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Environmental Justice: A Panoptic Overview Using Scientometrics

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Abstract: Since its initial introduction in the 1970s, the field of environmental justice (EJ) continues to grow, with significant contributions from the disciplines of sustainability science, geography, political science, public policy and administration, urban planning, law, and many others. Each of these disciplines approach EJ research from slightly different perspectives, but all offer unique and valuable insight to the EJ knowledge domain. Although the interdisciplinary nature of environmental justice should be viewed as a strength, it presents a challenge when attempting to both summarize and synthesize key contributions to the field, due to disciplinary bias, narrow subfield foci, or gaps in knowledge by a research team without a representative disciplinary composition. The purpose of this paper is to provide a succinct, panoptic review of key research contributions to environmental justice, while simultaneously minimizing common problems associated with traditional reviews. In particular, this paper explores the utility of co-citation network analysis, to provide insight into the most important subdomains of environmental justice research. The results suggest that while early EJ research is initially focused on environmental disamenities and a continued focus on race and inequality, the research gradually shifts to foci more concerned with environmental amenities, such as parks and greenspace. We also find that race and inequality remain an important and consist line of research over the duration of the study time period. Implications for environmental justice research and its allied subfields are discussed.

Keywords: environmental justice; environmental injustice; citation analysis; co-citation network

1. Introduction

Environmental justice (EJ) is an expansive domain that has received attention from a multitude of academic disciplines. From its genesis in the 1970s [1,2] to the more recent research of the 2000s, EJ has been a key research topic in geography, political science, public policy and administration, urban planning, sustainability, law, and many other fields. EJ has been defined by the Environmental Protection Agency (EPA) as the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws regulations and policies" [3] (p. 1). Brulle and Pellow cite a similar definition: "Environmental justice is the principle that all people and communities are entitled to equal protection of environmental and public health laws and regulations" [4] (p. 104). EJ, then, is concerned with the equity of laws pertaining to the environment. Specifically, there should be an equitable distribution of access to regulations, and an unbiased representation of all groups, classes, and races that may be impacted by specific environmental or human health risks.

Over time, as EJ progressed as a field, allied (but separate) research domains have emerged. For example, environmental inequality can be distinguished from EJ by its focus on specific social groups disproportionately affected by environmental hazards [4,5]. Environmental racism has also

gained traction, and explores specific discriminatory acts of environmental policy making, enforcement of regulation, and the deliberate targeting of communities of color as the site for environmental disamenities or hazardous facilities [6,7]. More simply, environmental racism refers to any policy, practice, or directive that differentially affects or disadvantages individuals, groups, or communities based on race or color [8]. Many would argue that environmental racism was first brought to the fore following an attempt to place a highly toxic polychlorinated biphenyl (PCB) disposal facility in Warren County, South Carolina—a rural, low-income county with predominately black residents. The move was eventually blocked, and led to the landmark regional study conducted by the United Church of Christ (UCC) documenting the discriminatory situating of toxic waste facilities in the United States. Following the UCC study and increased awareness of EJ, the EPA subsequently adopted its definition of EJ, and President Clinton signed Executive Order 12,898 in 1994, which brought environmental and human health issues for minority and low-income communities into the federal spotlight, with a goal of achieving environmental protection for all communities [9].

As illustrated above, several terms have been used in the discussion of EJ issues. Not surprisingly, throughout the 1980s and 1990s researchers from a variety of disciplines were meticulously addressing issues of EJ, inequality, and racism. Initial efforts relied on exploratory statistics and descriptive work [10]. However, over time, EJ researchers realized the need to develop stronger theoretical frameworks for identifying the processes that fueled disparate levels of exposure to pollution and environmental problems among communities [11]. This was especially important for decision-makers at the federal, state, and local levels, as they attempted to develop a deeper understanding of the causal mechanisms of environmental injustices that differentially affected communities, especially those of color.

One of the ways the evolution of EJ can be captured and characterized is through scientific literature. As detailed by Chen [12], scientific literature generally refers to the collection of publications that focus on testing, developing, and explaining the theories and issues in different substantive fields—representing recorded human intelligence. Wei and colleagues [13] note that although much of this literature is understood at an elementary level (e.g., read and understood), the relationships between authors, articles, publication outlets (e.g., journals), and publication years can be much less clear. This is especially true in the domain of EJ because so many different fields have contributed to the literature. There are myriad tools and techniques to uncover these hidden connections in the scientific literature [14], including bibliometric approaches, such as co-citation analysis [13,15,16]. Co-citation analysis is an approach focused on the systematic analysis of bibliographic records of scientific documents. This recorded information is used to uncover the hidden (or frequently overlooked) linkages in a field or between fields.

The purpose of this paper is to explore how the field of EJ has evolved since the year 2000 through a co-citation analysis. This time frame allows for the capture of important research topics that carried over from the 20th century, while also providing valuable insight into the emergent topics of the field. This paper explores the knowledge domain of EJ through four key subdomains: (1) environmental justice; (2) environmental injustice; (3) environmental inequality; and (4) environmental racism. We are particularly interested in identifying important theoretical frameworks and advancements, as well as highlighting the most influential scientific works and their underlying connections. Given the depth and breadth of EJ research, we cannot hope to cover every subdomain. However, the four subdomains highlighted in this study comprise the largest and most high-profile contributions in the EJ literature. In short, this work is not purposed or structured as an exhaustive analysis of environmental justice research—rather, it is meant to illustrate how bibliometric techniques can be utilized to explore hidden knowledge spaces and identify the important, and sometimes overlooked, connections between EJ subdomains.

2. Environmental Justice 1.0: An Overview of the Field and Its Dynamics

Much of the early work in environmental justice was fueled by the obvious bias in the placing of environmental burdens with respect to ethnic and racial minorities, as well as socioeconomic

class [5,17]. The bulk of this research was dedicated to providing descriptive or statistical evidence of the unequal burdens of exposure to pollution and toxins in specific communities [18–21]. While important, this work was slow in establishing a strong theoretical basis for examining EJ issues, and in identifying the underlying causal mechanisms and differentiated forms of spatiality that fueled inequities in exposure [22]. In response, the work of the late 1990s and 2000s demonstrated a stronger push for defining and testing new and improved theoretical bases for many of the early observations made in EJ studies. This work helped to move the field beyond examining localized pollution patterns.

Interestingly, this push evolved concurrently, and in somewhat disparate disciplines. For example, work in the 1990s covered everything from children's exposure to lead (public health), racial disparities in health (sociology), farm worker and pesticide exposure (agricultural studies), the consumption of fish with differing levels of pollution (fisheries science), and the geographic coincidence of hazard and population (geography) [10,23]. Again, the concrete theoretical frameworks that allowed for the identification of the specific causal linkages between communities of color or low socioeconomic status to the prevalence of environmental and human health hazards were largely underdeveloped. This changed when more rigorous sociopolitical theories were introduced to EJ. For example, Vicki Been, a prominent law professor from New York University, published a controversial article demonstrating that EJ was primarily a function of immigration into a polluted area. Using a push-pull neighborhood change model, Been [24] suggested that movement into communities with established toxic release facilities was driving the disproportionate distribution of noxious facilities in communities of color and the poor. Been [24] argued that the land around the noxious facilities was inexpensive, thereby pulling those that could not afford to live elsewhere to the area, while at the same time pushing out those that could afford to move. This was a controversial perspective, because it largely absolved direct forms of racism from the process and contradicted the bulk of EJ research that connected the intentional establishment of hazardous facilities in areas of high racial or ethnic minority populations or low-income communities.

Reactions to Been's research were mixed. Some scholars were supportive of her argument, emphasizing that the existing EJ debate was ahistorical and needed to include data on the immigration patterns for a city or region [25]. Others argued that neighborhoods were segregated prior to the building of noxious facilities [26]. In effect, both the segregation of the neighborhood and the decision to place the facilities could be driven by blatant racism, the Coase theorem [27], or the theory of collective action [28].

Causal mechanisms aside, the arguments for and against immigration or racism highlighted the importance of a historical perspective and an associated context for EJ outcomes. Several existing theories of neighborhood change were enlisted for the EJ arguments. In addition to the push-pull model described above, additional neighborhood change theories included the classic invasion–succession model [29], life cycle model [30], and the institutional theory of neighborhood change [31], all of which describe processes other than racism in siting decisions. Other frameworks included the "perpetrator-victim scenario", which gained traction in the late 1990s as a way to describe the locational distribution of hazards. This scenario proposed that communities with higher exposure to hazards were comprised of the poor or people of color (victims) because they were less powerful than the corporations or government entities (perpetrators) that were making the locational decisions for the environmental or human health hazards [32]. Critics of this framework suggested that this explanation was too simplistic and ignored important details [18], such as political mechanisms or any underlying historical processes that shaped how locational decisions were made.

Several other prominent theoretical bases have been used to understand the dynamics between facility locations and demographics. A broad field of economic and locational theories include externalities and public goods [26], welfare economics [33], residential location theory [34], and industrial location theory [35]. Unlike the theories of neighborhood change, some economic and locational theories hypothesize that demographic variables will be strongly related to decisions about

where to build; however, rather than being malicious, industries are seeking the most economically viable locations that coincide with resources, work force, rent, and externalities.

Others called on the field to disentangle whether race or class matter more, and to study processes rather than outcomes [36]. Interestingly, these calls to action and intellectual inquiry emanated from a rather differentiated group of actors turning their attention toward EJ in the 1990s. While only a few scholars have been highlighted in this brief review, their academic backgrounds vary significantly. For example, Been is a law professor, Krieg and Weinberg are sociologists, Bullard a professor of public administration, Pellow's background is environmental studies, and Silliman is a professor of women's studies. This list is by no means complete, but it does illustrate the diversity of the backgrounds of those engaged in EJ research.

As the field of EJ moved into the 21st century, the literature strongly pointed towards a disproportionate allocation of environmental disamenities existing within specific communities, especially in locales where poor and minority populations were more prominent. Again, this era of EJ research also serves as an inflection point, with scholars calling for more work on the underlying causal mechanisms of the distribution of environmental and human health hazards. One way to determine progress (or lack of it) in advancing research on processes associated with EJ, injustice, racism, and inequality is through scientometric analysis, and a deeper dive into the EJ knowledge domain as a whole.

3. Methods, Tools, Data, and Process

3.1. Scientometrics

Scientometrics is a field dedicated to the quantitative study of science, communication in science, and science policy [37]. That is, scientometricians seek to understand how science and knowledge are produced, as well as how science is interlinked. As indicators of scientific output have become increasingly available through databases, publications, and patents, the field of scientometrics has developed advanced tools and methods for quantifying scientific output by using citation analysis. Consider, for example, the metrics used to rank the impact of scientific contributions from individual authors. These include the h-index [38], the g-index [39], and the i10 index, the latter of which is exclusive to Google Scholar (GS). The field of scientometrics also focuses on the "mapping of science", by establishing citation networks through keywords, titles, authors, or specific disciplines. Both PubMed and the Web of Science (WOS) are major database contributors in this domain. These databases provide citation information for each journal entry, and this information can be leveraged to explore the network connections and the relationships between different scientific fields [40–42]. One of the more recent advancements in the field of scientometrics is the addition of advanced visualization tools for bibliometric analyses. These tools graphically illustrate how a field has developed over time, and how each of the individual articles within that field are related (or not). One of the most popular is CiteSpace [12], which will be used for this analysis.

3.2. Tools

CiteSpace is a desktop application, written in the Java programming language, which was built for the purposes of visualization and analysis of the bibliographic linkages between authors, institutions, countries, keywords, journals, or references, using the citation information stored within article databases and search engines [12]. CiteSpace is particularly adept at summarizing large and sometimes disparate information from multiple domains or literatures. A key advantage of using CiteSpace is its ability to parse large sets of references and create clusters and network links that are difficult (if not impossible) to construct without a strong background in data mining or machine learning.

Although CiteSpace offers scores of different tools, metrics, and associated features, there are several in particular that help build the foundation for this analysis. First, this paper makes use of the *betweenness centrality* score. Betweenness centrality is an important metric which provides insight into articles that connect two different bodies of research within a specific knowledge domain. Difference is

calculated using a combination of title or keywords used by papers within the network. Betweenness centrality provides a measurement of the boundary-spanning potential of a paper that can lead to shifts in research or theories [43]. Specifically, nodes (i.e., papers) gain centrality as the number of paths making up the network pass through a node, or when a particular node is more "central" to the network overall. Betweenness centrality is widely used in other domains, including infrastructure systems [44], social network analysis [45], statistical physics [46], and air transport [47].

Another foundational metric used in this study is *burst level*. Burst detection is a technique used to measure a substantial change in an event or other type of information [48]. In this context, a burst signifies that a manuscript has received an above-average number of citations for a given year. For example, a paper published in 2005, which receives only one or two citations for the first few years after publication, would have a low burst level. Subsequently, if that paper begins to receive citations at a higher rate, CiteSpace will highlight this burst of activity. Bursts are a useful metric, because they highlight when (and what) topics and papers gain traction within a knowledge domain for a certain period of time. Sustained bursts indicate a particularly salient topic or paper that remains important to the field.

Finally, CiteSpace can use keywords, abstracts, or paper titles to create *clusters* of papers. Clusters can be identified in several ways, including a hierarchy of key terms from articles that cite the cluster, the most important members of the cluster, or themes that reoccur within the articles that cite papers within the paper [48]. Each of these cluster descriptions are used to reflect the interrelationship between the intellectual base and the research domain. A cluster can be thought of as typifying the underlying specialties of the cluster members.

3.3. Data, Resources, and Process

We built the EJ knowledge domain network using the Web of Science (WOS) and CiteSpace [12]. We queried WOS using the four most common terms used to refer to EJ research and subdomains: "Environmental Justice" OR "Environmental Injustice" OR "Environmental Inequality" OR "Environmental Racism". The date range for the query was restricted, so that only articles published between 2000 and 2017 would be returned. The list was sorted by citation count, and the associated bibliometric information for the top 2500 articles in the list were downloaded and used to build the network. Within those 2500 articles, 98,742 valid references were cited. After some sensitivity testing, we decided to use the top 50 most-cited articles from each time slice, which resulted is a network of 747 nodes and 2629 links.

A few caveats regarding WOS merit further consideration. Even though WOS is one of the most comprehensive databases for academic literature, it does not contain all articles from every journal, conference, or conference preceding. For example, if we were to compare the citation counts between WOS and GS, the latter would certainly report more citations. One reason for this is that GS includes unpublished papers, as well as reports that are stored on the servers of academic institutions or publicly accessible websites. However, although the WOS is slightly limited in specific references, it is more strongly curated. Some work has also concluded that WOS is biased toward journals and articles published in the United States [49]. The database tends to have higher numbers of journals and articles published in the U.S. when compared to other countries, which may ultimately skew results to a U.S.-leaning substantive foci. Still, because CiteSpace builds the network using citation information rather than the individual papers themselves, global inclusivity is less of a concern. If an article references a work that is not included in the WOS database, the citation network will still be able to include that citation as a node in the network.

3.4. The Network

Figure 1 is the graphical representation of the citation network. Citation information is represented through variation in color and size. The link color between nodes corresponds to the time period (year) when the co-citation was first made. For example, blue links represent references co-cited

by a paper published in 2000, while orange/red links correspond to the first co-citation occurring in 2016/2017. Second, the size of the nodes correspond to the frequency of citation, and indicates its relative importance in the field. Third, pink rings represent an article with a relatively high betweenness centrality. Again, these papers are paradigm spanners, bridging two research areas within the knowledge domain. A quick look at the co-citation network reveals the progression and evolution of EJ over time, with respect to highly-cited papers (larger nodes) and the papers that help create intellectual bridges within the EJ knowledge domain (pink rings around the node). In the interest of enhancing clarity and space limitations, we will be focusing this analysis on peer-reviewed research articles, although books and conference proceedings could also be included.

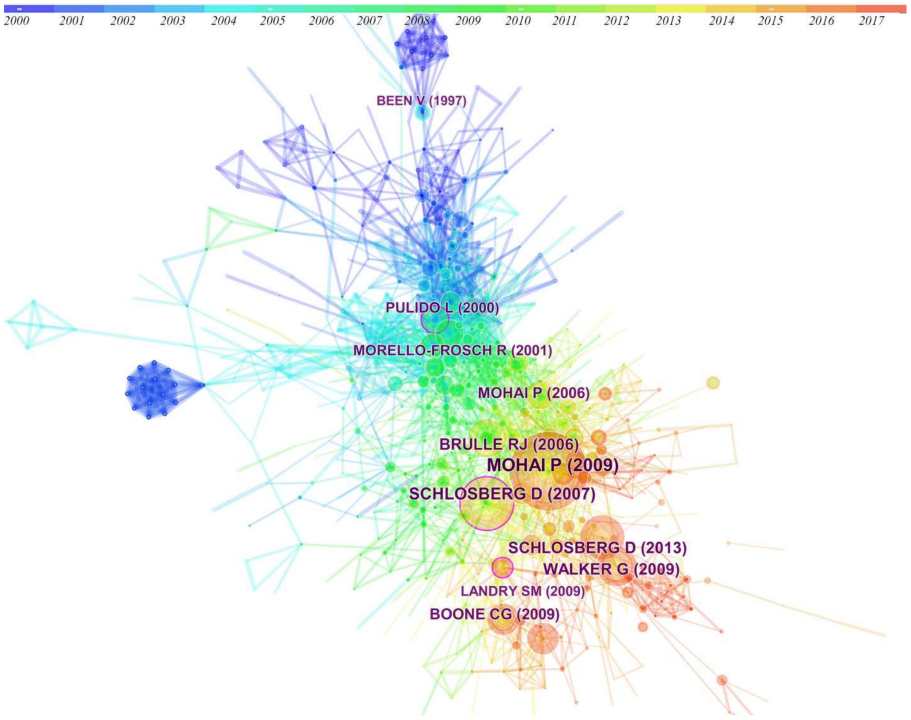

Figure 1. Co-citation network built using environmental justice articles published between 2000 and 2017. Link color corresponds to the year when the co-citation first occurred. Node size represents citation frequency. Purple rings around the node signify a high betweenness centrality score.

Table 1 provides some interesting insight into the geographic location of where authors publish from. As the reader can see, the United States has a large and overwhelming presence within the EJ literature, with almost seven times more articles than the next country. Basically, many of the authors within this corpus of literature are working at an institution within the United States. Interestingly, England has the largest centrality within the network (0.55) meaning that the papers published by English authors provide an important link between the different countries. So although authors residing in the United States may publish more papers, authors from England remain a crucial component for facilitating knowledge within the network.

Consider, for example, the eight papers highlighted in Table 2—all of which had a significant impact in the field of EJ. While we cannot say for certain why these articles ended up as both highly central and highly cited, we can make some inferences based on their content, cluster membership, and linkages to other papers. The Schlosberg [11] piece is particularly interesting. Although it is not one of the most-cited papers, it is the most recently published paper with a high number of citations—its burst extends into 2017, and connects two or more bodies of research together. Given the paper's relative newness, is this type of impact unexpected? Perhaps it is. In the following section, we dig

deeper into the papers detailed in Table 2, exploring the structure of the co-citation network in an attempt to provide a more holistic view of the field and its growth over the past two decades.

Table 1. The co-author country of origin for the papers included within the co-citation network. Multiple occurrences of the same country within a paper are only counted once. The U.S. has the largest presence, followed by England and Canada.

Country	Centrality	Year	Article Count
U.S.	0.24	2000	1553
England	0.55	2000	258
Canada	0.1	2001	178
Australia	0.04	2001	93
Spain	0.06	2001	73
Germany	0.04	2002	73
Scotland	0.06	2005	57
The Netherlands	0.08	2004	56
China	0.04	2005	48

Table 2. Important papers worth further consideration. These papers have a high citation frequency, prominent citation burst, high centrality, or a combination of all three.

Author/s	Title	Year	Cite Frequency	Burst Level	Burst Year/s	Centrality	Journal
Boone, et al.	Parks and People: An Environmental Justice Inquiry in Baltimore, Maryland	2009	57	13.60	2012–2017	0.03	*Ann Assoc Am Geogr*
Mohai, P.; Pellow, D.; Roberts, T.	Environmental Justice	2009	129	31.15	2012–2017	0.09	*Annu Rev Env Resour*
Walker, G.	Beyond Distribution and Proximity: Exploring the Multiple Spatialities of Environmental Justice	2009	68	19.25	2013–2017	0.03	*Antipode*
Brulle, R.J.; Pellow, D.	Environmental Justice: Human and Environmental Inequalities	2006	67	19.97	2008–2014	0.03	*Annu Rev Public Health*
Morello-Frosch, R.; Pastor, M.; Sadd, J.	Environmental Justice and Southern California "Riskscape"	2001	45	14.23	2004–2009	0.07	*Urban Aff Rev*
Pulido, L.	Rethinking Environmental racism: White Privilege and Urban Development in Southern California	2000	48	15.82	2002–2008	0.10	*Ann Assoc Am Geogr*
Mohai, P.; Saha, R.	Reassessing Racial and Socioeconomic Disparities in Environmental Justice Research	2006	51	16.74	2008–2014	0.03	*Demography*
Been, V.; Gupta, F.	Coming to the nuisance or going to the barrios? A longitudinal analysis of environmental justice claims	1997	33	13.00	2000–2002	0.09	*Eco. Law Quar.*
Schlosberg, D.	Theorizing Environmental Justice: The Expanding Sphere of a Discourse	2013	71	27.71	2014–2017	0.03	*Environ Polit*

4. Influential Papers

Astute readers will immediately recognize that two of the nine papers highlighted in Table 1 are reviews. Structured reviews are often highly cited because of their ability to synthesize a wide range of related (and sometimes disparate) work in a particular domain. We will cover these contributions only briefly. The remaining five papers in Table 2 are not reviews, yet they are critically important to the field of EJ. The question is, why? We will delve into these contributions, highlighting their role within EJ.

4.1. Environmental Justice Reviews

The earliest review included here is Brulle and Pellow [4]. The review begins by highlighting the main contributions to the field and its development up until 2006. The authors present a strong theoretical base for *environmental inequity*, with a strong focus on the debate between race versus class. For example, the treadmill of production [50] and historical racial segregation are summarized

as illustrations of two larger theoretical frameworks, which "systematically create environmental inequality" [4] (p. 108)—the *market economy* and *institutionalized racism*. The market economy theory is realized through the "treadmill of production", which supposes that industries are on a treadmill and constantly seeking new resources as they use up others. The byproduct of industrial production is inevitably pollution, which negatively effects surrounding communities. Racial segregation elements are more focused on the persistent historical processes perpetuated through differential opportunities for housing, occupation, and education [51]. These disparities contribute to the unfair allocations of environmental hazards, which often materialize through a "class pattern" or "race pattern". In sum, these theories and their empirical outcomes motivated much of the EJ research up until 2006. The succinct review provided by Brulle and Pellow is supported by a substantial number of relevant works that strongly connect their paper to EJ scholarship.

Mohai et al. [52] is similar in structure and content to Brulle and Pellow [4]. The main contribution of this review is a description of three broad, interrelated causal factors found among the articles included in their review: (1) economic considerations, (2) path of least resistance, and (3) racism. These conceptualizations fall within the already established theoretical frameworks used in the EJ field, namely the historical nature of hazard sites versus minority immigration/emigration; racial determinants compared to class determinants; and coalition theories, which fall under economic theories of EJ.

A unique perspective offered by Mohai et al. [52] is whether or not decisions, ostensibly based on economics, are actually forms of racism if there is no explicit intent to discriminate. Critical race theory is used to inform this discussion, highlighting the concept of intersectionality—where market forces and class inequalities are never race-neutral. As a result, economic motivations are, in fact, racially biased. What makes this review so important is the call for future research in the EJ domain. Mohai and colleagues [52] note that research on successful (and unsuccessful) EJ movements is necessary in order to understand the social dynamics of EJ. They also note that EJ problems must expand in scope to include global processes, especially as global markets and trade becomes more prominent. Not surprisingly, this call for future research links multiple disciplines, and is one of the major reasons that paper has the highest betweenness centrality score.

4.2. Substantive Contributions

The remaining articles highlighted in Table 2 explore important, substantive elements of EJ, focusing on the fundamental processes and methods that gave credence to the theories developed and summarized in the two review articles detailed above. For example, Pulido [53] examines historic zoning and land use polices, as well as segregation, in Los Angeles, California. The article is an expertly crafted historical reconstruction of the cultural processes that resulted in racial segregation and ultimately zoning regulations, in which lower-income, non-white communities were forced to reside in areas with environmental hazards. An important facet of this article is its ability to disambiguate the core concept of racism. Specifically, racism is more than just deliberate acts of malicious intent. Pulido approaches environmental racism and inequality through a structural lens, and explicitly acknowledges geographic space in the production of white privilege. In short, the article broadens environmental racism research by highlighting the less obvious and conscious forms of racism.

Been and Gupta [54] take a longitudinal approach to the investigation of whether facilities tend to be deliberately situated in areas with greater lower-income/minority populations, or whether the presence of the facility creates lower land values and thus attracts social groups based on housing costs. Their large longitudinal data set provided strong evidence of the market-based forces—that the lowering of land and home prices due to the presence of a disamenity attracted social groups of lower socioeconomic status. The article connects a dense cluster of papers within the law field, while also providing insightful statistical evidence to the discussion on market-based theories of facility situating. As a result, the article has a relatively high centrality score and burst level. Been also serves as a link to Pulido [53], which continued to investigate questions of minority move-in and what constitutes racism.

Several of the remaining articles turn their attention towards the spatiality of EJ issues by asking questions and performing studies beyond the localized presence of pollution and toxic facilities. The importance of an explicit account of geographic space in the analysis of environmental inequality is developed and demonstrated by Mohai and Saha [55], who examine and evaluate the unit-hazard coincidence process—an effect that emerges when evaluating the impact of a facility and its associated location within a discrete geographic area, without metrics for distance or proximity. When one only considers the effects of a facility within its native geographic unit, biased results can be produced. In this context, distance and/or relative proximity matter, especially when facilities are located near the edges of administrative boundaries. If proximity and distance are unaccounted for beyond geographic units, statistical results concerning the impacts of a facility may be unobservable, biased, or run counter to theory.

An additional nod towards the importance of geographic space in EJ studies is presented by Boone and colleagues [56] and their analysis of park access in Baltimore, Maryland. The core contribution of this work is the examination of a non-traditional form of environmental inequality: access to greenspace. While this is a unique substantive focus, it is wrapped in core EJ theory, by explicitly considering historical segregation in the area to help explain the empirical results. The analysis shows that populations with a high need for access to parks (e.g., the impoverished, those with no car, the elderly, the young) do indeed have the best access. However, two of the core indicators (poverty and no car) in the high-need group are shown to be positively correlated with non-white populations. Boone and colleagues [56] also note that population-adjusted park acreage is lower in non-white communities when compared to the majority white communities in and around Baltimore. The authors examine the historical impacts of segregation in Baltimore, and in doing so move beyond the ubiquitous descriptions and documentation of inequality by providing a more holistic explanation of the underlying mechanisms contributing to 21st-century differences in the distribution of greenspace (an effective tool also used in [53]). Because of its ability to blend historical EJ research with newer substantive material, Boone et al. [56] achieved the third highest betweenness centrality score in the network.

Another paper that explicitly accounts for geographic space is the work of Morello-Frosch et al. [57], who analyze exposure to hazards in relation to cancer risk when evaluating environmental inequalities. The authors do this by calculating a lifetime cancer-risk measure, derived from ambient air pollution levels at a number of locations in and around Los Angeles, California. By evaluating exposure, rather than individual units, the authors make progress in addressing some of the peskier analytical problems associated with the unit-hazard coincidence method detailed previously [55]. One of the most interesting findings from Morello-Frosch and colleagues [57] was that all races within the study area had higher levels of exposure than the EPA standards, but non-white communities were still at a disproportionately higher risk. This spurred further research into air quality [58], as well as other exposure pathways using toxic release data [59].

Walker [22] provides the reader with a refreshing conceptualization of EJ from a geographical perspective and the role that "space" has played within the EJ field. In fact, Walker begins to broaden the scope of what "space" means in the EJ context. Similar to [55], Walker acknowledges the limitations of conducting EJ research within the discrete boundaries that make up geographical units, but also characterizes other limitations of EJ research, namely that it is critical to understand how different bodies, households, and social contexts are implicated by patterns of pollution. In many ways, Walker pushes the readers to move beyond objective measurements of pollution and toxicity by noting that early EJ research was done with reference to an "average white male". Walker offers an alternative by supporting the idea of a more subjective EJ research agenda. Specifically, he suggests that it is important to differentiate vulnerability and well-being in relation to the sociocultural geography of locales where environmental amenities or disamenities exist (and ultimately, who is responsible).

Finally, Schlosberg [11] is responsible for the most recent paper to have a significant co-citation impact within the EJ domain. Schlosberg notes the continued expansion of EJ discourse boundaries, both vertically (geographic scale) and horizontally (topical) (also see [60]), highlighting the explicit consideration of individuals, communities, and the expansion of EJ to non-human entities.

Specifically, research prospects related to climate change (climate justice) and sustainable materialism (sustainable living) are conceptualized as new forms of EJ scholarship, and are examples of how EJ has expanded horizontally. The EJ discourse can also be seen as expanding vertically when considering the increase in attention to the global nature of EJ topics. This movement is evidenced by new research that crosses national and international boundaries, and includes water rights, gold mining, and pesticide drift [60]. Although this has been covered previously (e.g., [22]), Schlosberg's take organizes the research well and provides several prospects for future work. The article demonstrates the breadth of EJ and its progression in developing underlying causal mechanisms, as well as detailing the many new ways of understanding both the "environmental" and "justice" aspects of the domain.

5. Citation Analysis

To reiterate, a co-citation network can uncover the underlying structure of an academic field or knowledge domain by analyzing a network of articles that are cited together. The papers in Table 2 are a few of the most influential works published in the EJ field during the 21st century. Yet, by themselves, they do not necessarily provide a complete picture of the EJ knowledge domain. To provide a more complete view, it is important to decipher the network structure of Figure 1 with two important metrics.

5.1. Citation Bursts

We begin by examining the citation bursts of articles that were especially strong and enduring. These articles can be seen as a representation of major milestones within the EJ knowledge domain. Articles with a sustained strong citation burst are those that tend to make a large contribution to the field, and continue to do so for the length of their burst. Figure 2 highlights the articles with burst levels over 10 and a sustained burst of at least five years. Several of the articles highlighted in Section 3 have also made this list, further demonstrating their importance to the EJ knowledge domain in the 21st century. The articles noted with arrows on the left hand side have a strong burst level that has been sustained through 2017. The burst metric suggests that Mohai et al. [52] and Boone et al. [56] continue to be influential, but so too is Landry and Chakraborty [61], which explores the inequalities related to desirable land uses and environmental amenities.

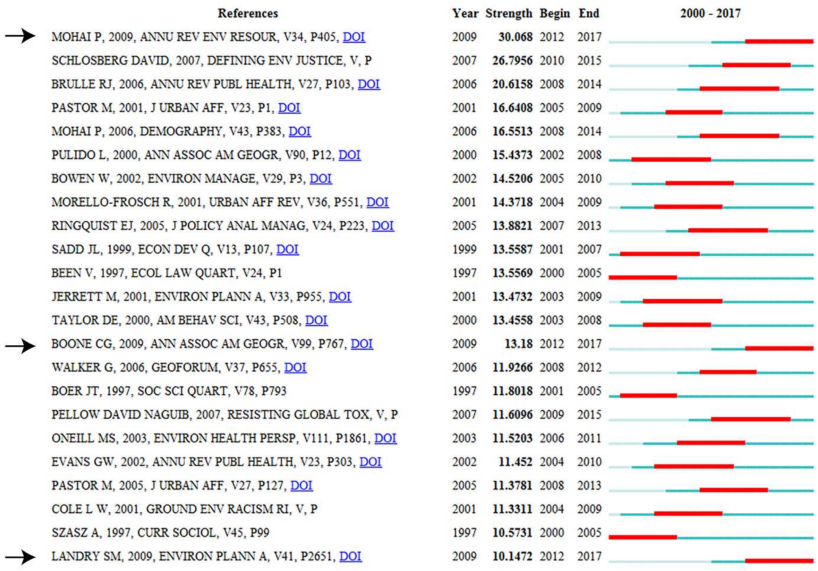

Figure 2. Environmental justice articles sorted by burst strength. Articles have had a sustained burst for at least five consecutive years. Year denotes the publication date of the article. Strength is a measure of burst magnitude. Begin is when the burst started and End is when the burst finished. The red bars on the right are a graphical illustration of the years that the article was actively experiencing a burst in citation amount.

Of course, by requiring the citation burst to have lasted for at least five years, one readily dismisses a handful of important, frequently-cited articles with a burst of fewer than five years. If one relaxes the temporal constraint on bursts to only two years, a different set of papers emerges. We see that several of the papers outlined in Section 3 make the new list (Figure 3). Readers will also notice that this list now contains six papers with a high burst level extending through the year 2017. For instance, Wolch, Byrne, and Newell [62] explore issues of greenspace access, but address the paradoxical effect of too much greenspace, which can lead to gentrification, and ultimately result in the same distributional problem that the introduction of greenspace was meant to solve. Another emergent work is that by Walker [23], who explores the notion of justice and what it means in the context of EJ, as well as the politics of EJ discourse.

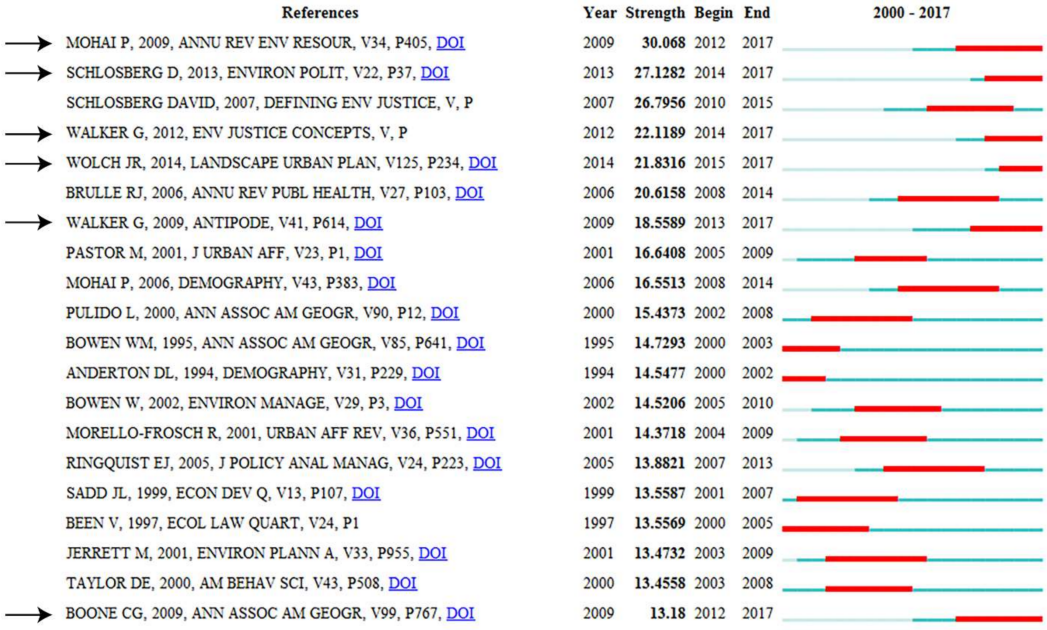

Figure 3. Articles in the co-citation network with a sustained burst of at least 2 years. Articles are sorted by burst strength. Year denotes the publication date of the article. Strength is a measure of burst magnitude. Begin is when the burst started and End is when the burst finished. Red bars on the right are a graphical illustration of the years that the article was actively experiencing a burst in citation amount.

5.2. Clusters and Timeline

A final technique for deepening our understanding of the EJ knowledge domain is through the use of cluster analysis. The identification of publication clusters within a knowledge domain can provide insight into the patterns and trends associated with a body of knowledge. To determine the composition of a cluster, CiteSpace extracts noun phrases from the titles of papers that cite the cluster members. Three key metrics can be used for this process including term frequency*inverse document frequency (TF*IDF), which searches for common terms in documents and determines how important those terms are based on how often they are used [63]; latent semantic indexing (LSI), which uses a matrix of words existing within a paragraph to determine phrase importance for a document [64]; or log likelihood ratio (LLR) tests, which use common statistical methods in the analysis of text [65]. As detailed by Lee et al. [66], LLR usually gives the most unique results and greatest coverage of themes associated with a cluster—this metric is used below. In addition, the silhouette metric [67] is used to estimate the quality of cluster composition. Ranging in value from -1 to 1, higher silhouette values indicate better separation from peer clusters. One last quirk associated with the results detailed below is the composition of the "top terms" generated by LSI. The top term for each

cluster is "environmental justice", but to provide some additional perspective, we labeled each cluster with the second or third LSI term. In practice this is not uncommon, especially in knowledge domains where the central focus shares a common label or scientific name/term. Additionally, cluster groups also vary in membership size, with Cluster 0 being the largest (99 members) and Clusters 4 and 5 being the smallest (51 members) (Table 3).

Table 3. The top six clusters within the co-citation network, based on cluster size. Size denotes the number of member papers within the cluster. Silhouette is a measure of cluster cohesiveness based on title terms. Mean (year) is the average year of publication for the cluster members.

Cluster ID	Size	Silhouette	Mean (Year)	Top Terms (LSI)	Top Term (LLR)
0	100	0.789	2008	Air quality	Environmental health hazard
1	80	0.793	1996	Emissions	Re-thinking environmental racism
2	79	0.841	2010	Human Health	Energy Justice
3	70	0.776	2000	Impacts	Urban Traffic
4	51	0.934	2008	Access	Observed park
5	51	0.855	2001	Urban political ecology	Unsustainable development

Given the results detailed in Table 3, clusters can (and should) be thought about as the major specialties within a knowledge domain [48]. For example, within EJ we uncovered 122 clusters when drawing from the 50 most-cited articles in each time slice. The top six clusters are detailed in Table 3. Among those, Cluster 1 is the oldest (average article publication year is 1996) and Cluster 2 is the newest cluster (average publication year of 2010). The silhouette score, a metric explaining the homogeneity of publications within a cluster, is relatively high for all of the clusters, but is especially high for Cluster 4. Articles within Cluster 4 will most likely be cited by articles that are highly similar in subject area. If the goal was to explore EJ inequalities from the perspective of access, greenspace, or environmental amenities, we might begin by examining the papers grouped in Cluster 4.

Cluster 0 is the largest grouping, and is labeled as "environmental health hazard" using LLR, and "air quality" using LSI. For those familiar with the EJ literature, the prevalence of these terms will come as no surprise. Both of the terms strongly reflect core topical foci from EJ publications seeking to identify connections between the environment and socioeconomic status. As illustrated in Figure 4, clusters can (and do) overlap. This means that we might expect to find articles in Cluster 3 cited with articles from Cluster 0. Again, these topical foci sit at the heart of many EJ studies.

It is also possible to add a temporal component to the cluster analysis using the timeline view in CiteSpace. This helps delineate when certain specialties were active and how long they remained active areas of inquiry (Figure 5). The timeline visualization gives a temporal overview of the knowledge domain. Again, the colors of the links correspond to the date of the article that first co-cited the two documents. These dates are indicated by the color bar at the top of the image. The smaller set of dates just above the timeline network correspond to the individual article publication date. Generally speaking, the timeline view allows us to examine the duration of a specialty and which specialties remain particularly active.

The most recently active clusters are 0, 2, and 4 but these results suggest that activity in Cluster 0 might be fading, while Cluster 2 has emerged as the most active specialty area. For those articles published from 2000 to 2017, the oldest cited articles were published in 1992. We can also see that the citing articles of these earliest publications (links between nodes) are purple to dark blue in color, indicating that the majority of the citing articles were published in the years 2000–2002. These early publications largely appear in Clusters 1, 3, 8, 9, and 10. The articles published in the mid-2000s (light blue to green links) cite papers published in the early 2000s, and are, for the most part, members of Clusters 5, 6, and 7. Finally, the most recent articles (orange links) are connected to Clusters 0, 2, and 4, which were published in the late 2000s and early 2010s. This represents the cutting edge of EJ research. More importantly, Figure 5 provides both analytical and visual confirmation of how the EJ field has progressed since 2000.

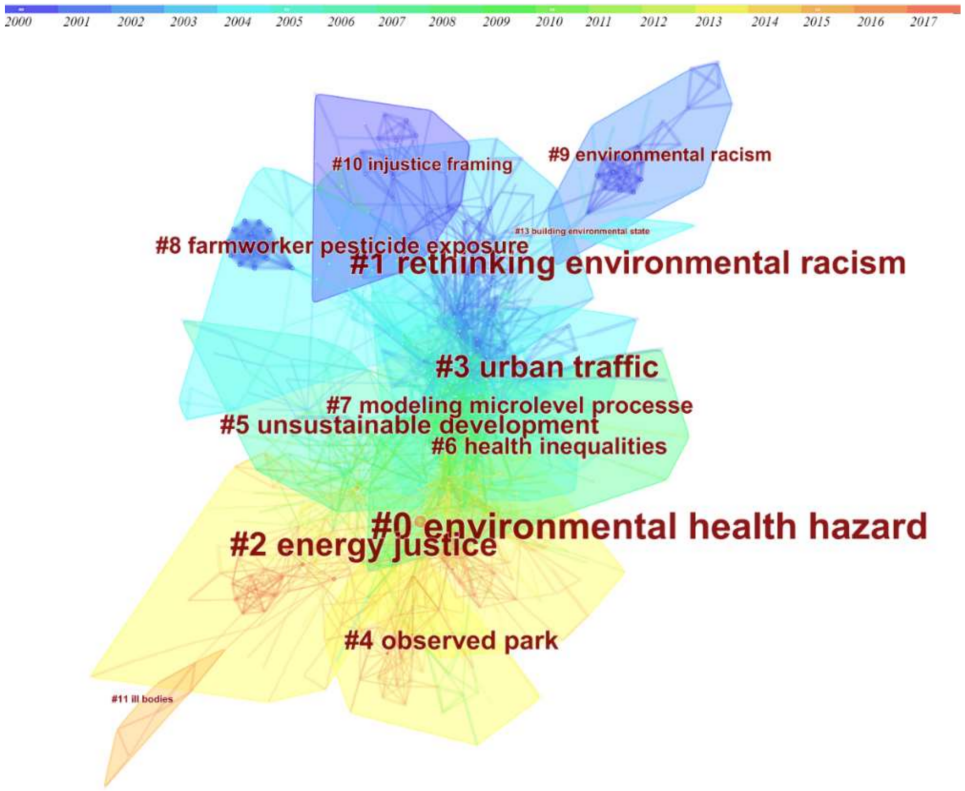

Figure 4. Graphical illustration of cluster membership, using convex hulls to draw boundaries around the clusters of papers. Larger cluster labels indicate more members within the cluster.

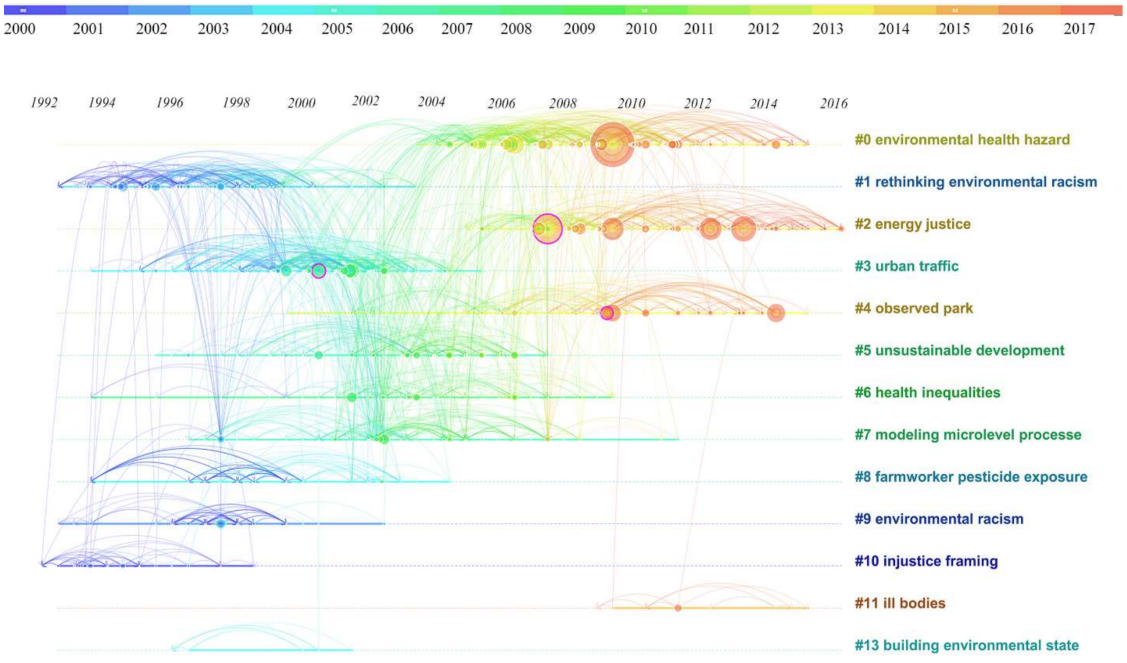

Figure 5. Timeline view of the top clusters in the co-citation network. Cluster terms are denoted on the right and ordered by size of the cluster. Papers (nodes) are organized horizontally by when the individual paper was published. Links are colored based on when the co-citation between the two nodes was first made.

6. Discussion

The purpose of this paper was to provide an additional and perhaps more technical account of what the EJ knowledge domain looked like as it moved into the 21st century. We used the bibliometric software CiteSpace to build a co-citation network, and to help explore and visualize the evolution of the EJ field since 2000. Burst level was used to identify articles that experienced (or are experiencing) sustained and recent high citation counts while cluster analysis was used to identify the major specialties of the EJ knowledge domain. Finally, the timeline view was used to gain a better idea of the prevalence of the specialties and the timing at which they occurred. Each analysis offers several important insights that may otherwise not be clearly seen through a traditional literature review. Those points, as well as the general trends of the knowledge domain, are worth further discussion.

The network itself (Figure 1) is fairly dense, but it does show how the field has progressed from 2000 onward. The emergent clusters are well-defined in both Figure 1 and by the associated diagnostics (e.g., silhouette values) in Table 3. There is some overlap between clusters, which makes logical sense. Many papers are relevant to a variety of EJ specialties, some of which are active concurrently. Moreover, regardless of what the substantive topic may be, the idea of inequality, as it relates to race, remains a defining characteristic for the field. There will be, of course, some overlap in the substantive focus of the research. Indeed, as mentioned previously, the first term for every cluster found in Figure 4 was "environmental justice", which implicitly means that each of these topics has some focus on the inequalities between different social groups. However, when comparing the results of the EJ knowledge domain to other fields, such as geographic information systems [13] or medical informatics [68], our results suggest that EJ has evolved in a relatively sequential manner: a particular cluster emerges, then declines as another emerges. This is a compelling temporal footprint, and is evidence of a quickly evolving field.

Been [54] is a node that connects a distinct cluster of important papers co-cited in the early 2000s. This work is unique in that it connects a dense cluster of papers focused on environmental racism within the law literature to the rest of EJ network. It is also important because of the methodologically rigorous longitudinal approach to investigate location decisions. Given the specialties of the early 2000s, and that period's strong focus on understanding the allocation of environmental disamenities in relation to air quality and emissions, urban traffic, and farmworker exposure, there seems to be a strong carryover from the foci of the 1990s (not detailed). As a result, the importance of Been in early co-citations makes sense. However, as detailed by Figure 5, the second largest cluster (Cluster 1) is defined by the term "rethinking environmental racism". This is a domain focus that saw most of its activity in the early 2000s, and provides evidence of how the EJ field was beginning to move away from the traditional research approach of EJ (the coincidence of race and disamenity), and adopting a more critical research agenda. Of all the articles discussed in Section 3 of this paper, Pulido [53] best captures this transition. By taking a historical approach to understanding inequalities, Pulido sheds light on how past planning decisions continue to effect minority communities disproportionately. Not surprisingly, Pulido's work exhibits one of the highest betweenness centrality scores, and a strong burst level from 2002 to 2008.

As EJ research moved into the mid- and late 2000s, researchers were turning their attention toward the inequalities associated with environmental amenities rather than disamenities. As Table 3 shows, Cluster 4 is defined by "access" and "observed park". Within this cluster, there are several articles on greenspace and open space, including [56,61], both of which explore topics related to environmental amenities. It's also worthwhile to note that Cluster 4 ("access" and "observed park") has several connections with other major clusters, namely Cluster 2 ("energy justice") and Cluster 5 ("unsustainable development"). The connection between these three clusters can potentially be explained by the substantive content under study. As noted by [69], one example of unsustainable development is the development of communities without regard for pollution and flood abatement, greenspace preservation, or recreational opportunities, while energy justice is concerned with the outcomes of energy production (in relation to clean or "dirty" energy production) and the impact it

has on communities at varying geographical scales [70]. Access (as described in Cluster 4)—whether it be to clean air, greenspace, biodiversity, or protection from pollution and floods—underpins much of the work embedded within these clusters. These topics also grew in research popularity as the field moved into the 2010s.

Finally, the EJ domain from 2010 to the present continues to focus on various inequalities related to greenspace and parks, energy justice, and environmental health hazards (Figure 5). Due to limitations in clustering algorithms, some of the nuances of the most recent works are obfuscated by the generated clusters. However, if we look at the articles with recent and sustained bursts, we can see that EJ research in the 2010s is defined by questions of what the "justice" in EJ means. Although it is traditionally viewed in a distributive sense, recent work from Walker [23] and Schlosberg [11] ask whether this is too narrow a definition. At the same time, scholars are reconsidering the effect of greenspace in a justice context [62]. As EJ scholarship moves forward, we see questions of scale becoming more prominent. More specifically, we see questions surrounding EJ issues related to how the activities of the Global North are impacting countries of the Global South. We also see greenspace remaining an important and influential EJ topic. In particular, many of these contributions explore the uncertainty in how the presence of greenspace influences the surrounding areas, and if some types of greenspace are more influential in changing a community than others.

7. Conclusions

Our results show that the EJ knowledge domain has evolved quickly over the past 18 years. Given the evidence presented in this paper, the EJ domain is likely to continue along this growth trajectory, as issues of EJ come to the fore, particularly in urban areas. We encourage readers to use the results of this paper as a map, both literally and figuratively, to the existing EJ literature. We found that EJ specialties are well-defined, and this manifests in the citation patterns of the literature. Of course, space limitations prevent us from exploring many of the smaller, less obvious subdomains within EJ, but interested readers always have the option to explore these areas further, using this work as a guide. At the very least, the analysis in this paper reveals how specialties emerge, and how new paradigms within a knowledge domain are born. In particular, the paradigm-spanning papers were shown as critical for connecting EJ to its past, and catapulting the domain into new and innovative research foci. The Web of Science data used in this paper, combined with the quantitative analysis and visualization tools provided by CiteSpace, provides a powerful combination for exploring the corpus of the EJ knowledge domain. Not only does that data avoid the implicit bias of limited literature reviews that focus on a particular subfield, it also mitigates the potential gaps in knowledge that might emerge from scholars with limited knowledge of how key subdomains interact and connect, providing a more panoptic, inclusive, and holistic perspective on EJ as a discipline.

Author Contributions: Nelson and Grubesic conceived and designed the study; Nelson performed the citation analysis; Nelson and Grubesic analyzed the data and wrote the paper. All authors read and approved the final manuscript.

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