. Although conventional or/and fossil fuels products are relatively cheaper and easily to approach, but it took longer cycles lasting, from one season to about 100 years [2]. The novel technology for biobased materials is emerging to be one of the most promising alternatives to replace the non-renewable or fossil-based materials. Biobased materials is environmentally friendly which offers significant benefits on environmental impact and sustainable [3, 4, 5].

The biobased products are products that fully or in a significant amount derived from biological products or renewable domestic agricultural materials, such as plants, trees, or animals that potentially undergoing physical, chemical or biological treatment [6]. The biobased products can include adhesive, fuel additives, construction materials, fibre, paper, lubricant, plastics, paints, solvent, inks, and another. Biobased products could also provide additional product functionalities, less resource intensive production and efficient use of all-natural resources.

Azhar et al. [7] conducted a survey on biobased materials towards the sustainability in Malaysia found that public willing to pay more for a product which can help reduce environmental damage. Schneider, Kläy and Zimmermann [8] and Stark [9] also reported that biobased products such as bioplastics and biocomposites can act as alternatives to achieve the United Nations Sustainable Development Goals (SDGs). Nattrass et al. [10] also revealed that the development of the biobased industry can contribute economic growth and process sustainability. A new model of economic sector has been created by the biobased industry is called as bioeconomy or biobased economy, which using biobased product to produce food, industry goods, chemicals and so on. Moreover, it also makes use of the untapped potential that millions of tonnes of biological waste and leftover materials have.

In recent years, the bioeconomy has become an essential part of economic strategy in many nations throughout the world, supporting not only growth but also technical innovation, ecological sustainability, and resource efficiency. In this past decade, many countries are focusing in development the bioeconomy by conducting research and policy-making to support this bioeconomy. Malaysia is one of the global leading countries in biobased sector, besides of Europe, United State America, Brazil, Canada and China, that emphasis the biobased sector according to the existing and planned production capacity, the industrial innovation, and the availability of feedstock [10]. Furthermore, biobased products can be a key factor in achieving the targets of the Sustainable Development Goals of clean water and sanitation, climate action, and life below water. Due to the disadvantages of fossil based detergents, the public would be more willing to accept more green and eco-friendly detergents to replace the common petroleum-derived detergents.

Although there has been a growing focus on biobased products, there is a conspicuous gap in the availability of documented evidence pertaining to the emerging trends of academic research and publications on biobased products.

Therefore, this paper aims to integrate and provide a review of the existing research related to biobased product. There are six objectives in this study. The first objective is to identify the publication trend for the biobased product. This step is essential to track the progress and development of the research related to biobased products. By analysing the publication trends, researcher can identify the theoretical or knowledge gaps of the research, which allows the researcher to decide the research directions. Next, this study also identifies the top productive countries that publishing the articles about biobased products. With this, scientist, investigator and public can predict what is the most significance countries on introducing and acceptance on the biobased products as the research topics are always connect to the community interest, innovation, and industry development. The third aims of this paper is to study the international collaboration on biobased product research and development. An institutional co-authorship network is analysing in order to explore the partnerships among the researcher in leveraging their expertise and resources. The fourth objective is to determine the top productive journal in publishing the article related to biobased product and the top cited papers during the year 1993 to 2022. Knowing the top productive journals and highly cited papers can provide valuable insights to the young researcher or students when they want to investigate or conducting research related to the biobased products. Furthermore, this paper also investigates the co-occurrences and frequency of the keywords exists in the publications related to the biobased research through a bibliometric analysis. It is crucial to conduct a keyword co-occurrence analysis in order to understand how certain research.

II. Data and Methodology

Bibliographic coupling analysis is used in this paper in order to achieve the research objectives. Bibliographic analysis is a method of analysis of the large-scale bibliographic metadata of scholarly research written on a particular topic, such as author, institution, keyword, and citation. This method is currently used in reviews of several disciplines and sustainable development research [11].

The data in this study is retrieved from Web of Science database. The flow of the data filtration is reported in Figure 1. The Bibliographic Network Analysis was used in this study to analysis the data. There are five stages where the first stage of the study is to develop the research questions which is used to achieve the aims of the study. Stage 2 is the location of study. The database is identified in this stage. There are two large and reputable databases in research which is Web of Science (WoS) and Scopus. These two databases represent the major database and citation indexes. It includes the publication in terms of journal article, book, review paper, proceedings etc [12]. The WoS database was chosen for this analysis because it provides extensive coverage of science research, whereas Scopus provides more coverage of social science research [12, 13]. Stage 3 is screening of the published materials in WoS. A total of 3782 documents were found from the database by using the keyword-biobased product. Documents other than journal, including 575 proceeding papers, 379 review articles, 83 early access, 76 book chapters, 38 editorial materials, 34 new items, 21 meeting abstracts, and 2 books are excluded from this study. After document filtration there are 2595 articles obtained. Next, language filtration is permits and a total of 15 non-English articles are excluded from the data and therefore 2580 articles are extracted for the further analysis. Stage 4 is data analysis where VOSviewer software is used for cluster analysis and Biblioshiny analysis also employed in this study to perform a visual analysis to detect the patterns, publication trends and network analysis. Next, a comprehensive discussion about the findings presented in this paper and a concluding remark which encompasses a set of recommendations are presented in Stage 5 in order to provide a actionable guidance and insights for future research in this field.

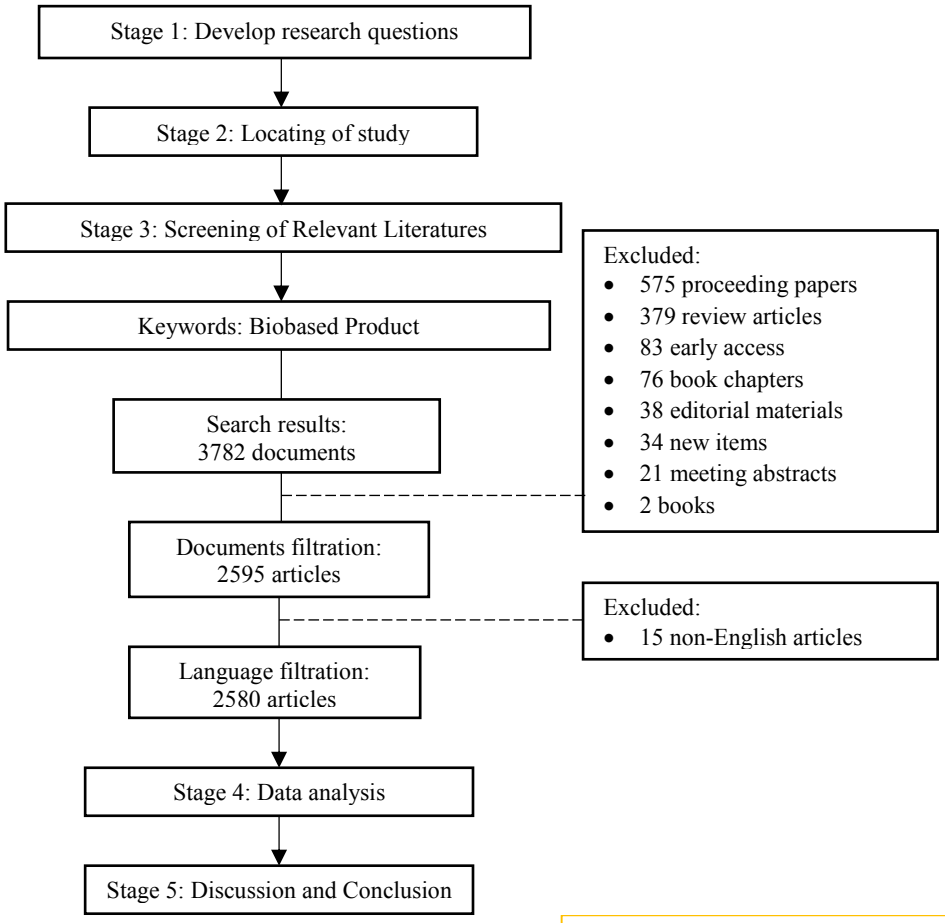

Figure 1: Flow chart of data filtration

III. Results and Discussion

3.1 Publication and Citation

Figure 2 represents the annual publication and citation analysis from 1993 to 2022. From 1993 to 2003 there are very few publications and citations related to biobased products. This can be related to the limited awareness of biobased products. Furthermore, lack of the acceptance on biobased product such as bioplastic, biomaterials and biomass products hinder the transition and research towards a bioeconomy [14, 15, 16]. The publication is gradually increasing from 2004 to 2021 but have a slightly drop on 2022 due to the Coronavirus pandemic. The highest publication being produced is the year 2021 with 420 articles. Meanwhile the citation has fluctuated from 2005 to 2018 and the highest citation is on year 2016. Meanwhile from 2019 to 2022, the number of citations of biobased products has been significantly decreasing. This problem may be related to the researcher's interest in the causes and effects of the coronavirus epidemic on society and the economy.

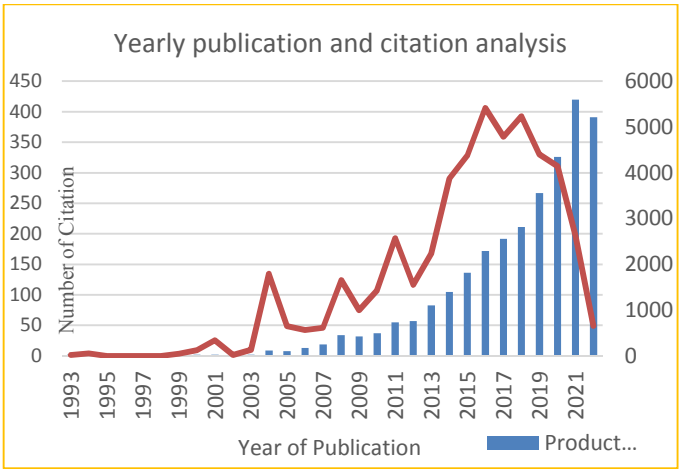

Figure 2. Yearly Publication and Citation Analysis

3.2 Productive Countries

The number of publications and citations are important to provide a global impact and recognized by the international research community on which country is contributing valuable knowledge related to the biobased products. This also can indicate the scientific level of scholar activity in a particular country. Table 1 shows the number of articles, citations, and average citation for the top 10 productive countries. The top 3 countries which published most articles regarding biobased product are People's Republic of China, United State of America, and Netherland. The People's Republic of China have

published 820 articles related to biobased products, with 12032 citation and average citation is 14.67 citation. Although United States of America is second top productive countries with 446 articles published, but the number of citation and average citation is the higher than People's Republic of China that 12614 citations and average citation is 28.28.

Table 1: Top 10 productive countries

No.	Countries	Articles	Citations	Average Citation
1.	People's Republic of China	820	12032	14.67
2.	*United States* of America	446	12614	28.28
3.	Netherlands	409	9468	23.15
4.	Germany	186	3140	16.88
5.	France	133	2883	21.68
6.	Italy	125	2630	21.04
7.	Canada	109	2443	22.41
8.	South Korea	85	1395	16.41
9.	Spain	83	1712	20.63
10.	India	78	1394	17.87

3.3 Co-authorship of Countries

Figure 3 shows the networking among the countries of international co-authorship. The VOSviewer software was applied to create the bibliometric network map for co-authorship of countries. The minimum number of the publication of a country is set to 5 papers which means that the countries involved in the co-authorship analysis have at least 5 publications [17, 18]. The threshold of 5 papers is selected based on the size of the dataset. This step helps to filter out incident collaborations that may not represent a strong or enduring research connections.

Table 2: The 5 main clusters of co-authorship of countries

Clusters	Items
1 (Red)	Australia, Bangladesh, India, Indonesia, Latvia, Malaysia, Pakistan, Saudi Arabia, Scotland, South Korea, Thailand, Tunisia, United Arab Emirates, Vietnam
2 (Green)	Argentina, Chile, Columbia, Finland, Germany, Italy, Mexico, Netherlands, Romania, Russia, South Africa, Spain
3 (Sky blue)	Austria, Croatia, Denmark, Greece, Slovenia, Sweden
4 (Yellow)	Canada, People's Republic of China, Singapore, Taiwan, USA
5 (Light purple)	Belgium, France, Japan, Luxembourg

Among the 85 countries, 53 countries meet the threshold and the rest of them have been excluded due have only 1 until 4 publications. Table 2 shows the top 5 main clusters of the co-authorship of countries.

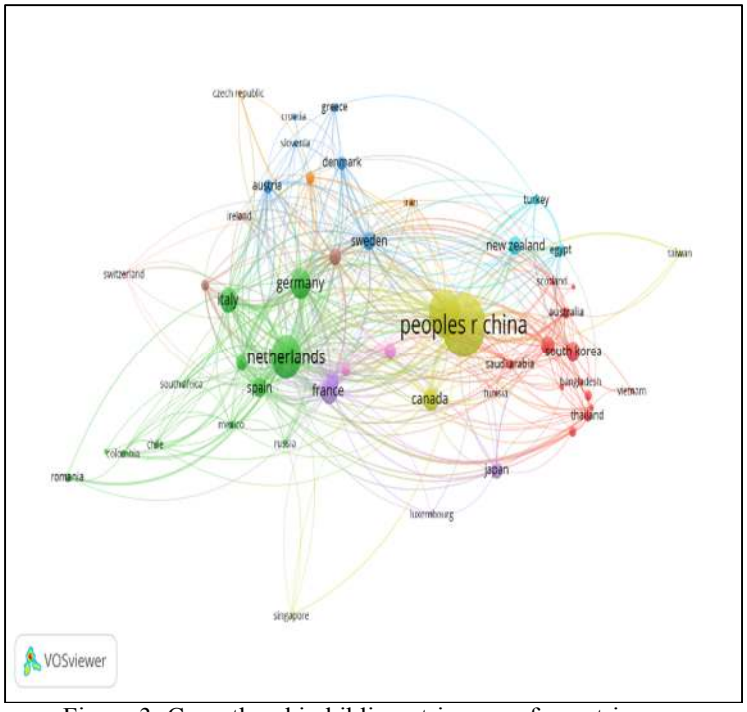

Figure 3: Co-authorship bibliometric map of countries

3.4 Productive Journals

The top 10 productive journals related to biobased products are shown in Table 3. The year of journal published total publication, citation, and average citation was discussed in this study. The highest productive journal is ACS Sustainable Chemistry & Engineering with a total publication of 159 articles. The total citation for this journal is 4838 articles and the average citation reach 30.43 articles. The ranked 2nd productive journal is Journal of Biobased Materials and Bioenergy, which was first published in year 2007 with 116 articles published. Meanwhile, the third productive journal related to biobased products is Industrial Crops and Products.

Table 3: Top 10 productive journals

No.	Journal	First Publication Year	Total Publication	Total Citation	Average Citation
1.	ACS Sustainable Chemistry & Engineering	2013	159	4838	30.43
2.	Journal of Biobased Materials and Bioenergy	2007	116	1254	10.81
3.	Industrial Crops and Products	2005	61	1334	21.87
4.	Polymers	2012	52	397	7.63
5.	Green Chemistry	2008	49	2502	51.06
6.	Journal of Cleaner Production	2007	48	1109	23.10
7.	Journal of Applied Polymer Science	2006	43	734	17.07

8.	Bioresource Technology	1999	42	1346	32.05
9.	Journal of the American Oil Chemists Society	2004	35	884	25.26
10.	Bioresources	2008	32	492	15.38

3.5 Highly cited articles

The top 10 highly cited articles throughout the period from 1993 to 2022 is presented in Table 4. The highest citated article during this period is the research from Kim and Dale [19]. with the paper title "Global potential bioethanol production from wasted crops and crop residues". The total citation of their article is 1252 citations and the average citation during this period is 65.89. This article proposes some potential crops and wastes to be used to produce bioethanol. The objective of this paper is to determine the feasibility and sustainability of utilizing agriculture waste as a renewable resource for biofuel production. The key findings of the paper are to investigate the potential of waste crops as an environmentally friendly and sustainable resource for bioethanol products.

The second mostly cited articles written by Nagarajan, Mohanty and Misra [21]. entitled "Perspective on Polylactic Acid (PLA) based sustainable materials for durable applications: focus on toughness and heat resistance". The total citation of this article is 468 citations from year 2016 to year 2022, with average citation 14.86 citation yearly. This paper focuses on discussing the challenges and strategies for improving polylactic acid properties to achieve sustainability.

The third mostly cited articles are "Metrics of Green Chemistry and Sustainability: Past, Present, and Future" which is written by Seldon [22] have 398 citations with 16.05 citation annually. This study highlighted the development of metrics towards the environmental and sustainability of chemical processes and products. This paper offers a valuable insight to researchers, policymakers and practitioners on the historical development, current landscape and future direction related to green chemistry and sustainability.

Table 4: Top 10 highly cited articles

No.	Article	Author	Year	Journal	Total Citation	Average Citation
1.	Global potential bioethanol production from wasted crops and crops residues	Kim and Dale	2004	Biomass and Bioenergy	1252	65.89
2.	Perspective on Polylactic Acid (PLA) based Sustainable Materials for Durable Applications: Focus on Toughness and Heat Resistance	Nagarajan, Mohanty and Misra	2016	ACS Sustainable Chemistry & Engineering	468	14.86
3.	Metrics of Green Chemistry and Sustainability: Past, Present, and Future	Sheldon	2018	ACS Sustainable Chemistry & Engineering	398	16.05
4.	*Acid in ionic liquid: An efficient system for hydrolysis of lignocellulose*	Li, Wang and Zhao	2008	Green Chemistry	386	7.92
5.	Biomass and renewable fuels	Chum and Overend	2001	Fuel Processing Technology	344	1.99
6.	Towards industrial products from microalgae	Ruiz et al.	2016	Energy & Environmental Science	337	10.70
7.	Isolation and characterization of cellulose nanofibers from four plant cellulose fibers using a chemical-ultrasonic process	Chen, Yu, Liu, Hai, Zhang and Chen	2011	Cellulose	322	6.89
8.	Synthesis and applications of alkyl levulinates	Demolis, Essayem, and Rataboul	2014	ACS Sustainable Chemistry & Engineering	301	8.17
9.	Comprehensive elucidation of the effect of residual lignin on the physical, barrier, mechanical and surface properties of nanocellulose films	Rojo et al.	2015	Green Chemistry	286	8.90
10.	Techno-economic evaluation of microalgae harvesting and dewatering systems	Fasaei, Bitter, Slegers, Boxtel	2018	Algal Research	236	9.52

3.6 Keywords Analysis

Table 5 presents the top 10 author's keywords related to biobased products. Keywords can help the researcher to explore and search for the content that they are interested in and thereby understand the research hotspot in the field. Besides that, keyword analysis can provide information about the main themes and topics of the study and hence the researcher can identify the emerging trends or topics within a specific field of research [20]. The keywords are biorefinery, lignin, biomass, biobased products, life cycle assessment, biobased, mechanical properties, sustainability, pyrolysis, and circular economy. The biorefinery is the keyword with the highest frequency due to the popularity of converting fossil energy to biomass as raw material for fuel and chemical production has become the driving force for the development of biorefinery complexes. The frequency of the lignin and biomass are the second and third keywords that appear in the articles. The lignin has proven to be a viable alternative to petrochemical-based polyols when incorporated into polyurethanes due to its low cost, abundance, reactive functional groups, and reduced isocyanate consumption. Besides this lignin also can be used as a raw material in various industries such as automotive, wood panel products, biodispersants, polyurethane foams, and epoxy resins [23].

Table 5: Top 10 author's keywords

No.	Keywords	Frequency

1.	biorefinery	86
2.	lignin	84
3.	biomass	82
4.	biobased products	55
5.	life cycle assessment	46
6.	biobased	45
7.	mechanical properties	42
8.	sustainability	35
9.	pyrolysis	31
10.	circular economy	29

In addition, a world cloud analysis is presented in Figure 4. The key findings of the world cloud analysis are like the keyword analysis, with a slightly different in presenting the outputs. World cloud is a visual representation of textual data. The keywords are present in different sizes based on the frequency or importance. Figure 4 shows that lignin has a large font size. Lignin is popular due to its present abundance in natural as a renewable resource and its able to use in production of biofuel and a lot of biobased products. While lignin is ranked second in Table 5. This difference is because keyword analysis provides a more comprehensive measure of keywords used in the research articles. It ranked the keywords based on the number of occurrences in the datasets. The other popular keywords are biobased, sustainability, circular economy, bioeconomy, pyrolysis and others. By observing the keywords displayed in the world cloud analysis, researchers, policymakers, and practitioners can identify the trends and research hotspot.

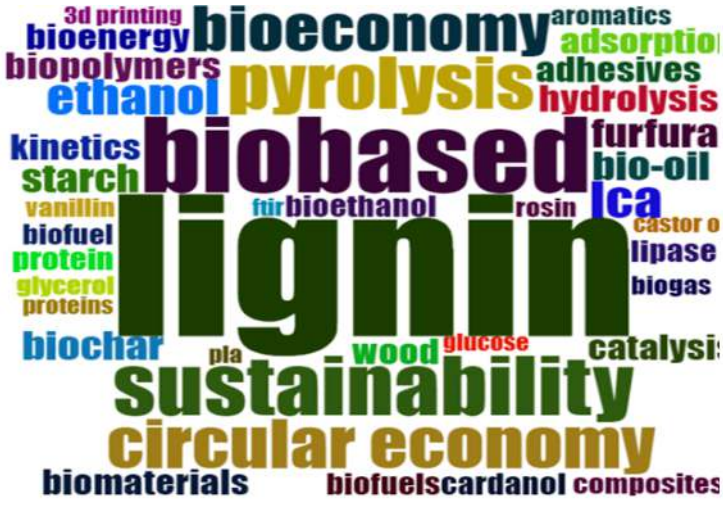

Figure 4. Word cloud of keywords

3.7 Co-occurrences of keywords

A total of 7296 co-occurrence of keywords were founded. In order to study the co-occurrences of the keyword, a threshold number 5 is selected based on the size of the data. Therefore, the keyword involved would need to appear at least 5 times among all publications. As a result, only 288 words out of the 7296 keywords have met the threshold and the findings are recorded and presented in Table 6. There are five main clusters of the co-occurrences keywords, and each cluster is labelled with a different colour for the purpose of allowing the reader to understand and visualize it easily.

Table 6: Top 5 main clusters of co-occurrences of keywords

Clusters	Items
1 (Red)	antibacterial activity, antioxidants, bio-based, biobased, biobased plastics, biobased polymers, biocompatibility, biodegradable polymers, biodegradation, bioeconomy, bioplastic, biopolymer, cardanol, cellulose fibers, circular economy, click chemistry, crystallization, electrospinning, end-of-life, epoxy resin, flame retardancy, food packaging, food waste, life cycle assessment (lca), migration, pla, poly(lactic acid), polylactic acid, recycling, renewable materials, shelf life, soybean oil, sustainability, thermal decomposition, thermal degradation, thermal stability, thermoset, vanillic acid, vanillin, waste management.
2 (Green)	5-furnandicarboxylic acid, adhesives, applications, biocomposite, biodegradable, biomaterials, bioplastics, biopolymers and renewable polymers, blends, catechol, cellulose and other wood products, coatings, composites, crosslinking, degradation, extrusion, fibers, films, isosorbide, modelling, nanoparticles, nmr, packaging, polyamides, polycarbonates, polycondensation, polyesters, polymers, polyphenols, properties and characterization, renewable resources, resins, self-assembly, starch, thermoplastics
3 (Sky blue)	abe fermentation, adsorption, biobased economy, biochemicals, bioconversion, bioenergy, bioethanol, biofuel, biofuels, biorefinery, butanol, corn, e.coli, enzymatic hydrolysis, ethanol, fermentation, ghg emissions, hemicellulose, inhibition, kinetics, lactic acid bacteria, lca, life cycle assessment, lignocellulosic biomass, miscanthus, polyhydroxyalkanoates, pretreatment, seaweed, succinic acid, techno-economic analysis, xylose
4 (Yellow)	3D printing, additive manufacturing, aging, antioxidant activity, biocomposites, biopolymers, bitumen, characterization, composite, emulsion, gc-ms, mechanical properties, microalgae, microstructure, natural fibers, optimization, ph, physicochemical properties, polysaccharide, polyurethanes, protein, response surface methodology, rheological properties, rheology, rosin, self-healing, structure, sugars, temperature, texture, thermal properties
5 (Light purple)	antimicrobial activity, biobased surfactant, biocatalysis, biofilm, biosurfactant, biosurfactants, biotechnology, by-products, carbohydrates, corn stover, enzyme catalysis, enzymes, energy, gamma-valerolactone, hemicelluloses, ionic liquid, lignocellulose, lipase, milk, monoclonal antibody, process design, purification, surfactant, surfactants, sustainable chemistry, switchgrass, xylan, xylanse

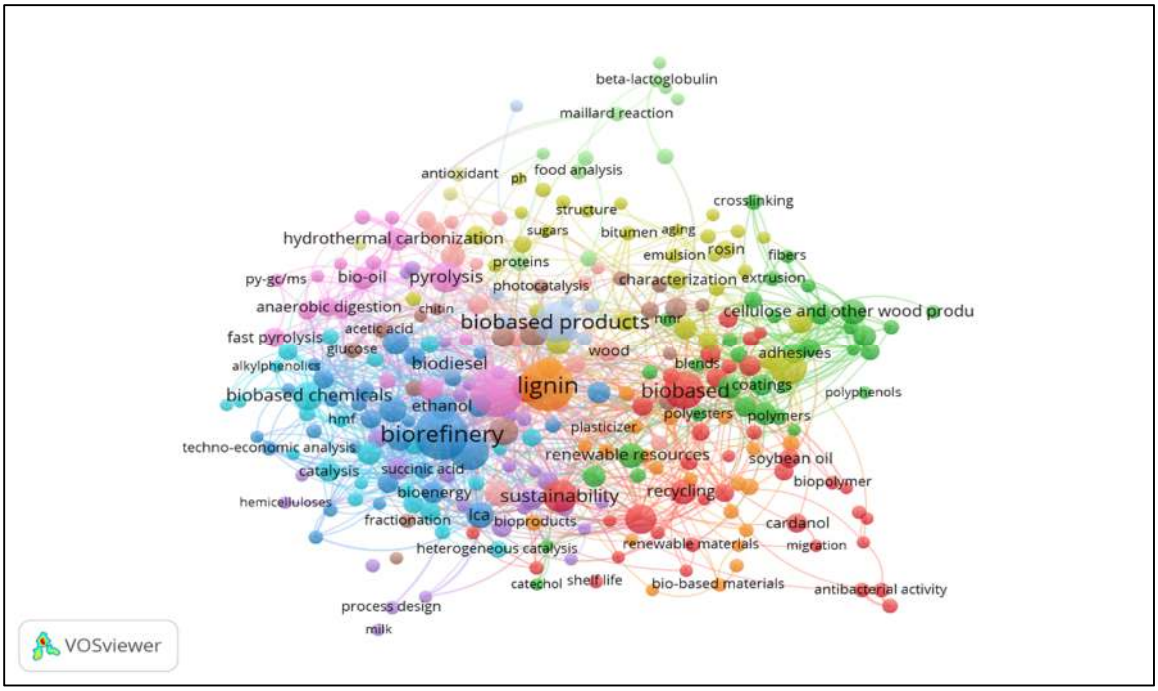

Figure 5: Co-occurrence bibliometric map of author's keywords

IV. CONCLUSION

A bibliographic or bibliometric analysis is employed in this paper to understand the research trends by studying a large-scale of the datasets. The data is retrieved from Web of Science database. A twenty year analysis from 1993 until 2022 is utilized in the study. A total of 2580 documents are selected after excluding the conference proceedings, book chapter, editorial material, new items, meeting abstracts, early access, review articles and books. Furthermore, there are 15 non-English articles also take out from the data. The findings show that the publication related to biobased products is gradually increasing throughout the year. Biobased products are created from sustainable resources, which can lessen reliance on scarce fossil fuels that are anticipated to increase in cost over the next few decades and have the potential to be more environmentally friendly. Besides this, the novel technology on creating biobased products such as bioplastic, bio-resin, biobased detergent, etc is also urged by the demand of the stakeholder and propelled by government. Biobased products are well known as the alternative to non-renewable materials which can help reduce environmental impact, conserve natural resources, and promote sustainability in various industries. In terms of the number of publications, The People's Republic of China have the highest article published related to biobased products, but United State of America have the highest number of citation and average citation from 1993 to 2022. Furthermore, there are 85 countries are reported to have at least one journal article about biobased products in the Web of Science database. In order to investigate the co-authorship of countries, the VOSviewer software is used to create a bibliometric network map and there are five clusters presented in Table 2 and Figure 3. The most productive journal obtained is ACS Sustainable Chemistry & Engineering which has 159 publications and 4838 citations. Meanwhile the title of the highest cited article is "Global Potential Bioethanol Production from Wasted Crops and Crop Residues" that was published by Kim and Dale in 2004. While the most used author's keywords are biorefinery and lignin. Besides that, the top 5 main cluster of the co-occurrences of keywords also be created by using the Biblioshiny software. There are some suggestion or recommendation for the future research based on the findings of this paper:

Science discipline:

1. Examine what is the potential materials to replace the non-renewable materials.
2. Investigate novel biobased materials and composites wuth enhanced properties for various application.
3. Determine the efficient bioprocessing techniques and integrated biorefinery approaches to maximze the utilization of the resouces.
4. Explore the efficient biobased product in reducing the waste in various industry.

Social Science

1. Analysis the market trends or consumer preferences and behaviour related to biobased product.
2. Study the efficient method on promoting the biobased product.
3. Discuss the impact of goverment policies and regulation on the development and adoption of biobased products, and recommend policy adjustments to promote sustainability.
4. Investigate the strategies for bioeconomy.

The implication of this study is to provide a systematic and

quantitative approach to evaluate the impact of journal articles, authors, institutions, and journals. This is essential to assist the researcher, policy maker and funding agencies in making informed decisions regarding to the research and development and funding allocation related to biobased research. Furthermore, this study also contributed to the researcher to identify the research gap. Additionally, this study may serve as a resource for industry stakeholders in the development of biobased products over the past 20 years, as such products, made from sustainable biobased materials, can provide companies with a competitive edge.

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