sustainability

MDPI

Article

Bibliometric Analysis of Multi-Level Perspective on Sustainability Transition Research

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Abstract: The multi-level perspective (MLP) is a prominent framework for transition research. However, few studies have used bibliometrics for conducting a global picture of the MLP research. This study identifies the worldwide trends at three levels: sources, authors, and documents, and uses the bibliometrix based on 757 articles published in WOS and Scopus from 2002 to 2020. The results show that the MLP research literature is proliferating, and the number of journals and countries concerned in this field is increasing. MLP research has mainly focused on transition, sustainability transition, socio-technical transition, energy transition, innovation, and governance; and will increase focus on agency, power, and policy. MLP research will focus on multi-niche, multi-regime, and multi-landscape interactions at the hierarchy levels. The results assist scholars in systematically understanding the current research status, research frontiers, and future trends of MLP from a macro perspective.

Keywords: multi-level perspective; transition; bibliometric; bibliometrix

Citation: Wang, C.; Lv, T.; Cai, R.; Xu, J.; Wang, L. Bibliometric Analysis of Multi-Level Perspective on Sustainability Transition Research. *Sustainability* **2022**, *14*, 4145. https://doi.org/10.3390/su14074145

Academic Editors: Huaping Sun, Keliang Wang and Feng Wang

Received: 23 February 2022
Accepted: 28 March 2022
Published: 31 March 2022

1. Introduction

Significant sustainability challenges such as climate change, ecosystem degradation, waste production and disposal, and poverty or inequality have caused various social problems, encouraging humans to think about sustainability transitions. Transition can occur at different levels, such as the entire society, urban society, rural to an industrial society, and specific levels, including transport, communication, housing, feeding, energy supply, use, and recreation [1]. Transition research has been recently upgraded to sustainable transition research and has become a new field, which is a 'long term, multi-dimensional, fundamental transition of production and consumption' [2] (p. 955). Technological innovation and the widespread availability of new infrastructure are critical for achieving sustainable development goals [3]. Transition research from socio-technical systems has become an essential aspect of transition research.

Currently, transition approaches mainly include the Multi-Level Perspective (MLP), Strategic Niche Management (SNM), Transition Management (TM), Innovation Systems, Techno-economic paradigm (TEP), and Socio–metabolic transitions [4]. The MLP was initially developed by Arie Rip and René Kemp [5] and then further refined and developed by Frank Geels and Johan Schot [6,7], and it integrates evolutionary economics, sociology of innovation, and Neo-institutional theory. The MLP describes the transition process of the socio-technical system as a non-linear process triggered by the interaction of three levels of innovation niche (micro), socio-technical regime (meso), and landscape (macro).

Furthermore, each level is composed of multiple elements; the stability increases with the level [7,8].

The core of MLP is the constituent elements of niche, regime, and landscape [5,7], the development process of co-evolution, and the accordingly summarized pathway of socio-technological transition [6]. Niches refer to a set of exciting innovations that are not protected by mainstream rules [9]; therefore, it generally needs to be protected as an "incubation room [10]." The socio-technical regime was established in institutions or technological regimes [11], which is a rule set or grammar, including public authorities, societal groups, research networks, user groups, producer networks, suppliers and financial networks, and their interaction [7]. The regime is characterized by stability and lock-in, for which only gradual, not fundamental, changes can be made [4]. The socio-technical landscape includes exogenous events and trends such as demographic changes, macro-economic trends, political developments, wars and crises, deep cultural and societal values, and climate change [4]. The landscape cannot be easily changed in the short term; nevertheless, landscape changes can pressure the regime and create opportunities for the niche [12].

Transition is defined in MLP as the transition from one socio-technical regime to another, which is a co-evolutionary process of niches, regimes, and landscape. Niche innovations generate endogenous and transformative dynamics, landscape changes generate pressures to destabilize socio-technical systems, and the resulting institutional instability creates opportunities for niche innovations to take center stage in socio-technical systems and displace existing regimes [13]. Niche-regime-landscape interactions lead to different transition pathways. Geels and Schot (2007) [6] developed a typology of four transition pathways: transformation, reconfiguration, technological substitution, and de-alignment and re-alignment.

Scholars have reviewed MLP research from diverse perspectives. Smith et al. (2010) [12] evaluated MLP to provide a framework to link the specific innovation activities of the niche with the reform of the regime structure and proposed five challenges. Geels (2019) [14] placed MLP research into the broader sustainability transition debate and responded to the criticisms raised in the related literature. Additionally, some scholars have used MLP to review a specific field, such as the sustainable transition of agriculture and food systems [15] and the combination of socio-technical transition and planning [16].

Similarly, some scholars have conducted bibliometric analyses of MLP. Bibliometrics is a quantitative, transparent, and repeatable method [17]. Fischer and Newig (2016) [18] selected 386 journal articles on transition management and sustainable transition in Scopus from 1995 to 2014 to discuss the role of agency and actors. Martínez Arranz (2017) [19] performed a meta-analysis to determine the most unstable non-technical factors during the energy and transportation system regime change and technical niche and contextual factors. El Bilali (2019) [15] reviewed the application of MLP in the agro-food sustainability transition. These bibliometric analyses primarily focus on a specific aspect of MLP or its application in a particular field but lack the overall analysis of MLP. To resolve this documentation gap, the global trend of MLP in transition research over time were determined by considering the three pillars of the scientific literature: researcher (authors), publication sources (sources), and themes (documents). Specifically, the article seeks to answer the following questions:

(1) What is the annual publishing trend of MLP from 2002 to 2020?
(2) What are the most influential authors, sources, and papers on MLP?
(3) What are the research themes in MLP, how have these themes evolved?

The study is structured as follows: Section 2 discusses the materials and methodology, Section 3 presents the descriptive and bibliometric indicators used to obtain the main conclusions from three levels, and Section 4 presents the conclusion, limitations, and future research agenda of the MLP.

2. Materials and Methods

2.1. Sample Collection and Cleaning

This study mainly considers peer-reviewed papers and reviews and selects two citation databases, WOS and Scopus. Figure 1 shows the data collection and cleaning strategy, and 757 studies are available for bibliometric analysis. Data from 2020 was included in this process because it was already near the annual peak at the search time.

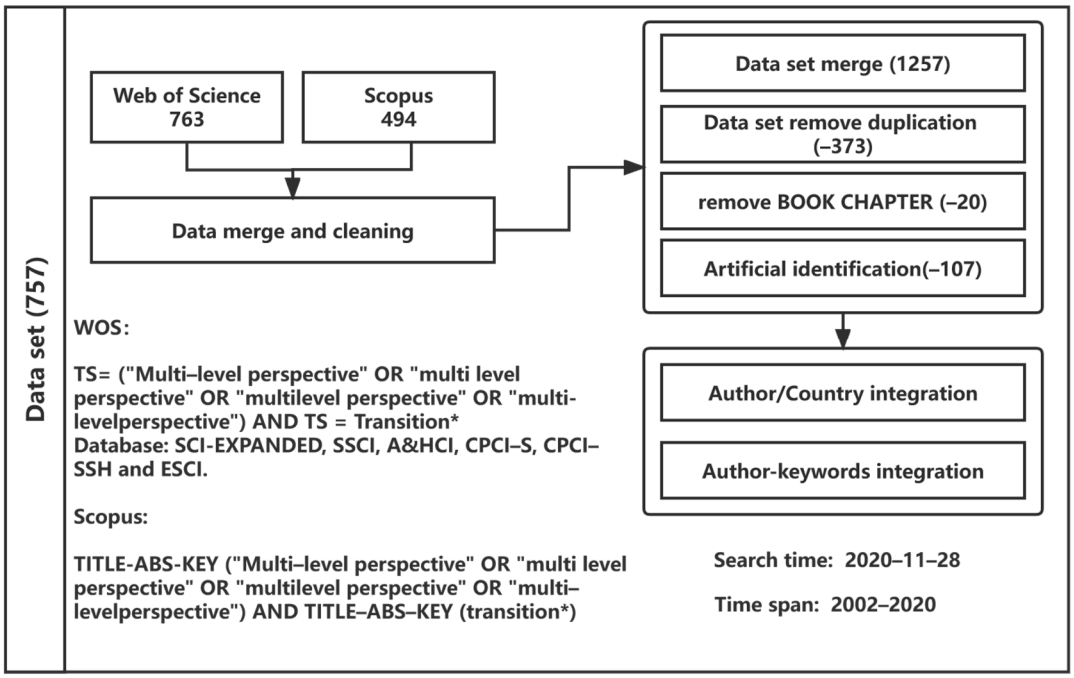

Figure 1. Strategy for setting up the dataset.

The data cleaning process used the strategy of Wang et al. (2020) [20], which mainly included integration of the authors, countries, and author-keywords.

- The unification of author names, such as Geels FW and Geels F into Geels F.
- Merging of synonyms in keywords, such as "multi level perspective," "Multi-level perspective," "multilevel perspective," "multi-level perspective," "multilevel," and "MLP" were all unified into multi-level perspective. Similarly, "Sustainability Transition" and "Sustainability Transitions" were merged into "Sustainability Transition." "Socio-technical transition" and "socio-technical transitions" were merged into "Socio-technical transition."
- England and Scotland had to be unified under the United Kingdom (UK), and Taiwan was merged with China.
- Simultaneously, some documents lack the Author-keywords (DE) field. The method adopted was intended to address this gap with the Keywords plus (ID). If there is no ID information, DE is added manually based on the title.

Overall, the annual number of published MLP research articles shows an increasing trend; specifically, rapid growth was observed in 2012 and 2018. Considering annual production, we divided the sample into three-time slices: period 1 (2002–2011), period 2 (2012–2017), and period 3 (2018–2020). Time slices are usually divided equally; however, considering the considerable differences in production levels, period 1 consists of 10 years, and period three only contains three years to strengthen understanding of the latest trends.

2.2. Scientometric Methods

This study used the bibliometrix R-package for bibliometric analysis [21] and VOSviewer [22] for visualization. Bibliometrix can perform complete bibliometric analysis and visual display, statistical analysis, data preprocessing, co-occurrence matrix construction, co-citation analysis, coupling analysis, co-word analysis, and cluster analysis of Scopus and WOS databases [21]. The Bibliometrix R-Package is advantageous because it provides a comprehensive bibliometric analysis, while the open-source environment R provides the opportunity to integrate with other software packages.

Authors, sources, and documents were used at three levels for the bibliometric analysis. First, the scientific production and citation indicators such as H-index and Total Citation are considered. Second, intellectual structures are used to analyze the collaboration of countries. Third, conceptual structures focus on the main themes and trends of MLP research, and the thematic mapping and thematic evolution were conducted for longitudinal bibliographic network analysis.

3. Result and Discussion

3.1. Scientific Production

The production in the first period showed a gradual upward trend, and the MLP has not attracted much attention (Figure 2). However, publications and citations increased rapidly in 2012 and reached the highest value. All this partially attributed to a series of sustainability conferences and the Sustainability Transition Research Network (STRN) establishment since 2009, and then the research of sustainable development has proliferated [23]. In 2018, the number of publications reached the highest value of 153 articles and will be even higher in 2020. In terms of annual citations, there was an apparent trend in fluctuations. The most highly-cited papers reached 2154 times in 2002.

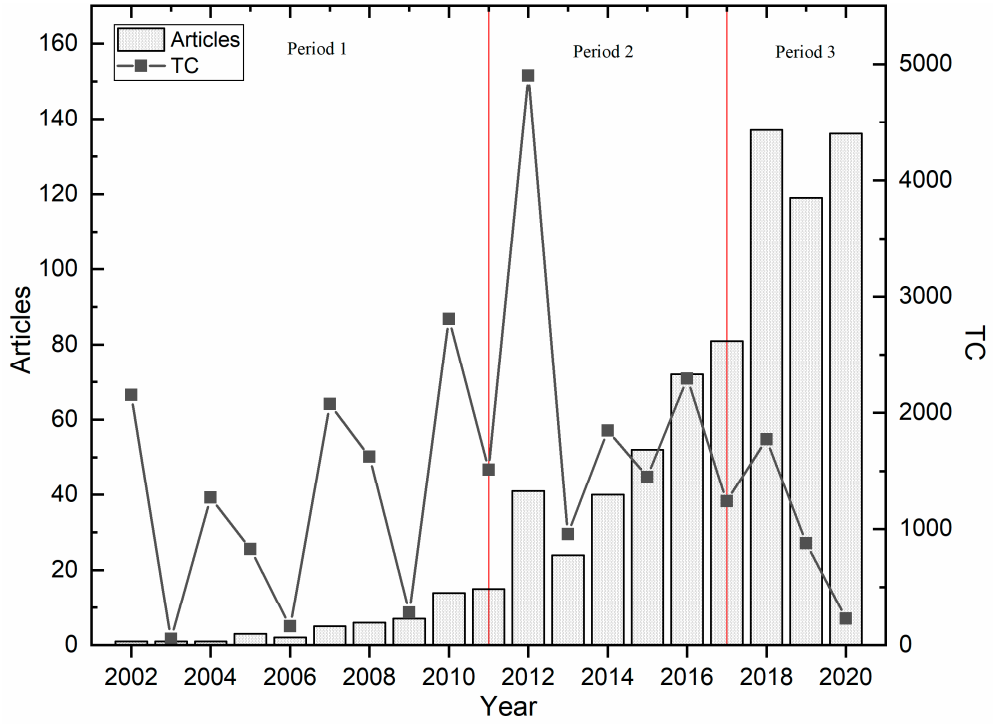

Figure 2. Annual Scientific Production and Total Citation (TC).

From the literature overview of all the periods (Table 1), although the number of studies in the second and third periods kept increasing, the number of sources did not change significantly, demonstrating that the journals considering MLP are relatively fixed. The average annual number of published papers has rapidly increased, from 5.5 to 130.7 in

the first period to the third period, respectively, reflecting the rapid increase in the attention of MLP research from another aspect.

Table 1. Main information for different periods.

	Topic	Period 1	Period 2	Period 3	Total
Main Information	Documents	55	310	392	757
	Sources	28	129	134	233
	Keywords Plus (ID)	234	762	977	1507
	Author's Keywords (DE)	202	993	1278	2115
	Years	10	6	3	19
	Average citations per documents	232	40.94	7.352	37.44
	Authors	83	642	948	1514
	Author Appearances	120	821	1173	2114
	Documents per Author	0.663	0.483	0.414	0.5
	Authors per Document	1.51	2.07	2.42	2
	Co-Authors per Documents	2.18	2.65	2.99	2.79
	Collaboration Index	2.08	2.38	2.76	2.31
	References	2570	15,432	22,951	37,773
	Publications/year	5.5	51.7	130.7	39.8

3.2. Sources

Table A1 describes the 20 most productive journals in MLP research from 2002 to 2020, which published 416 research articles, accounting for 51.2% of all publications. The total sample includes 249 journals covering multiple disciplines and published in environmental science and management journals. In the past two decades, most journals (about 95%) have published fewer than ten MLP-related research papers. *Environmental Innovation and Social Transformation* (impact factor: 9.68), a journal related to STRN, topped the list with 83 articles, followed by *Technological Forecasting and Social Change* (impact factor: 8.593) and *Research Policy* (impact factor: 8.11); these three journals contributed 26.2% of the publication output. *Research Policy* ranked 3rd in production regarding source influence, but its citations and H-index ranked first. Contrastingly, although *Sustainability* ranked 4th in production, it ranked 8th in citations. In addition, eight sources had an H-index greater than 10.

In Figure 3, a few journals focused on this field during period 1, *Research Policy* accounted for 20% and continued to publish MLP research articles, with five articles published in 2010. Furthermore, *Technological Forecasting and Social Change* published nine papers on the MLP during period 1. During period 2, the number of journals focusing on MLP increased significantly, while *Environmental Innovation and Societal Transitions* published an average of 6.3 articles annually, followed by *Technology Analysis & Strategic Management* with 3.7 articles annually. *Research Policy* published articles annually during this period. The top 20 sources all published MLP papers in period 3, among which the sources with a large number of publications were as follows: *Environmental Innovation and Societal Transitions* published 13.7 articles annually, followed by *Sustainability* (12.3), *Technological Forecasting and Social Change* (12), *Energy Research & Social Science* (11.3), *Research Policy* (7.7), and *Journal of Cleaner Production* (5.3). *Environmental Innovation and Societal Transitions* accounted for 12.3% and 10.5% in the second and third periods. *Sustainability* rose from sixth place in period 2 to second place in period 3. *Energy Research & Social Science* increased from 2.6% in period 2 to 8.7% in period 3, indicating that these journals are increasingly considering MLP.

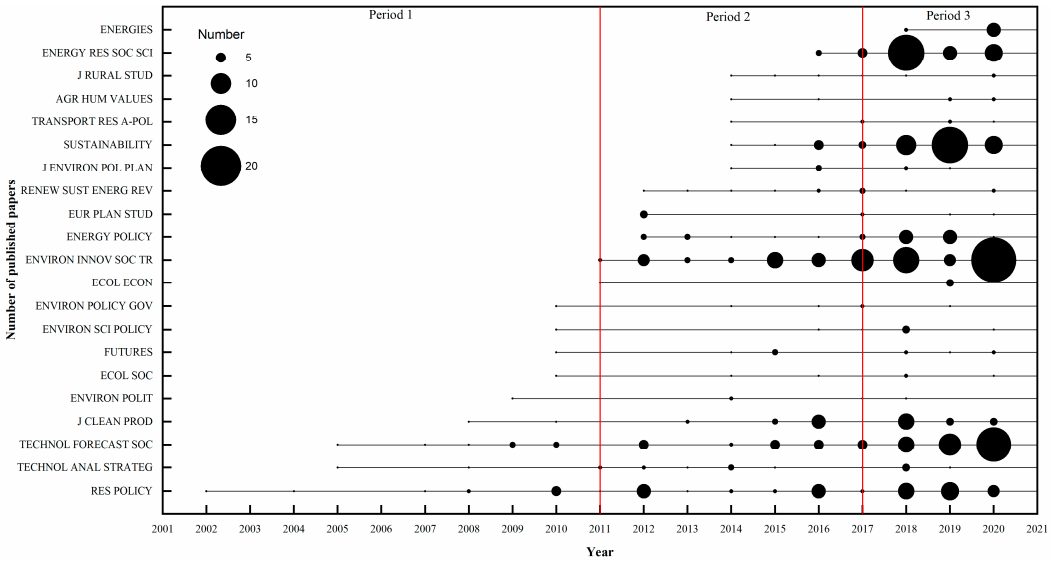

Figure 3. The annual publication trend of the top sources by scientific production. Source abbreviations are shown in Table A6.

3.3. Authors

The results showed that 1514 authors participated in MLP research, but surprisingly only eight authors published ten or more papers, all of them shown in Table A2. Geels F ranks first (37 articles) with an absolute advantage in the number of published papers and is also the most cited, with an average annual citation of 561.3 times, so his H-index is also the highest. Interestingly, although Truffer B published only ten papers, it ranked second in the number of citations, with an average annual citation of 150.7 times. In contrast, Markard J, although ranked 10th in terms of published articles, ranks third in citations, with an average of 112.5 citations per year. On the other hand, Upham P ranks 8th in terms of publications but 15th in citations, which may be related to its relatively short time in the field of MLP. Hekkert M has ten papers in the dataset. Although he did not directly extend MLP or use MLP for case analysis, his papers discussed niches and regimes included in the dataset.

3.3.1. Production of Productive Authors over Time

Regarding the production time distribution of highly productive authors (Figure 4), fewer authors were in period 1. Except for 2003 and 2009, Geels F published papers in the MLP field almost annually, while other scholars have been published articles only since 2008. In period 2, the number of authors of MLP research increased significantly, as did the number of published articles. Contrastingly, Geels F published relatively fewer documents during this period, but the annual citations of published documents were higher, such as Geels (2012) [8] and Geels et al. (2017) [24], cited 322 times and 77 times, respectively. During this period, more case studies and criticisms of MLP led to increased discussion. In period 3, in addition to Geels F, several influential authors, such as Sovacool B, Kivimaa P, and Hyysalo S. Only Geels F continually maintained a high number of publications and influence overall. Contrarily, some scholars started MLP research in period one but gradually faded out. For example, Truffer B did not publish relevant documents during the third period.

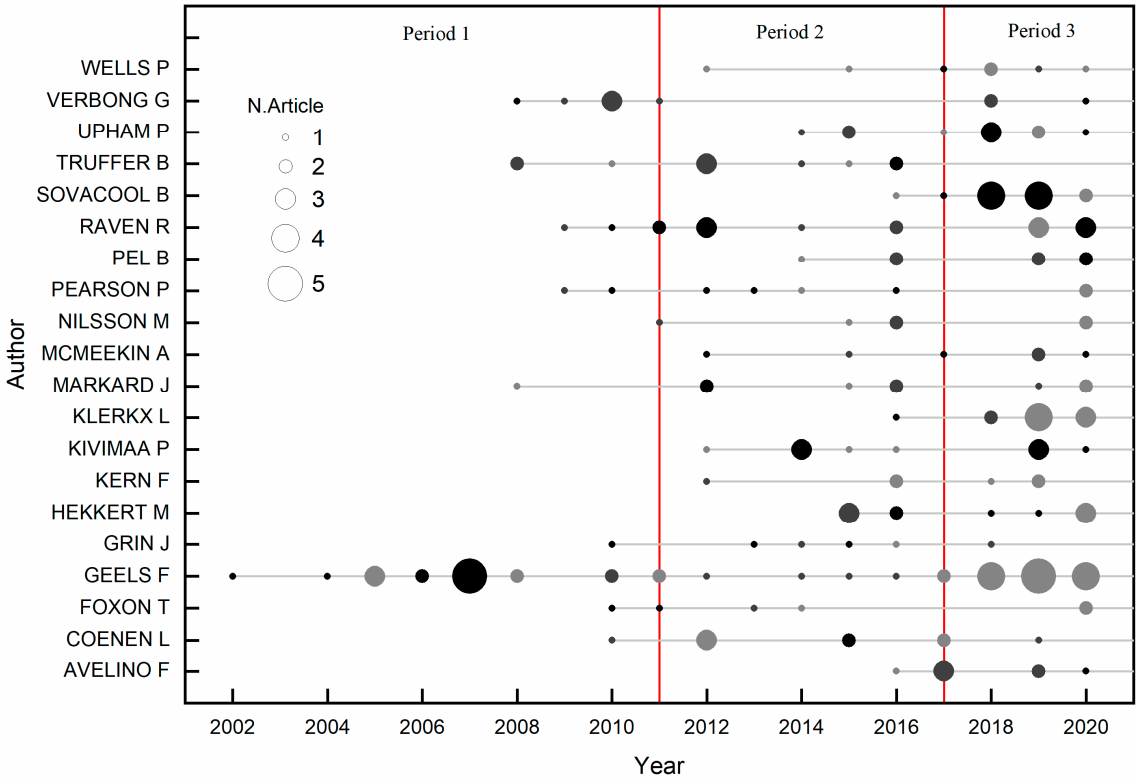

Figure 4. Top 20 Author's production over time. The lightness of the color represents the number of citations. The darker the color, the greater the citations.

3.3.2. Author's Country

In the current study, 62 countries were highlighted among the 757 publications on MLP research, of which 42 were the corresponding authors. The UK, Netherlands, and Germany published the most papers considering the national scientific production, accounting for 36.7%, 32.1%, and 18%, respectively. From Table A3, the Netherlands, which ranked second, published 37 papers in the first period, far ahead of other countries, but the UK became the most published papers in the second and third stages. Some countries, such as China, Austria, and Italy, appeared in MLP literature in the second period.

Considering the relationship between citations and production, the UK has published the most papers, but its total citations ranked behind the Netherlands related to the highly cited literature published by Geels F in the early years. Interestingly, Switzerland ranked 12th in scientific output, but in citations, it ranked third. Judging from each period's citations, the average citations of the articles as a whole are the highest in the first period and lowest in the third period. It should be noted that Italy has no paper in the first two periods; however, in the third period, it ranked 5th in terms of citations.

In Figure 5, the most frequent interactions between several countries, namely the UK, the Netherlands, and Germany, are also the most collaborative countries. The frequency of countries that cooperate with other countries in the UK, Netherlands, and Germany is 32, 30, and 23, respectively. The UK and the Netherlands cooperation with 576 articles, the UK and Germany 576 articles, and the Netherlands and Germany 400 articles. One of the reasons for the UK becoming an important cooperating country in the field of MLP is that Geels F joined the UK University in 2010. Several other frequent cooperating countries are the Netherlands and Sweden (196), the UK and the USA (100), the UK and Denmark (144), and the Netherlands and Australia (100).

Figure 5. Country Collaboration Network. The node's size indicates the number of papers published in the country. The larger the node, the more the amount of literature published. The connection between the nodes indicates the cooperation between countries, and the thicker the line indicates the more cooperation between countries. The node of China includes papers published from Taiwan (5 articles). Among them, Taiwan cooperated with Sweden and Malaysia to produce three pieces of articles.

Nevertheless, as for cooperation rate, Italy had the highest cooperation rate (40.9%), followed by Australia (39%), China (37%), the Netherlands (34.1%), and the UK (33.3%). Although Germany ranked 3rd in scientific output, it ranked eighth at 28.8% in cooperation. From the perspective of national cooperation in various periods (Figure A1), the number of Multiple Country Publications (MCP) of the Netherlands during the first period was an obvious advantage, and other countries had no cooperation. During the second period, the number of MCP countries increased significantly, and the UK surpassed the Netherlands to become the number one country. In the third period, the top three countries in the MCP ranking were the UK, the Netherlands, and Germany, and all 13 countries cooperated with other countries.

3.4. Documents

3.4.1. Top Highly Cited Papers

Often highly cited articles are more likely to attract attention. Table A4 summarizes the top 20 most cited papers in the dataset. The 757 articles were cited 28,340 times, and 119 articles were never cited, with an average of 37.4 citations per article. These 20 papers were cited 13,535 times, accounting for 47.8% of the total citations, further showing these papers' importance to MLP research.

Geels (2002), a highly cited paper on MLP, has received 2154 citations, which elaborated the theoretical framework of MLP for technology transition in addition to case analysis. Notably, among the top 20 highly cited papers, the proportion of articles published in *Research Policy* accounted for 60%, and papers contributed by Geels F reached 45%. Compared with Total Citation (TC), Total Citation per Year (TCY) can better reflect the continuous attention of the literature. Geels and Schot (2007) [6] had the highest TCY, which interpreted MLP from the perspective of typology and proposed four social-technical transition pathways, playing a significant role in the development of MLP. Markard et al. (2012) ranked 3rd, which reviewed sustainable transition.

The other two indicators were Global Citation (GC) and Local Citation (LC); LC was used to describe the research citations related to MLP topics, while GC has a broader scope, indicating that the literature was related to other topics links between sustainability developments. From this perspective, the GC of Markard and Truffer (2008) [25] ranked 10th, while the LC ranked 5th, focusing on the integration framework of technological innovation systems and MLP. Similarly, Geels (2012) [8] ranked 16 in GC, while LC ranked 10, Geels (2011a) [9] ranked 5 in GC, and 20 in LC.

3.4.2. Reference Co-Citation Analysis

The dataset contains a total of 37,773 citations. We used the reference co-citation of bibliometrix to perform a co-citation analysis of the dataset and citations (Figure 6) to discover the research basis of MLP research. We roughly divided the co-citation map into red, blue, and green clusters. All the highly-cited papers in Table A4 appear in the clusters, with eight documents in the red cluster, four in the blue cluster, and eight in the green cluster.

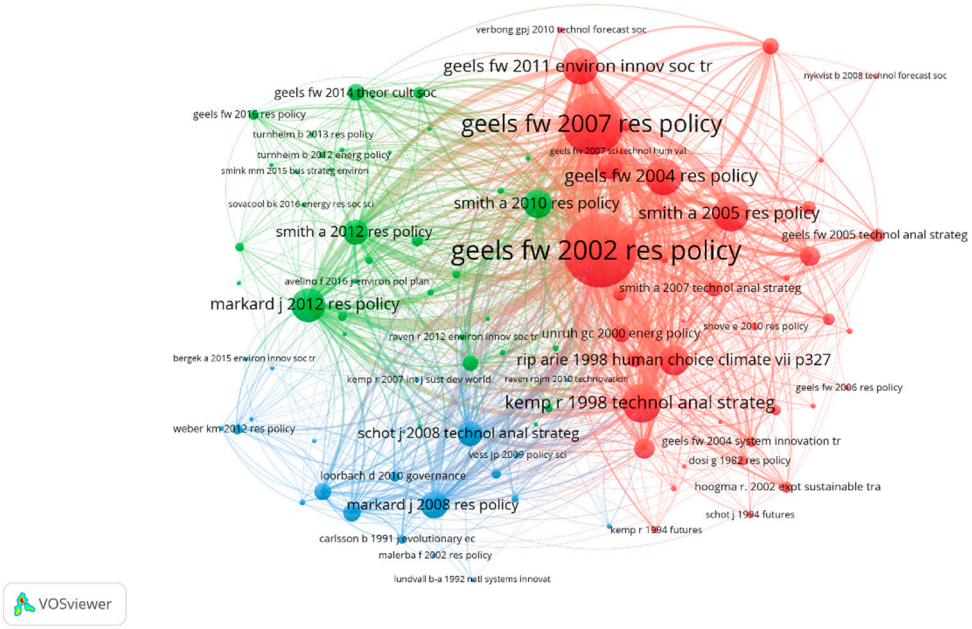

Figure 6. Reference co-citation network. Clustering Algorithm: Walktrap, N of Nodes: 100, Min. Edges: 2, N of labels: 20. The node size represents the number of times a document has been cited. The larger the node, the greater the number of citations. The connection between the nodes indicates the citation relationship between the two papers. The thicker the line indicates the more frequent citations.

Cluster 1 (Red): Criticisms and Extensions

This cluster was the largest, containing 41 nodes and eight highly cited papers, mainly focused on "criticisms and response of the MLP" and "extensions to the MLP."

- Criticisms and response to the MLP

There are some criticize focusing on the definition of the concept of regimes [25], operating specifications, heuristics, epistemology and explanatory style [26], lack of agency [27], insufficient attention to politics, culture, and power [28], bottom-up change models [29], flat ontologies versus hierarchical levels [30], etc. Subsequently, the creators of the MLP, such as Geels F, responded to relevant criticisms. Geels and Schot (2007) [6] responded to three issues: how to apply the three levels to case analysis [29] (p. 54), the relative neglect of agency [27] (p. 1492), and overemphasized technological niches in the regime change [29] (p. 62). Geels (2019) [14] responded to seven criticisms: "*lack of agency, operationalization*

of regimes, bias towards bottom-up change models, epistemology and explanatory style, methodology, socio-technical landscape as a residual category, and flat ontology versus hierarchical levels." And then summarized some criticisms and suggestions on the MLP from seven aspects: "*politics and power, cultural discourse and framing struggles, grassroots innovation, multiple transition pathways, incumbent firm resistance and reorientation, destabilization and decline, and policy analysis*."

In addition, some suggestions have played a significant role in advancing MLP. For example, Genus and Coles (2008) [26] proposed that MLP case studies were not systematic enough, and a large number of MLP case studies have appeared in the following ten years. Smith et al. (2005) [27] noted that MLP only considered a single regime when analyzing niche innovations and landscape developments, leading to the gradual consideration of multi-niche and multi-regimes in Geels (2007) [31]. The following section concentrates on the scholars' extensions of the MLP.

- Extensions to the MLP

Combination of MLP and Models

MLP is an abstract and improved narrative framework that analyzes the transition qualitatively. Many scholars have tried to combine MLP with quantitative models, but some have suggested that the combination was not the best strategy but just a pluralist bridging strategy and dialog [32]. Turnheim et al. (2015) [33] proposed three methods of analyzing the transition for a sustainable and low-carbon society: quantitative systems modeling, socio-technical transition analysis, and initiative-based learning. Köhler et al. (2020) [34] applied this bridging method to analyze mobility niches in the Netherlands.

Another integration strategy was using MLP for scenario analysis and combining MLP scenario analysis with the assessment model. Geels et al. (2016) [35] believed that bridging based on the sequence and interactive expression of diverse methods could generate a more comprehensive and helpful evaluation chain to support the formation of policies and actions taken. The mainstream approach was the combination of MLP and Integrated Assessment Models (IAMs), using MLP to develop new quantitative scenarios for IAMs [36]. Meanwhile, Hof et al. (2020) [37] combined MLP scenario analysis with two global IAMs and one detailed European electricity system model, and Zwartkruis et al. (2020) [38] combined MLP, Initiative Based Learning (IBL), and IAMs. In addition, other scholars have integrated the MLP scenario analysis with specific quantitative models. Geels et al. (2020) [39] established an eight-step procedure for generating socio-technical scenarios and establishing interactions with various computer models. Rogge et al. (2020) [40] combined energy scenario models with social technology system analysis, focusing on the transition policy mix. Some scholars have combined socio-technical transition studies with initiative-based learning and applied economics to enrich model-based scenarios [41]. In addition, scholars have combined the MLP with a philosophical modal aspects framework [42], business model theory [43], actor-network theory, ant-inspired scholarship [44], social representation theory [45], and system dynamics [46].

Spatial scale

The lack of attention to spatial dimensions is one of the criticisms faced by the MLP. Smith et al. (2010) [12] pointed out that one of the criticisms of the MLP is that the role of location and space ratio has not attracted people's attention yet, and the spatial heterogeneity of niche, system, and landscape had a particular impact [47]. Therefore, it is necessary to re-examine and theorize the work of sustainable transition from a spatial perspective [48]. Some scholars have attempted to combine the MLP with economic geography. Hansen and Coenen (2015) [49] found that the contribution of sustainable transition geography was primarily concentrated in the geography of niche development, adding spatial sensitivity to the transition framework, but few studies have proposed a sustainable transition framework combining spatial dimensions. Coenen et al. (2012) [50] combined the sustainable development transition geography and economic geography.

Meanwhile, some scholars have further investigated the sustainable development space, time, and other geographical characteristics of social and technological regimes [51].

Raven et al. (2012) [52] proposed a second-generation multi-scalar MLP including spatial scales that explained the dynamics of the socio-technical system by the interaction between actors and institutions located at different spatial scales. Boschma et al. (2017) [53] established a theoretical framework for regional diversification based on evolutionary economic geography and transition research.

Actors and Agency

Lack of agency was proposed as a criticism of the MLP [27]. Later, many scholars tried to strengthen the research of actors and agencies in the MLP framework. It mainly covered repositioning actors, such as redefining consumers in low-carbon energy-saving systems as actors in transition [54] and the ant-based approach [55]. The intermediary role of actors also has a focus of attention. For instance, actors played an intermediary role between institutions and technologies [56], intermediary organizations [57], boundary spanners [58], and transition intermediaries [59].

Likewise, another concern about actors was the impact of incumbent actors on transition, such as actor behavior [60], innovative capacity [61], "regime actors" as conservative forces [62], incumbent actors, and radical niche innovations [63,64].

Power and policy

Power, policy, and political dimensions responded to the pressures of the regimes and landscape. MLP was criticized for its limited attention to power and policy early [12,65] and insufficient attention to policy-relevant dimensions and processes [66], leading to many extensions in this area. The expansion of power and policy mainly includes the following aspects: the first is using political science theories to locate the role of power in MLP [67] and the relationship between re-conceptualization power and structural changes [68]. The second is the role of policy in transition, such as politically accelerated transition [69], conditions and intervention strategies [70], and policy intervention points for sustainability transition [71]. The third aspect is political dimensions, such as political struggles between niche and regime actors [72], linking the MLP to the advocacy coalition framework [73], political economy [74], international political economy [75], and political coalition theories [76].

Regimes

Some scholars have focused on the structuralism of socio-technical regimes by introducing institutional theory into regime [77], while others have applied social movement theory to MLP for understanding how external normative concerns affect existing regime [78]. Kanger (2021) [79] extended two concepts by rebuilding the MLP model: the regime life cycle transition model and the transition path method based on the attribute of space to analyze the national energy transition.

Cluster 2 (Green): Hierarchy evolution of MLP

The MLP consists of three interdependent and nested layers in a hierarchy: niche, regime, and landscape. In cluster 2, the most significant piece of paper includes Smith et al. (2010) [12], Smith and Raven (2012) [80], Markard et al. (2012) [2], and Frank W Geels (2014) [81], which were all connected with the three clusters and included analysis of niche, regime, and landscape at different levels.

- Niche

Niche's conception comes from technological niches, strategic niche management, and transition management, which refers to a set of exciting innovations that not protected by mainstream rules [9]; therefore, it generally needs to be protected as an "incubation room [10]." Shielding, cultivation, and empowerment [80] are the relevant characteristics where socio-political work needs empowerment [81,82]. Schot and Geels (2008) [83] researched the role of various niche internal processes such as learning, networking, vision, and the relationship between local projects and global rule sets that guide actors' behavior. It also includes corresponding political patterns, economic and cultural influences, etc. For example, in the existing regime, niche markets provide space for establishing social networks that support innovation, such as supply chains and relationships between users and

producers. As for new technologies, this niche market does not always exist, which means that new technologies, markets, and user preferences need to be jointly constructed [84].

The development of a niche was not linear but was related to the learning process, network establishment, and interaction between expectations. This nonlinearity and change were related to internal learning and external development [85]. The niche phase may last a long time, and the invention-to-innovation period (introduction to a viable market) usually lasts 20 to 30 years. Schot and other scholars integrated the niche into evolutionary theory and developed the SNM theory [83,86].

- Regime

Nelson and Winter (1977) suggested the concept of the technological regime [87], and Nelson and Winter (1982) later conceptualized coordination as the outcome of organizational and cognitive routines [11], based on which MLP established the concept of "*technological regimes*" [7]. Kemp et al. (1998, 2001) defined a broader notion of technological regimes [88,89], while Rip and Kemp (1998) (p. 340) further expanded the definition of technological regimes to the sociological category of "rules." Subsequently, Frank W Geels (2006a) [90] defined three interrelated elements of the socio-technical system: "*a network of actors and social groups, formal, cognitive, normative rules, and material and technical elements*." The socio-technical regime was established in institutions or technological regimes [11], which is a rule set or grammar, including public authorities, societal groups, research networks, user groups, producer networks, suppliers and financial networks, and their interaction [7]. Later, Geels (2004a) [1] used socio-technical regimes to refer to the semi-coherent rules of diverse social groups.

The regime was stable, but niche development and landscape pressure may cause instability. Holtz et al. (2008) [91] defined a regime as composed of actors with technical, institutional, economic, social, cognitive, and physical requirements and personal goals, values, and beliefs. Its basic form is dynamic and stable, free from external constraints, and is mainly formed and maintained through mutual adaptation and co-evolution of actors and requirements. The regime is characterized by stability and lock-in, for which only gradual, not fundamental, changes can be made [4], which shows that niches and regimes have similar structures but differ in scale and stability. Coincidentally, Turnheim and Geels outlined this destabilization using lessons from the British coal industry and established a framework to deal with the interaction between the accumulation of external pressures, industry response strategies, and the gradual weakening of commitments to existing institutional elements [92,93].

Some scholars have also tried to develop multi-regimes, which is helpful for some cross-regime analysis, such as sustainable transport, including an automobile regime co-existing with changed public transport regimes [94].

- Landscape

Rip and Kemp (1998) [5] introduced the socio-technical landscape concept in a wide-ranging review of theories of technological change. Suarez and Oliva (2005) [95] later suggested distinguishing between different types of landscape changes. Rip and Kemp (1998), focusing on the technological regime, proposed a "landscape" view including an "artifact" view and called it a "*multilayered perspective*." The landscape has two meanings: one is something around us that we can travel through, and the other metaphorical meaning is something that we are a part of, something that sustains us. Further, Jan et al. (2001) [96] identified different levels: the socio-technical landscape (macro-level), regimes (meso-level), and niches (micro-level). The MLP expanded the concept of landscape and further promoted the connotation of the framework [7,90,97]. A landscape is an exterior structure or an environment in which the participants interact. It comprises a series of deep-level structures and is a broader technical-external factor than regulation. The landscape cannot be easily changed in the short term, even if exogenous events such as demographic changes, macroeconomic trends, political developments, wars, and crises occur [4]. Nevertheless, landscape changes can pressure the regime and create opportunities for the niche.

Cluster 3 (Blue): Theoretical basis of MLP

This cluster focused on the theoretical basis and broader theories, such as technological innovation systems, technological systems, transition management, and sustainable transition. The theoretical basis of MLP mainly includes evolutionary economics, the sociology of innovation, neo-institutional theory, and typological theories used to combine multiple variables in a configuration with the inherent logic and bind them together.

The MLP started in the STS community of the Netherlands and the field of history of technology. Rip and Kemp (1998) [5] defined technology as a "configuration that works." Latour understood Technological development as "heterogeneous engineering," including knowledge, prototypes, resource mobilization, social networks, market construction, and regulatory frameworks [98]. From the viewpoint of the sociological framework, Van de Poel's sociological framework was utilized in MLP, which divided society into three elements: regime insiders, regime actors, and the environment [99,100]. Moreover, the borders of the technological system may not coincide with the national borders. Carlsson and Stankiewicz (1991) [101] defined a technological system as "*a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology*." The socio-technical perspective was based on understanding the technology in context [102] (p. 176).

Levidow and Upham (2017) [45] further analyzed the technological system in the energy sector's transition. The transition characteristics include technological innovation and the use (selection and adoption) of social applications, a multi-participant process, and a transition from one system to another. The fundamental transition was a long-term process (40–50 years) and a macro-level transition [67].

Geels and Schot (2007) [6] applied Suarez and Oliva's typology for landscape change [96] when describing transition pathways, and Freeman and Perez's (1988) innovation typology was used in Frank W Geels (2006a) [13] and Frank W Geels (2006b) [103]. The concept of system levels is derived from Dosi et al. (1988) [104], and the concept of co-evolution was built by Douthwaite et al. (2002) [105], who described the concept of the evolutionary cycle and how individual cognition affected each other [106]. The multi-level concept was derived from Braudel's notion of different levels of historical time [107].

The innovation system believed that the process of innovation and diffusion was both collective and individual behavior [46], which included Technological Innovation Systems (TISs) [101]. Related literature on clustering studied contextual structures, interaction dynamics [108], and functional dynamics [109] of TISs. Innovation is often combined with a sustainable transition. Sustainable development-oriented innovation and technological research have attracted particular attention over the past decade, and the sustainable transition has become an emerging field [2]. Markard and Truffer (2008) combined technological innovation systems with the MLP, which has attracted much attention. Transition management theory has a definite effect on the transition of complex societal systems [110]. Kemp et al. (2007) [111] applied transition management to social technology systems, and LOORBACH (2010) [112] regarded transition management as a new governance method for sustainable development.

3.4.3. Author-Keywords Analysis

According to the author-keywords (DE) distribution by the period in Table A5 and the annual appearance in Figure 7, *Multi-level perspective* and *transitions*, as the search keywords, were ranked at the top, and their attention has constantly increased from the annual number. It is worth noting that *sustainability transitions* ranked 8th in period 1, 4th in period 2, and 2nd in period 3, indicating that sustainability transition has become an important research subject in the MLP field. In addition, the first period mainly focused on the development of the MLP. Correlated keywords such as *socio-technical transition*, *strategic niche management*, *transition management*, and *transition pathways* became the top keywords. In the second period, keywords such as *sustainable transition*, *energy*, and *governance* were added, indicating that MLP research paid increased attention to the transition of social tech-

nology systems in sustainable transition and its application in the energy field. *Renewable energy* is a significant way for establishing the sustainable transition of the energy system; thus, it has become a hotspot in the field in the third period.

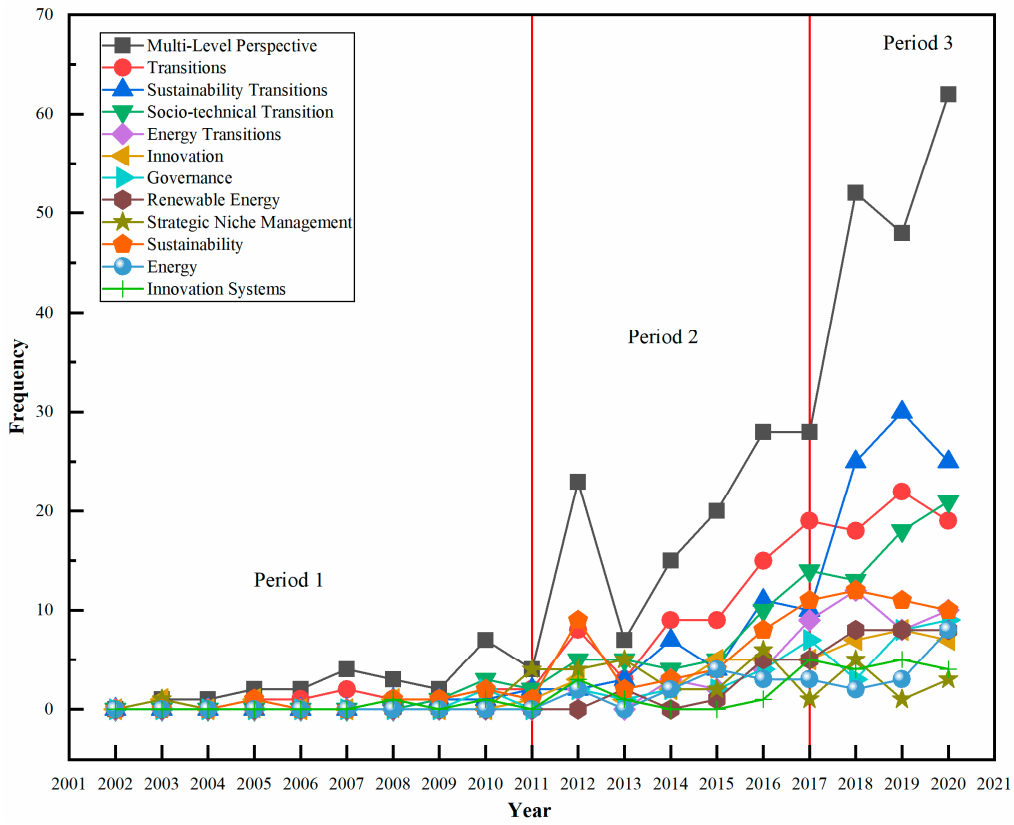

Figure 7. The annual change of the top 12 Author-keywords.

Current developments in sectors, such as energy, transport, agri-food, are unsustainable, and sustainability transitions are socio-technical transitions related to sustainability goals [2], which can be seen as a response to critical sustainability challenges such as Climate change. Sustainability transitions research can provide orientation and policy insights, and MLP is one of the prominent frameworks in sustainable transition. Therefore, sustainability transitions became a keyword with high frequency.

3.4.4. Themes and Thematic Areas

Based on the three periods, three strategic diagrams (Figures A3–A5) and a thematic evolution map (Figure 8) were used to demonstrate the evolution of the MLP research. In the strategic diagrams, Centrality was used to measure the strength of external connections with other topics and reflect the importance of a topic in the development of the entire research field. Density was used to measure the internal connection between themes and understand theme development [113]. Finally, the themes were displayed in a two-dimensional space using a visualization method. The vertical and horizontal coordinates represented density and centrality, respectively. The coordinate system was divided into four quadrants, and different types of topics were then categorized into four quadrants (Figure A2).

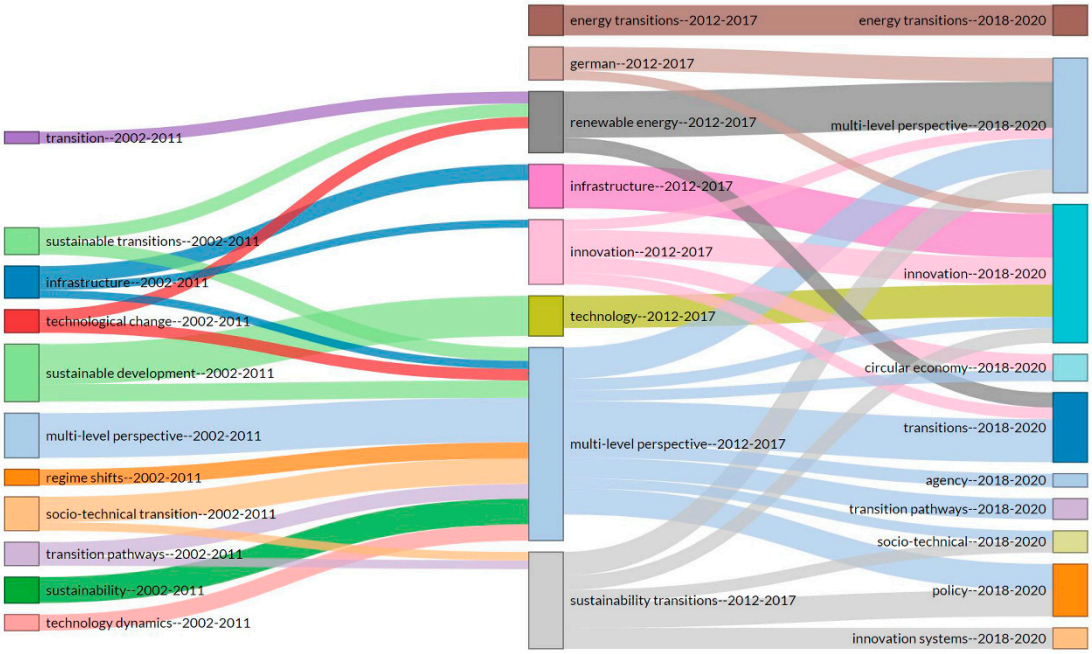

Figure 8. Thematic evolution in stages. Thematic Evolution parameters: Number of words = 400, Min Cluster Frequency = 5, Min weight index = 0.1, Weight index = inclusion index weighted by word-occurrences.

In this sub-period 2002–2011(Figure A3), the author-keywords were identified in 12 themes, and the largest one was *MLP* (Cumulative Frequency, CF = 102, expressed as the size of spheres in the thematic map [114]), which had a high centrality. As a socio-technical system analysis framework, it can be applied to the transition analysis of various systems, such as renewable energy [115], agriculture [116], aviation systems [13], power systems [117,118], and transportation system [119]. The *MLP* was in the third quadrant in all three periods. Contrastingly, the second vital theme, *sustainability transitions* (CF = 37), was in the first quadrant in period 1, the motor theme, and this theme is incorporated into the MLP in the third period. *Sustainable Transitions* has gone from a well-developed theme to a basic and transversal theme and has become the object of academic debate in more and more disciplines. The motor theme also included *technology* (CF = 24) and *infrastructure* (CF = 10) in this sub-period. One of the foundations of MLP is technology development. The theory about technology has been relatively perfect in the primary stage of MLP development, so *technology* has become a fully developed theme at this stage. Similarly, *infrastructure* plays an essential role in economic development and socio-technical systems.

In this sub-period 2012–2017 (Figure A4), the number of papers was significantly higher than in the first period, but the number of topics reduced from 12 to 7. *MLP* remained the most prominent significant node. Its density value rose slightly, but the CF value increased significantly, from 102 in the first period to 794, reflecting that with the development of the MLP, many keywords such as *sustainability transitions*, *socio-technical transition*, *SNM* are integrated into MLP. MLP is increasingly applied in different sectors, such as energy transitions, renewable energy, transport, agriculture, etc. At this stage, only the *innovation* (CF = 223) is still the motor theme, and the *transitions* (CF = 347) are transformed from the second quadrant to the third quadrant, becoming a basic and transversal theme. Innovation activities are affected by the sustainability transition and can also trigger social changes and impact environmental and social sustainability [12]. In the third period, *innovation* is still a motor theme, and its density value was high, showing that research on innovation within MLP research is becoming a new focus.

In the last sub-period, 2018–2020 (Figure A5), the number of themes increases to 11. With the development of MLP, attention to *policy* and *agency* has gradually increased, and

the theme *Policy* (CF = 4) has entered the fourth quadrant and became an essential but not developed theme. In the process of MLP development, it has been criticized for not paying attention to the agency [26,27], which led to the theme *agency* (CF = 9) at this stage, making it a well-developed theme. *Renewable energy* (CF = 58) entered the first quadrant as a new member. Renewable energy is an essential support for energy transition, and the energy system is one of the essential socio-technical systems, and its transition is a complex process. The MLP has advantages in explaining the socio-technical transition of such complex systems. Therefore, many studies on energy transitions have appeared during this period [79,120]. Renewable energy, an important measure to solve climate problems in the energy field, has also been concentrated. It is worth noting that the theme of *energy transitions* (CF = 24) is in the fourth quadrant and *renewable energy* (CF = 58) is in the first quadrant.

Figure 8 demonstrates the evolution and development of the theme in different periods. The themes of period one were relatively scattered, revolving around the theoretical basis of MLP, such as *transition*, *technological change*, *social-technological transition*, and other themes; this included the core regime shifts of MLP. The number of articles posted in the second period increased significantly, but the topics concentrated. *MLP* became the largest topic, followed by *sustainability transition* and *innovation*. During this period, research on MLP focused more on sustainable transition, while research on niche focused more on innovation niche. In addition, two new themes appeared at this stage, namely *energy transitions,* and *German*, indicating a gradual increase of MLP application in energy transition research. For example, this stage contains 63 energy-related MLP studies, covering energy transition [121], renewable energy [122], district heating [123], energy policy [124], etc. *German* is included in the theme because 13 articles on MLP applied to Germany appeared at this stage, including a sustainability-oriented science system [125], sustainable e-mobility [119], car industry [126], offshore wind [127], and energy transition [128].

In the third period, the number of themes remained 10, but there was some differentiation. *Innovation* became the most prominent theme, followed by *MLP* and *transitions*. The *sustainability transitions* of period two further differentiated into multiple themes, such as *MLP*, *innovation*, *social-technical*, *policy*, and *innovation systems*, which were closely related to sustainable development. In this period, *MLP* was further subdivided into *innovation*, *circular economy*, *transitions*, *agency*, *transition pathways*, *socio-technical*, and *policy*, among which *agency*, *transition pathways*, and *policy* represent the current hot topics of MLP research.

Innovation and *sustainable development* are closely related. The 'sustainable development' first appeared in the Brundtland Report in 1987 [129] and has become 'the foundation of theoretical approaches like the green economy and circular economy' [130]. The challenge of sustainable development is a 'transition' to a more sustainable socio-technical system [12]. Innovation research is no longer limited to economic potential but includes social changes caused by innovative activities and their impact on environmental and social sustainability. MLP believes that innovation should be considered at the system level. At present, innovation research has paid more attention to green innovation. Green Innovation includes green product innovation, green recycling, and green publicity [131]. The goal of green innovation is sustainable development, and the combination of green innovation and digital finance influences energy and environmental performance [132]. Meanwhile, the *Circular Economy* (CE) is becoming more and more attention with its environmental, economic, and social impacts on both production systems and consumers in sustainable development [133]. CE is a paradigm shift, and how to measure the rate of adoption of the CE by organizations has also become one of the recent research topics [134].

4. Conclusions and Perspective

This study aimed to discover the development and evolution of the MLP in the past two decades from the three main pillars of scientific production. For this purpose, we retrieved 757 documents from two merged databases using the bibliometrix tool.

Since the MLP was proposed, published papers have increased, especially in 2012; it doubled from the previous year, increasing by nearly one-half in 2018. Seemingly, there was more interest in MLP from 2018 to 2020 because nearly half of the literature was published, and the number of sources, authors, and references also increased accordingly.

The sources analysis revealed that *Environmental Innovation and Societal Transitions* have the most papers, with nearly one-tenth of the total papers published. Recently, sources published MLP papers have mainly focused on *Environmental Innovation and Societal Transitions*, *Sustainability*, *Technological Forecasting and Social Change*, *Energy Research & Social Science,* and *Research Policy*. The number of sources focusing on the MLP is also increasing, indicating a precise relationship with the attention of sustainable transition research.

The authors' analysis showed an upward trend in the number of scholars focusing on MLP, from less than 100 in the first issue, 642 in the second period, to 948 in the third period, and the number of authors in the last two decades has reached 1514. Considering author cooperation, 2018–2020 had the most cooperation, followed by 2012–2017 and 2002–2011, which had the minor cooperation. However, the average number of authors per article is below three.

Some exciting phenomena have been discovered at the national level. The UK, the Netherlands, and Germany ranked in the top three production and citations. The Netherlands ranked first in production and citations, taking the lead in the production and citations in the first period, while the UK led production in the second and third periods. Finland's production increased rapidly during the third period. In addition, some countries such as Austria, China, and Italy did not consider the MLP in the first period, but the attention began to rise in the third period.

This research identified three research topics through reference co-citation network analysis: criticisms and extensions, hierarchy evolution, and theoretical basis. Criticism mainly includes the concept of regimes, operating specifications, lack of agency, attention to politics, culture, power, hierarchical levels. Conversely, MLP criticisms promote MLP development, resulting in the expansion of the MLP, such as the MLP combined with other models, the spatial scale joining the MLP, and paying more attention to actors, agencies, power, and policy. These analyses are helpful for readers to understand the origin, development and evolution, shortcomings, and improvements of the MLP.

As for the frequency of keywords, high-frequency keywords all show an increasing trend, and sustainability transition, socio-technical systems, and governance rapidly increased in the third period. The frequency of energy transition and renewable energy has increased since it appeared in 2013, indicating that the energy sector is an important application area of the MLP. As a significant topic of sustainable transition research, the energy transition considers the transitions of energy supply, such as renewable energy, Cogeneration, and Trigeneration [135], and considers energy demand-side management. The frequently-used methods are the low-carbon energy-economic models for energy simulation and optimization. Among these, the New Economics Energy Transition Models are considered to better analyze the energy transition in terms of system, complexity, time, and path dependence. Furthermore, the integration of MLP and the energy Model is also considered as the signal research direction [136]. As MLP provides a theoretical analysis framework for the socio-technical systems towards sustainable systems, it has received more and more attention in sustainable development. We consider themes and thematic areas at three periods. Some new themes, such as renewable energy, technology, infrastructure, etc., were included in the second period, but they were all integrated in the third period. The exception is energy transition, which became an independent theme in the second and third periods. New concerns such as agency, transition pathways, policy, green innovation, sustainable transition and circular economy emerged in the third period. These themes are currently the focus of the research.

However, this study had some limitations. The research data are built on two influential databases, which still cannot cover all available literature on MLP. It is also a deficiency for bibliometric analysis, which should slightly impact the analysis from a macro

perspective. The same limitation may occur during the data cleaning. The correlation between each document and MLP was manually identified as much as possible. There may be errors in the marginal literature during the identification process, but the impact on the overall analysis was slight. However, the results obtained from the analysis are helpful for researchers in understanding the MLP. The analysis of cooperation has played a supportive role in groups seeking to transform research investigations or policy analysis. This research provides the possibility for further research on the future of the MLP, such as increasing the scope of the database using automatic procedures for obtaining a data set containing research reports and working papers.

With the future in mind, the research of MLP mainly reflected in: first, focus on the dynamic changes at the niche level, multi-niche innovation and its internal interaction; second, further enrich the connotation of the registry, in addition to the original, consider the culture, social relations and other factors, while further considering multi-regime and the interaction between them; the third is to consider the interaction between niche-regime-landscape from a system perspective, especially between multi-niche, multi-regime and multi-landscape. In order to further summarize the transition pathway of the socio-technical system; fourth, the research on MLP in the transition will further consider the spatial characteristics, and pay more attention to the spatial heterogeneity in the niche-regime-landscape interaction; fifth, from a methodological perspective, bridging MLP with quantitative models and evaluation models will be a frontier research direction, which can further enrich the transition research methodology.

Author Contributions: Conceptualization, T.L.; Data curation, C.W.; Funding acquisition, T.L. and J.X.; Investigation, R.C.; Methodology, C.W.; Supervision, T.L.; Validation, J.X.; Visualization, R.C.; Writing—original draft, C.W.; Writing—review & editing, L.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China [grant number 72074212, 72004218], National Social Science Foundation of China [grant number 20FGLB011], Carbon Neutrality and Energy Strategy Think Tank [grant number CUMT_2021WHCC01], General Project of Philosophy and Social Science Research in Universities of Jiangsu Province [grant number 2019SJA1639], and Jiangsu Social Science Foundation Project [grant number 20EYD001].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data for this article was obtained from Scopus [https://www.scopus.com] and Web of Science [https://www.webofscience.com] (accessed on 28 November 2020) using the search string in Figure 1.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

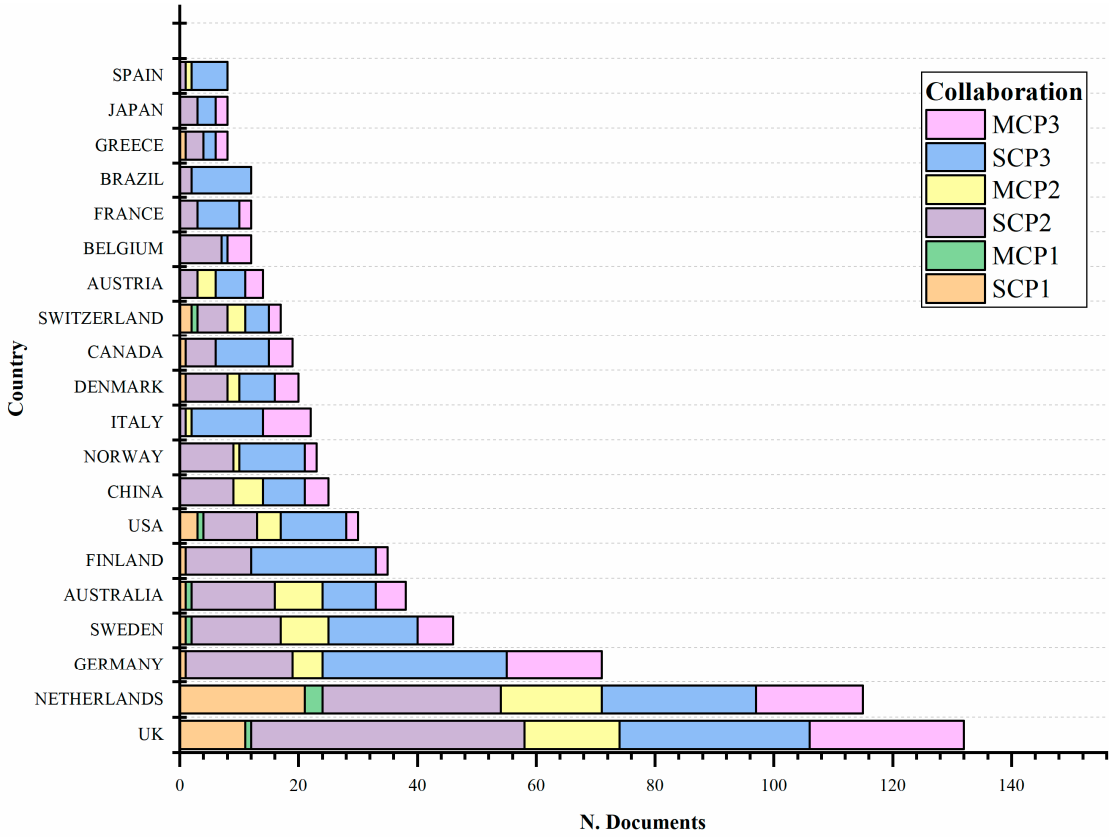

Figure A1. Country collaboration. SCP = Single Country Publications, MCP = Multiple Country Publications. 1, 2, 3 represents the period, such as SCP1 represents the SCP of period 1.

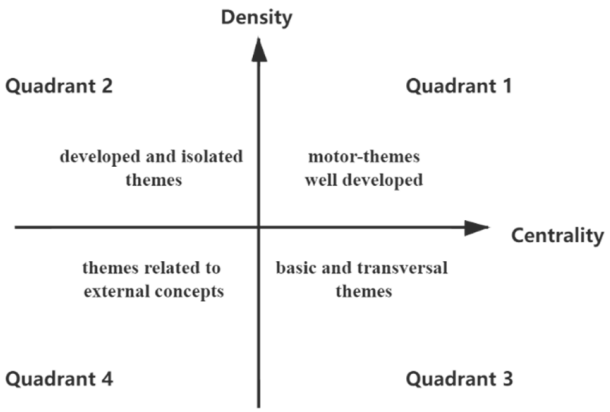

Figure A2. Four quadrants of a Strategic Diagram. Adapted from Ref [113].

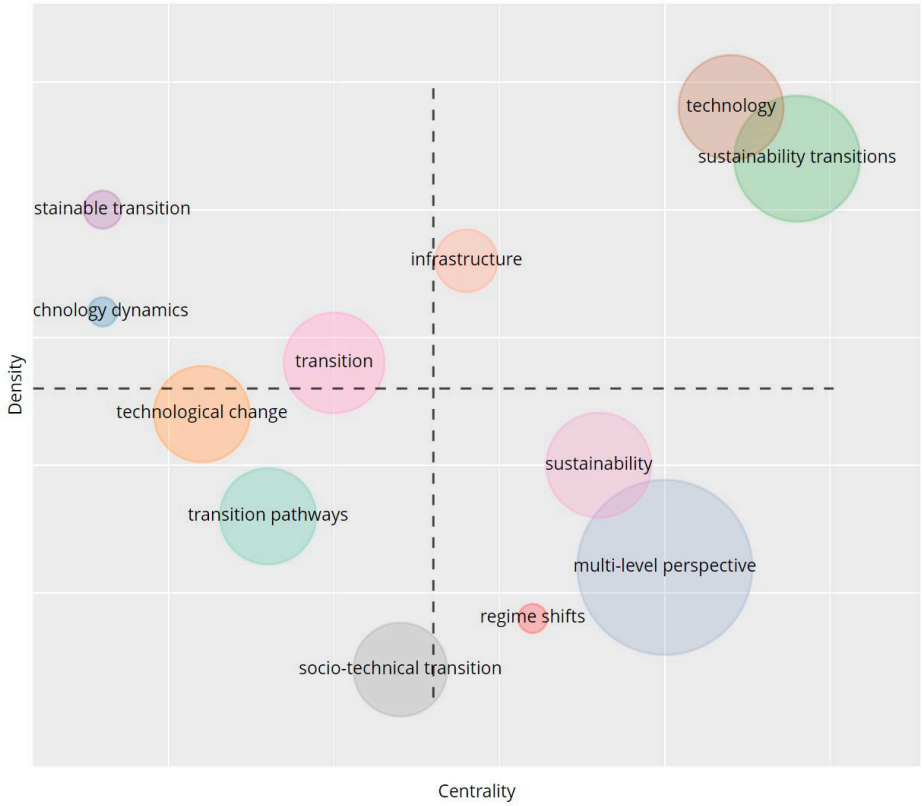

Figure A3. Thematic map of MLP research between 2002 and 2011. The sphere size represents the number of publications related to the theme.

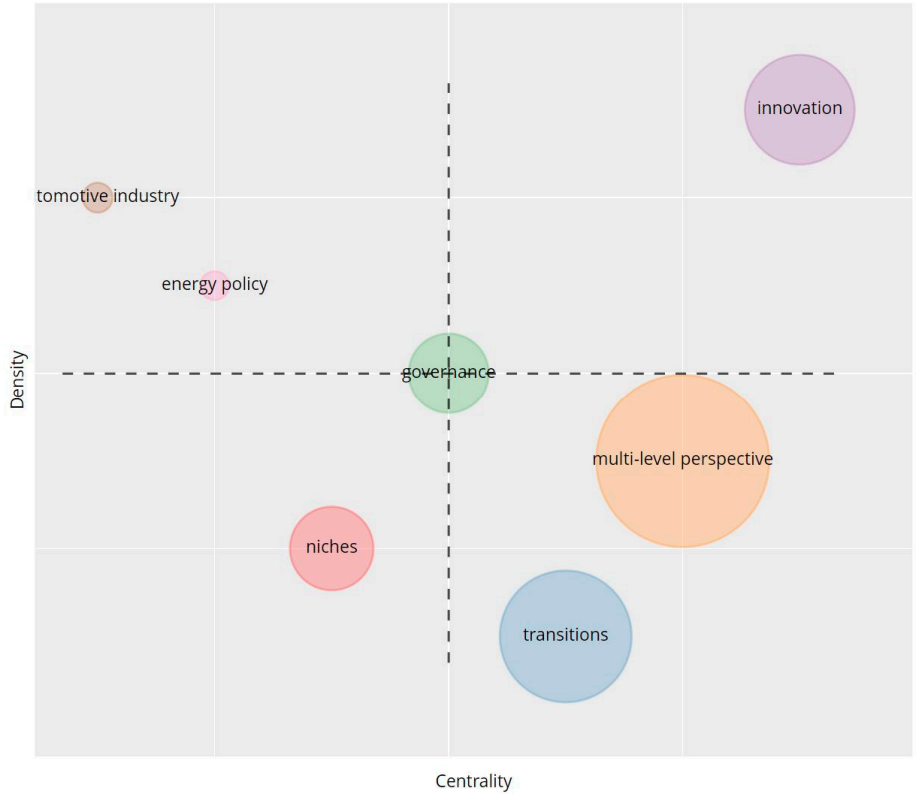

Figure A4. Thematic map of MLP research between 2012 and 2017. The sphere size represents the number of publications related to the theme.

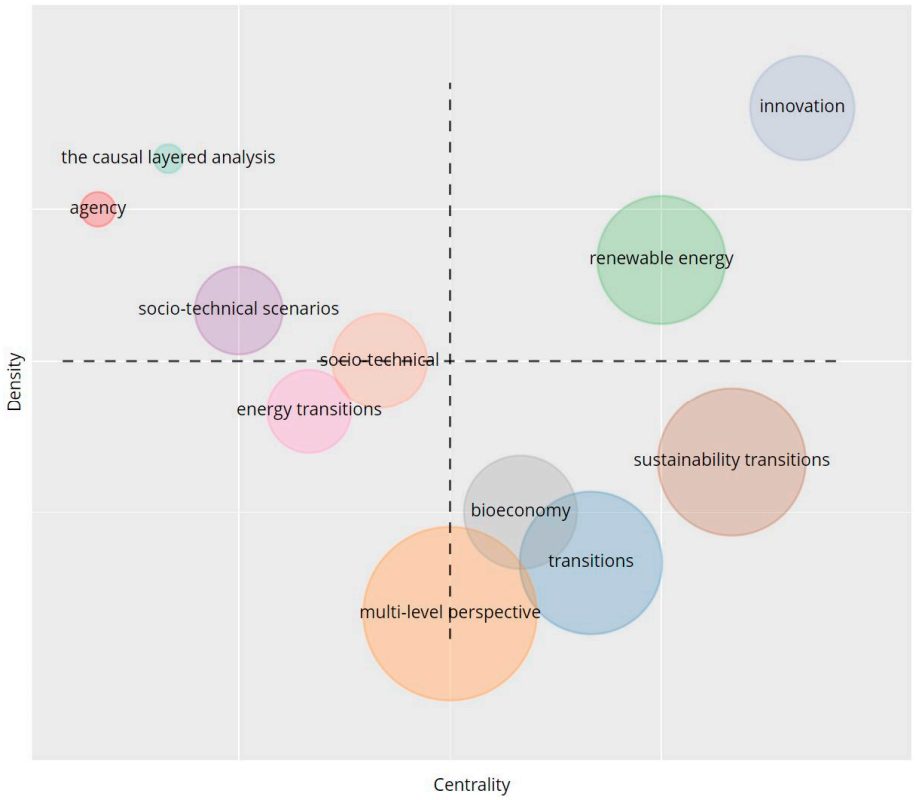

Figure A5. Thematic map of MLP research between 2018 and 2020. The sphere size represents the number of publications related to the theme.

Table A1. Scientific Production by Sources.

	Period 1: 2002–2011		Period 2: 2012–2017		Period 3: 2018–2020		Total: 2002–2020			
R	**Source**	**N**	**Source**	**N**	**Source**	**N**	**Source**	**N**	**H**	**TC**
1	Research Policy	11	Environmental Innovation and Societal Transitions	38	Environmental Innovation and Societal Transitions	41	Environmental Innovation and Societal Transitions	83	23	2592
2	Technological Forecasting and Social Change	9	Technological Forecasting and Social Change	22	Sustainability	37	Technological Forecasting and Social Change	67	23	2345
3	Technology Analysis & Strategic Management	4	Research Policy	21	Technological Forecasting and Social Change	36	Research Policy	55	32	11,881
4	Technology in Society	4	Journal of Cleaner Production	12	Energy Research & Social Science	34	Sustainability	48	10	395
5	Journal of Cleaner Production	2	Energy Policy	12	Research Policy	23	Energy Research & Social Science	42	13	834
6	Environmental Innovation and Societal Transitions	2	Sustainability	11	Journal of Cleaner Production	16	Journal of Cleaner Production	30	15	678
7	Science Technology & Human Values	2	Renewable & Sustainable Energy Reviews	9	Energy Policy	15	Energy Policy	27	14	663
8			Energy Research & Social Science	8	Energies	9	Technology Analysis & Strategic Management	17	10	1358
9			Technology Analysis & Strategic Management	8	Environmental Science & Policy	5	Renewable & Sustainable Energy Reviews	12	8	244
10			European Planning Studies	6	Futures	5	Futures	10	7	205
11			Environment and Planning A-Economy and Space	4	Technology Analysis & Strategic Management	5	Energies	9	3	18

Note: R = Rank, N = production of articles, H = H index, TC = Total Citations.

Table A2. Most relevant authors.

Rank	Period 1			Period 2			Period 3			Total			
	Author	**N**	**TC**	**Author**	**N**	**TC**	**Author**	**N**	**TC**	**Author**	**N**	**H**	**TC**
1	Geels F	18	9025	Coenen L	7	1027	Geels F	13	383	Geels F	37	26	10,665
2	Verbong G	6	497	Truffer B	7	2227	Sovacool B	10	398	Raven R	16	11	2366
3	Raven R	4	252	Geels F	6	1257	Klerkx L	9	161	Sovacool B	12	9	714
4	Smith A	3	1065	Kivimaa P	6	409	Raven R	6	160	Hekkert M	10	7	402
5	Truffer B	3	636	Raven R	6	1954	Upham P	6	35	Kivimaa P	10	9	629
6	Bai X	2	169	Hekkert M	5	370	Hekkert M	5	32	Klerkx L	10	7	225
7	Foxon T	2	340	Markard J	5	1463	Hyysalo S	5	219	Truffer B	10	10	2863
8	Kemp R	2	208	Avelino F	4	409	Bogel P	4	30	Upham P	10	6	104
9	Pearson P	2	196	Chang R	4	93	Boon W	4	75	Coenen L	9	8	1161
10	Schot J	2	2441	Grin J	4	241	El B H	4	35	Markard J	9	8	2138
11	Voss J	2	745	Loorbach D	4	347	Falcone P	4	76	Verbong G	9	7	542
12	Wieczorek A	2	169	Nykvist B	4	109	Kivimaa P	4	220	Pearson P	8	6	292
13	Witkamp M	2	83	Pearson P	4	92	Matschoss K	4	35	Markard J	7	6	601
14	Alexander K	1	24	Upham P	4	69	Pel B	4	192	Pel B	7	5	386
15	Angel D	1	37	Zhao Z	4	93	Rogge K	4	92	Wells P	7	5	285

Note: N = Number of articles; H = H-index; TC = Total citation.

Table A3. National productions and citations.

Country	Period 1		Period 2		Period 3		Total	
	TC	N	TC	N	TC	N	TC	N
UK	2679	21	3729	116	697	141	7105	278
NETHERLANDS	7974	37	2110	99	384	107	10,468	243
GERMANY	75	3	669	43	393	90	1137	136
SWEDEN	146	6	1052	48	160	63	1358	117
AUSTRALIA	64	5	397	37	175	32	636	74
USA	114	5	666	30	61	39	841	74
FINLAND	14	1	229	23	91	47	334	71
CHINA [a]	-	-	251	28	12	23	263	51
ITALY	-	-	4	8	169	39	173	47
FRANCE	-	-	24	14	49	31	73	45
NORWAY	-	-	107	21	74	22	181	43
SWITZERLAND	636	3	1623	21	46	19	2305	43
SPAIN	-	-	19	6	30	31	49	37
DENMARK	39	1	325	13	144	21	508	35
CANADA	67	1	131	8	94	21	292	30
AUSTRIA	-	-	490	9	40	17	530	26
BRAZIL	-	-	14	5	21	21	35	26
JAPAN	-	1	46	9	3	13	49	23
BELGIUM	-	-	172	12	3	10	175	22
NEW ZEALAND	-	-	29	10	46	9	75	19

Note [a]: China includes data produced by Taiwan, with Taiwan in the second period: N = 3, TC = 33, and Taiwan in the third period: N = 2, TC = 2.

Table A4. Top 20 highly cited papers.

Rank	Document	Year	GC	TCY	LC	LC (%)	Source	CC
1	Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study [7]	2002	2154	102.6	517	24.00	RES POLICY	Red
2	Typology of sociotechnical transition pathways [6]	2007	1704	106.5	376	22.07	RES POLICY	Red
3	From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory [97]	2004	1269	66.8	227	17.89	RES POLICY	Red
4	Sustainability transitions: An emerging field of research and its prospects [2]	2012	1017	92.5	206	20.26	RES POLICY	Blue
5	The multi-level perspective on sustainability transitions: Responses to seven criticisms [9]	2011	920	76.7	0	0.00	ENVIRON INNOV SOC TR	Red
6	Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy [83]	2008	737	49.1	158	21.44	TECHNOL ANAL STRATEG	Blue
7	Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges [12]	2010	671	51.6	168	25.04	RES POLICY	Green
8	What is protective space? Reconsidering niches in transitions to sustainability [80]	2012	621	56.5	154	24.80	RES POLICY	Green
9	Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective [137]	2010	605	46.5	157	25.95	RES POLICY	Red
10	Technological innovation systems and the multi-level perspective: Towards an integrated framework [25]	2008	510	34.0	160	31.37	RES POLICY	Blue
11	Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective [74]	2014	457	50.8	114	24.95	THEOR CULT SOC	Green
12	Toward a spatial perspective on sustainability transitions [50]	2012	443	40.3	95	21.44	RES POLICY	Green
13	Can cities shape socio-technical transitions and how would we know if they were [138]	2010	368	28.3	65	17.66	RES POLICY	Green
14	Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective [139]	2005	335	18.6	93	27.76	TECHNOL FORECAST SOC	Red
15	The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930) [140]	2005	328	18.2	93	28.35	TECHNOL ANAL STRATEG	Red
16	A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies [8]	2012	322	29.3	131	40.68	J TRANSP GEOGR	Red
17	The Politics of Social-ecological Resilience and Sustainable Socio-technical Transitions [141]	2010	306	23.5	32	10.46	ECOL SOC	Green
18	Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework [66]	2012	282	25.6	81	28.72	RES POLICY	Blue
19	Environmental Innovation and Sustainability Transitions in Regional Studies [142]	2012	246	22.4	33	13.41	REG STUD	Green
20	Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions [143]	2016	240	34.3	61	25.42	RES POLICY	Green

Note: GC= Global Citations, LC = Local Citations, TCY = Total citation per year, CC = the cluster where the document is located in the Reference Co-citation network and X means not in the cluster in Figure 6.

Table A5. Author-keywords frequency. DE = Author-keywords.

Period 1: 2002–2011		Period 2: 2012–2017		Period 3: 2018–2020	
DE	**Frequency**	**DE**	**Frequency**	**DE**	**Frequency**
multi-level perspective	26	multi-level perspective	119	multi-level perspective	158
transitions	11	transitions	70	sustainability transitions	81
system innovation	8	socio-technical transition	43	transitions	61
sustainability	7	sustainability	41	socio-technical transition	53
socio-technical transition	6	sustainability transitions	40	sustainability	36
strategic niche management	5	innovation	24	energy transitions	30
sustainability transitions	5	energy transitions	23	renewable energy	24
transition pathways	5	governance	21	innovation	22
innovation	4	strategic niche management	20	governance	21
sustainable development	4	renewable energy	15	innovation systems	15
technology	4	energy	14	energy	14
transition	4	policy	13	socio-technical systems	13
transition management	4	china	12	technological innovation systems	12
co-evolution	3	innovation systems	11	policy	10
patterns	3	dynamics	10	transformation	10
regime	3	innovation policy	10	agency	9
technological change	3	niches	10	strategic niche management	9

Table A6. Abbreviation for Sources.

Abbreviation	Sources
ECOL ECON	Ecological Economics
ECOL SOC	Ecology and Society
ENVIRON PLANN A	Environment and Planning A-Economy and Space
ENVIRON PLANN C	Environment and Planning C-Government and Policy
ENVIRON POLIT	Environmental Politics
GLOBAL ENVIRON CHANG	Global Environmental Change
THEO CULT SOC	Theory Culture & Society
POLICY SCI	Policy Science
PROG HUM GEOG	Progress in Human Geography
SUSTAIN SCI	Sustainability Science
J ENVIR ON POL PLAN	Journal of Environmental Policy & Planning
TECHNOL FORECAST SOC	Technological Forecasting and Social Change
J CLEAN PROD	Journal of Cleaner Production
RES POLICY	Research Policy
RENEW SUST ENERG REV	Renewable & Sustainable Energy Reviews
ENERGY RES SOC SCI	Energy Research & Social Science
ENVIRON INNOV SOC TR	Environmental Innovation and Societal Transitions
TECHNOL ANAL STRATEG	Technology Analysis & Strategic Management
SUSTAINABILITY-BASEL	Sustainability
SCI PUBL POLICY	Science and Public Policy
TECHNOL SOC	Technology in Society
IND CORP CHANGE	Industrial and Corporate Change
ACAD MANAGE REV	Academy of Management Review
SCI TECHNOL HUM VAL	Science Technology & Human Values
ENVIRON SCI POLICY	Environmental Science & Policy
ENVIRON POLICY GOV	Environmental Policy and Governance
EUR PLAN STUD	European Planning Studies
J ENVIRON POL PLAN	Journal of Environmental Policy & Planning
J RURAL STUD	Journal of Rural Studies
AGR HUM VALUES	Agriculture and Human Values
TRANSPORT RES A-POL	Transportation Research Part A-Policy And Practice

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