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From decarbonization to low carbon development and transition: a systematic literature review of the conceptualization of moving toward net-zero carbon dioxide emission (1995-2019)

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Abstract

The Paris Agreement on climate change has calls for urgent, radical, and transformative actions in mitigation and adaptation, particularly in terms of reducing greenhouse gas (GHG) emission. There are many terms used to describe the process of reducing GHGs, including decarbonization, low carbon development (LCD) or low carbon transition (LCT). The conceptualization of these terms remains puzzling and there has not been any consensus to explain the meaning and their interrelationship. Clearer definition and conceptual boundaries are necessary to improve the coherence of overarching practices to cut CO_2 emission. The paper aims to review key concepts related to climate change mitigation related to the reduction of $CO_2$and efforts toward net-zero emission in the academic literature, by (1) examining progress of the literature over time, (2) identifying geographical locus and sectoral focus of the literature, (3) determining the interrelationships between the key concepts. We use a Systematic Literature Review (SLR) method for data collection by selecting peer-reviewed literature from Scopus and analyzing the data with content analysis and bibliometric analysis. The findings are, firstly, the publications of the literature are influenced by global and national climate change policies and the interest of scholars affiliated to institutions from major emitter countries. Therefore, the literature is mostly originating from countries that emit the most CO_2 while also implement mitigations to reduce CO_2 emission. Secondly, China is the country where studies are mostly focused and also where the authors are affiliated/located. However, publications from the United Kingdom are cited the most. Thirdly, there are three clusters of literature found, namely that LCD and LCT are the terms used to identify visions for climate mitigation, while decarbonization is the actions and processes to achieve either LCD or LCT (as the visions).

Keywords: decarbonization, low carbon development, low carbon transition, climate change mitigation, systematic literature review

Highlights

- The dynamic of climate change policies influence the literature trend.
- The literature is mostly originating from major CO_2 emitter.

- Low carbon development and low carbon transition are visional terms.
- Decarbonization indicates the processes of decoupling CO_2 to achieve the visions.

1. Introduction

The occurrence of extreme weather events and climate variabilities have been more frequent and visible in different parts of the world for the last few decades. The Intergovernmental Panel on Climate Change (IPCC) argues that such events occur because of the effects of 1°C of global mean surface temperature warming (Allen et al. 2018). The temperature rise had already reached 1°C by 2017, and it is predicted to hit 1.5°C between 2030 and 2052 with the current trajectory as the concentration of CO_2 in the atmosphere continues to rise (IPCC 2018). Overshooting temperature above 1.5°C threshold will endanger natural and human systems, such as the loss of tropical coral reef up to 70-90% of the existing population. The IPCC also predicts that the risks of extreme heat and weather events will increase along with the temperature rise.

Reducing the amount of CO_2 in the atmosphere is one of the keys to limit the increase, and it has been a global development agenda for more than two decades. In 2015, the convention of the United Nations Framework for Climate Change Convention (UNFCCC) enacted the Paris Agreement that calls for actions by keeping the increase of human-induced global warming to well below 2°C and to pursue efforts to limit warming to 1.5°C. The target can be achieved through key activities, including mitigation, adaptation, GHG sinks conservation, and reservoir enhancement, and market- and non-market-based approaches of mitigation outcomes through Nationally Determined Contributions (NDC). The IPCC Special Report of 1.5°C suggests that the total of global CO_2 emission must be decreased by about 45% from 2010 levels by 2030 and reach net-zero before 2050 to limit warming 1.5°C with no or limited overshoot (IPCC 2018). On the other hand, the mitigation pathways for 2°C must fall by about 20% by 2030, and down to net-zero emission by 2070. The achievement of those ambitious targets depends on the underlying processes of development and societal choices that determine to what extent the energy sector and land-use change contribute to the production of CO_2 in the future (IPCC 2018).

In the academic sphere, different terminologies have emerged to describe what constitutes the shifting process toward CO_2 emission reductions. These words include but not limited to *decarbonization*, *low carbon development (LCD)*, and *low carbon transition (LCT)*. The first discussion of decarbonization concerning climate change in the literature appeared in an article authored by Ausubel (1995), who defines it as the process of decreasing the carbon intensity of primary energy[1]. About a decade later, the term "LCD" was introduced (Fulkerson et al. 2005, Pan 2005). However, there is still no single consensus on the definition. The discussion of LCD is centered around the reduction of fossil-fuel-based energy intensity in production and consumption in different economic sectors (Mirumachi, Sawas, and Workman 2019, Mulugetta and Urban 2010). Other researchers utilize the term "LCT" to describe an evolutionary process to produce less CO_2 emission (Bush et al. 2017, Castán Broto 2012, Geels 2018). Mander et al. (2007) used firstly in the literature the phrase to express the need for a transition to a low carbon energy system. Policymakers have gradually perceived the importance of pursuing net-zero CO_2 emission by adopting these terms into the development plan and policy documents, such as the United Kingdom (UK) (DECC 2009), China (Liu et al. 2013) and Indonesia (Bappenas 2019).

[1] Carbon intensity, according to UNEP (2018), is the amount of emissions of CO_2 released per unit of economic outputs (gross domestic product, output energy use, or agriculture/forestry products).

Despite the widespread use of these terms, there is no existing consensus on the definitions. Their conceptualizations to explain the process of moving toward net-zero CO_2 emission remain puzzling, such as how one differs from the others and what factors should be considered to support the process. To date, there is still lacking a comprehensive understanding of how these terms have been conceptualized. It could result in different interpretations of the meaning and diminish the coherence of overarching implementation to reduce CO_2 emission. A coherent review is needed to fill this conceptual gap because political and financial support has been increasing significantly to foster the implementation in recent years (Meltzer 2018, Bernstein and Hoffmann 2018). Having this knowledge can give implication to real practices, such as inputs to develop the strategies at the different level (i.e., national and city level) (Busch, Foxon, and Taylor 2018, van Sluisveld et al. 2017) and generable indicators to evaluate to track progress toward the Paris Agreement target (Vaidyula and Rocha 2018)

Previous works that can shed light on the questions mentioned above remain lacking, and they are yet to provide a comprehensive overview. Mardani et al. (2019) did a systematic review of the relationship between CO_2 emissions and economic growth. Gouldson et al. (2018) conducted a study to review the scale of co-benefits of low carbon actions in several sectors. Unfortunately, their results do not capture the progress of the literature beyond the city scope, and factors should be considered to stimulate the implementation of low carbon cities. Wang et al. (2017) provide a review of the progress of low-carbon development transformation in the literature. Their paper could provide the answer, but the paper has some limitations. First, although it gives general progress of LCD research, the timeframe of the review is between 1995 and 2014, whereas there have been significant milestones in climate change diplomacy afterward. Second, the paper does not reveal specific and essential details on the existing literature to inform opportunities for future research, such as study locations and sectors. Third, they did a cluster analysis to determine the main fields of the research, but it does not explain different types of factors that contribute to LCD.

This paper aims to review the key concepts related to climate change mitigation related to the reduction of CO_2 toward net-zero emission in the academic literature. There are three objectives and guiding questions to achieve this aim. The *first* is to examine the current progress of literature related to CO_2 mitigation toward net-zero emission (i.e., the publication trend and its authorship patterns). The *second* is to identify the geographical locus and sectoral focus of the literature. The *third* is to determine the cluster of research themes and interrelationships between these key concepts. Since the aim is to unveil its conceptualization, scholarly publications are considered as the most appropriate sources for the review. A Systematic Literature Review (SLR) is applied to conduct a comprehensive search over literature databases.

The structure of this paper is structured as follows. Following the introduction, the second section reviews the broad conceptualization of CO_2 emission reduction toward net-zero emission. The methodology applied to conduct the review is explained in the third section. The fourth section presents the results arranged by the objectives. In the fifth section, we provide a discussion on the gaps and potential future research opportunities based on the results.

2. Reducing CO_2 emission as part of climate change mitigation: theory and background

2.1. Key policies and progress at the international and national level

Over the past two decades, there have been significant efforts to cut CO_2 at the global level and national level, especially after the establishment of IPCC and the UNFCCC. In 1988, the

IPCC was formed to become a pool of scientists that captures scientific evidence of climate change in their respective fields to informs climate change negotiation. One of their main publications is the Assessment Report (AR). Meanwhile, the UNFCCC, signed by 154 nations at the Rio Earth Summit, Brazil in 1992, is an international treaty to facilitate the negotiation and it has a mission to stabilize "*greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system*" (United Nations 1992). From 1995, the parties to the UNFCCC have met annually at the Conference of Parties (COP) to reach a collective agreement on how to deal with climate change.

In 1997 at COP 3 in Kyoto, Japan, the UNFCCC parties resulted in the Kyoto Protocol, their first agreement that has specific targets and timetables for the mitigation of GHG emissions. Thirty-seven developed countries listed in Annex 1 of the protocol were obligated to pursue their aggregate CO_2 emission by at least 5 percent below 1990 levels between 2008 and 2012 (UNFCCC 1997). Three mechanisms are proposed to assist those countries in meeting their target cost-effectively, including the Clean Development Mechanism (CDM), Joint Implementation (JI), and Emission Trading (ET). Under the CDM and JI mechanism, developed countries are allowed to conduct projects that facilitate technology investment and transfers to reduce GHG with other countries. The CDM was launched in 2006, and, by August 2009, the UNFCCC had authorized more than 4,000 CDM projects that are predominantly renewable energy-related projects (Rahman, Dinar, and Larson 2010). Meanwhile, ET is a market-based emission to controlling GHG emission with economic incentives, and it had been carried out by 39 national and 23 sub-national governments, such as the European Union (EU), China, and California by 2015 (World Bank 2015).

After the Kyoto Protocol entered into force in 2005, top emitter countries have reached different progress on the CO_2 emission reduction. First, some national governments were not able to ratify the protocol due to domestic political challenges, such as the United States (Lau, Lee, and Mohamed 2012). Second, some countries successfully ratified it, but they face difficulty in meeting their target according to the timetable. For instance, Canada could not reach its commitment to six percent below the 1990 level before 2012 because the government could not adopt fully the policies that they proposed to meet the target (Barrett 2009) and they decided to withdraw from the protocol in 2011 (Odeku, Maveneka, and Konanani 2013). Third, some national governments introduced low carbon policies (e.g., reducing carbon intensity and developing renewable energy infrastructure) into their development plan at the national level, such as China in 2006 (Liu et al. 2013) and the UK in 2009 (Rogelj, Schaeffer, et al. 2015, DECC 2009).

In parallel with the dynamic challenges at the national level, the UNFCCC has attained other milestones related to the effort to reduce CO_2 emission (Table 1). *Firstly,* the convention sets overarching temperature targets (Held and Roger 2018). The IPCC in the AR4 (2007) and the AR5 (2013) informs significant findings of what would be the risk if the temperature reaches beyond different degree tipping points. Initially, the UNFCCC parties at the COP 15 Copenhagen (2009) responded to this issue by establishing a long-term target to hold 2°C above the pre-industrial level (Held and Roger 2018). At COP 21 in Paris (2015), they reached another consensus to achieve the 2°C goal but also to pursue the possibility of holding even 1.5°C to the pre-industrial level before the mid of this century. *Secondly,* the net-zero CO_2 emission target becomes a guiding focal point for policy-making that links the long-term temperature goal and socio-economic pathways (Rogelj, Schaeffer, et al. 2015). Article 4 of the Paris Agreement urges the parties to pursue net-zero CO2 emission by the mid of this century to meet the goal. *Thirdly,* national governments adopt voluntary nationally-based commitment as the basis to attain their climate goals. At COP 19 in Warsaw, Poland, such type of commitment was coined that they were required to formulate their pledge in the form

of Intended Nationally Determined Contributions (INDC). After they ratify the Paris Agreement, their INDCs become the first NDC to guide them in implementing climate change actions beyond 2020. Fourth, there have been more financial instruments available to aid developing countries in reducing CO_2 emission, for example the Nationally Appropriate Mitigation Actions (NAMAs) Facility and the Green Climate Fund (GCF).

Table 1 Key Events and Policies Related to CO_2 emission Reduction after the Kyoto Protocol entered to force

Year	Key Events	Key Policies
2007	COP 13 in Bali, Indonesia	• The Nationally Appropriate Mitigation Actions (NAMAs) were introduced to help developing countries reducing their GHG emissions across development sectors, including developing renewable energy infrastructure (e.g., wind farms and hydro-electric generator), improving public transportation, and reforestation (Hourcade, Shukla, and Cassen 2015).
	IPCC published the AR-4	• IPCC started providing different estimations of how achieving changes of average temperature in certain degrees above the pre-industrial level would have various impacts on the human and natural systems (IPCC 2007).
2009	COP 15 in Copenhagen, Denmark	• The idea of limiting the rise of global temperature no more than 2° Celcius was coined. Each party set its emission target voluntarily by 2020 and proposed its mitigation action (Held and Roger 2018). • Developed countries were committed to assisting developing countries, small island countries, and the least developed countries financially. The funding covers actions for adaptation and mitigation, including REDD+ program (*Reducing Emissions from Deforestation and Forest Degradation*), capacity building, and technology development and transfer (van der Gaast 2017).
2010	COP 17 in Cancun, Mexico	• Green Climate Fund (GCF) was established to channel financial needs for developing countries to adapt to the impact of climate change and to mitigate the emission of GHG (van der Gaast 2017)
2012	COP 18 in Doha, Qatar	• The Parties implementing the Kyoto Protocol adopts the Doha Amendment to extend their commitment until 2020 (van der Gaast 2017). • Some developed countries (e.g., Germany and the United Kingdom) commit to giving financial assistance for developing countries to reduce their CO_2 emission through the NAMA Facility (Winkler and Dubash 2016).
2013	COP 19 in Warsaw, Poland	• A voluntary pledge to reduce GHG emissions called the INDCs was coined (van der Gaast 2017).
2014	IPCC published the AR-5	• IPCC provides more comprehensive estimations of how a rising degree of global average temperature will result in different degrees of loss and damage to the human and natural systems (IPCC 2014b). • IPCC introduced the term decarbonization in the report to explain the need for reducing carbon intensity in the energy system (IPCC 2014a). • IPCC uses the term LCD to indicate where current financial, technological, and institutional capacity at the regional level should embark. No definition of LCD is given (Agrawala et al. 2014).
2015	COP 21 in Paris, France	• The parties of the UNFCCC agree on holding the increase global average temperature below 2°C and pursuing the possibility of pressing a more ambitious target to 1.5°C (UNFCCC 2015). • Net-zero emission must be achieved in the second half of this century, and the UNFCCC agree to implement their NDC to achieve the long-term temperature goal (Höhne et al. 2017).

2.2. Key terms and definitions

Reducing CO_2 emission is part of climate change mitigation, a human intervention to reduce the sources or enhance the sinks of GHG (IPCC 2014a). Socio-economic drivers determine the amount of CO_2 emission from the combustion of fossil fuel to generate energy and the conversion of land use due to deforestation and agricultural land expansion. Thus, the source of CO_2 emission can be categorized into two sectors: energy and non-energy sector (Bruckner et al. 2014). The energy sector includes sub-sectors consisting of electricity and heat, transportation, industry, and buildings, while the non-energy consists of Agriculture, Forestry, and Land Use (AFOLU), Industrial Process, and Product Use (IPPU), and international bunkers. By 2010, both the energy sector and AFOLU sector had shared CO_2 emission about 69% and 24% of total GHG emission respectively (Bruckner et al. 2014). There is a wide range of measures to mitigate CO_2 emission to alter the pattern of these socio-economic drivers in producing CO_2 emission. The measures include, but not limited to, improving energy efficiency, advancing renewable energy consumption, and even promoting the technology of Carbon Capture and Storage (CCS) (OECD 2015).

The pursuit of the long-term temperature targets by achieving net-zero emission must be implemented by the substantial transformation of key carbon emitter sectors, including how human activities produce and consume energy and utilize the land (Rogelj, Schaeffer, et al. 2015). More specifically, it requires a fundamental change in the current economic, technological, and behavioral factors, and the change should be within a trajectory called "*transformation pathways*" (Clarke et al. 2014). We identified three key terms that reflect how scientists and policy-makers translate this idea, including decarbonization, LCD, and LCT (Table 2).

Table 2 The Definition of Key Concepts of Reducing Carbon Dioxide Emission toward Net-Zero Level

Terminology	Definition	Source
Decarbonization	The process by which countries or other entities aim to achieve a low-carbon economy, or by which individuals aim to reduce their carbon consumption.	The IPCC AR-5 of Working Group III (IPCC 2014a)
	The process by which countries, individuals, or other entities aim to achieve zero fossil carbon existence. Typically refers to a reduction of the CO_2 emission associated with electricity, industry, and transport.	The IPCC Special Report of 1.5°C (IPCC 2018)
Low Carbon Development	An economic development that adopts strategies to cut the amount of CO_2 emission deeply (e.g., energy diversification or carbon sequestration) and involves some aspects: policy, a path with a paradigm shift, technology or measures, behavioral changes, and finance.	The United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP 2010).
	A development model that requires decoupling economic growth in the pattern of production and consumption from CO_2 emission	Urban and Nordensvärd (2013b)
Low Carbon Transition	Major changes in buildings, energy, and transport systems that substantially enhance energy efficiency, reduce demand, or entail a shift from fossil fuels to renewable inputs. These system transitions entail not only technical changes, but also changes in consumer behavior, markets, institutions, infrastructure, business models and cultural discourses	Geels, Berkhout, and Van Vuuren (2016)

The first approach is decarbonization, a process aiming for low carbon economy that entities reduce the consumption of carbon-based energy (IPCC 2014a). Rogelj, Luderer, et al. (2015) call for rapid and fundamental decarbonization by lowering carbon intensity in the energy system to avoid the tipping point of 1.5°C before the mid of the century. It entails immediate upscaling and investment of low carbon technology (relying on renewable energy and nuclear) in electricity generation, especially in developing countries. Rockström et al. (2017) propose a roadmap for decarbonization toward the long-term global temperature targets that include transformation in the energy system, carbon management in the food system, and the afforestation of degraded land. They emphasize the importance of governance, financial mechanism, and technology to support the implementation of the approaches.

The second one is LCD. The IPCC mentions the term in its AR-5, but no definition is given in the report. Nevertheless, it is often used in academic literature and policy documents that most of the discussion focuses on the integration of CO_2 mitigation strategies in the current economic development trajectory (UN-ESCAP 2010, Mulugetta and Urban 2010, Wang and Chang 2014). The emphasis is on the shifting pattern from fossil-fuel-based production and consumption to the renewable one. Urban and Nordensvärd (2013b) define it as a model of development driven by approaches geared to produce less CO_2 toward growth (e.g., switching to renewables and promoting carbon sinks such as forests and wetlands).

The third one is LCT that also does not have any firmed meaning of the term. Geels, Berkhout, and Van Vuuren (2016) view it as significant changes in the energy system from fossil-fuel input to renewables that entails a long-term process of technological, social, and institutional system reconfiguration. The social-technical transition theory is commonly used by scholars to depict the process (Geels et al. 2017, Keough and Ghitter 2019, Bulkeley, Castán Broto, and Maassen 2014). Usually, it is applied to examine the transition in a specific sector, such as electricity and heat (Hannon, Foxon, and Gale 2013) and transportation (Geels 2018). Some scholars use scenario analysis or energy modeling to depict changes in the transition in the energy system within the constraint of the CO_2 emission budget (Wang and Watson 2010, Liu et al. 2012, Dias et al. 2019). The analysis usually results in a plausible description of its alternative future under a given set of assumptions, such as urban economy growth or renewable energy technology development.

Based on this review on the existing definitions indicates LCT and LCD as a desired state or situation that entails transformational changes in the current development system to embrace net-zero CO_2 emission. Meanwhile, decarbonization denotes the process of decoupling CO_2 emission from the energy system that underpins the production of goods and services. There could be still possibilities where scholars might use the terms interchangeably because those share similar meanings to describe the process of lowering CO_2 emission. Their interrelationships will be further explained in the finding part of this review.

3. Methodological Approach

A Systematic Literature Review (SLR) is an explicit, accountable, and rigorous research method because it is done through a transparent and defined protocol (Gough, Oliver, and Thomas 2017). It is a methodological approach of identifying, selecting, and appraising available evidence of studies that have been conducted to answer a defined question (Sambunjak, Cumpston, and Watss 2017). It has advantages, including (1) minimizing bias and errors to ensure the quality of the review process (Drucker, Fleming, and Chan 2016), (2) ensuring the validity of the results because the steps can be replicated by others (Siddaway, Wood, and Hedges 2019), and (3) producing synthesis about body of knowledge in particular field (Fisch and Block 2018).

Scholars often use the approach to examine the current state of the art of a specific issue in the literature. It is widely utilized in different fields, such as medical studies (Craven and Levay 2019), education (Davies et al. 2013), computer science (Kolajo, Daramola, and Adebiyi 2019), disaster studies (Djalante 2018) and environmental science (Harrison et al. 2014). In climate change literature, it has been used to determine the impacts of climate change (Fatorić and Seekamp 2017, Benevolenza and DeRigne 2019) and the progress of climate change adaptation (Berrang-Ford, Pearce, and Ford 2015, Porter, Dessai, and Tompkins 2014, Shaffril, Krauss, and Samsuddin 2018).

This research adopts seven steps for the systematic review: 1) formulating the research problem; (2) developing and validating the review protocol; (3) searching the literature in literature databases; (4) screening for inclusion/exclusion; (5) assessing quality; (6) extracting data; (7) analyzing and synthesizing data; and (8) reporting the findings (Xiao and Watson 2017).

3.1. Data Collection

The articles were collected from Scopus. It is the most extensive database of peer-reviewed literature, especially in the field of social sciences in which the issue could be studied (e.g., political science, urban planning, economics, and geography) (Mongeon and Paul-Hus 2016). It features bibliographic data (e.g., year of publication, abstracts, and keywords) and search tools that can efficiently retrieve documents based on the users' needs. It is worth to note that the topic can also be documented in grey literature, such as dissertation/thesis, government, or institutional reports. However, searching articles in Google or other databases that provide grey literature are not performed to maintain the replicability of this review and avoid selection bias (Piasecki, Waligora, and Dranseika 2018).

Figure 1 shows the flow of data collection while the complete steps, along with the query string input to the search, is provided in the Appendix. Initially, the data collection was completed on the 12th of August 2019. The first step of the literature search was to input two terms in the document search: *low carbon development* and *low carbon transition*. Some scholars may use the term "low emission development." This term is not included in the data query because emission could include other types of GHG, for example, methane (CH_4) and nitrous oxide (N_2O). The exclusion should not affect the findings significantly because the straightforward use of "carbon" is central for this review because of its central role in energy generation (Rogelj, Luderer, et al. 2015). After performing the previous step, we found that "decarbonization" is often used too in the literature. So, the second search was conducted on the 14th of September 2019 to incorporate this terminology. Since decarbonization can also refer to the chemical process, and it would be too broad for the scope of this review. The term must be adjacent to "climate change" or "emission" to narrow down the result, so the operation of the data query placed the term within (w/) before both.

Similar subsequent stages of the data collection were applied to these two separate processes, and the data retrieved from both were combined in the end to eliminate duplication. For the time scope, the search was set between 1992 and 2019 because the efforts to cut GHG emission globally for climate change was started in the Earth Summit in Rio de Janeiro, Brazil. At this stage, both result in 1332 and 764 documents, respectively.

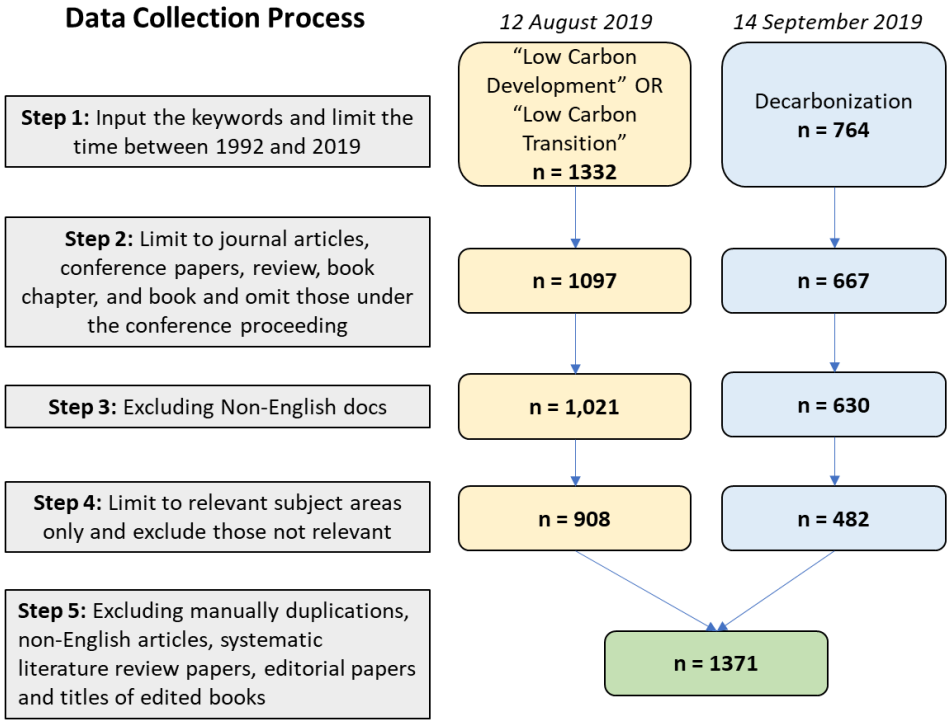


Figure 1 The Data Collection Process

The second step was to refine the search based on document types, including journal articles, review articles, and books. Book chapters and conference papers are also included as grey literature that can be useful to minimize publication bias (Paez 2017, Mahood, Van Eerd, and Irvin 2014). Both also often contain keywords that are important for bibliometric analysis. All of these sources typically provide findings of case studies or have a conceptual theory built upon previous experience. The entries for titles of edited books were excluded manually at the last step, and their chapters are treated as individual articles to prevent false positive (i.e., authorship duplication). Under the filter bar "*source type*" in Scopus, conference proceedings include documents that contain abstracts that might have been re-published as a journal article. If these are included, it will cause false positive in the result, so these are not counted in the search (Sweileh et al. 2017). There were about 1764 papers retrieved in total at this stage.

The third step excluded the documents written other than the English language. The fourth step was to omit the entries that are too broad from the subject of low carbon (i.e., mathematics and computer science). While Scopus has selected the entries based on the queries, some parameters cannot be performed through its online search tools. Hence, the last stage is done manually to exclude duplication, non-English articles, systematic literature review papers, editorial papers, and titles of edited books. The final stage resulted in 1,371 entries.

3.2. Data Analysis

This review utilized bibliometric analysis, a mix of quantitative and qualitative approaches to evaluate trends of publication number, co-citation pattern, authorship (e.g., authors productivity and institutional collaboration), and impact of publication in a particular field or topic (Sweileh et al. 2017). The measurement uses bibliography data gathered from the literature database search. In this review, two types of bibliometric analyses are used, including performance analysis and keyword analysis. Performance analysis summarizes quantitative data of the publications, especially the annual distribution of publication and authorship productivity pattern. The analysis of the authorship is based on three categories:

countries, organizations, and individuals. It identifies the leading actors who contribute to the body of the knowledge actively. Such information would be beneficial to establish future research collaboration as well as to identify the gaps of a pool of researchers and experts in the topic in certain countries. The results of the analysis are provided in graphs showing frequency and percentage.

Keyword analysis was performed with VOSviewer to map their research clusters and their intellectual structure in the existing publications. Keywords in a research article indicate what the authors perceive important to convey their research foci, including research objects, methodologies, and study areas (Wu et al. 2018). Keyword analysis constructs the relationship of the keywords with a network. Thus, based on that association, the analysis could build research clusters and even groups of keywords that share similar characteristics (e.g., methodology and research locus). Some keywords in the obtained bibliographic data indicate similar meanings, but they are not the same in the naming style, for example, carbon dioxide and CO_2. Therefore, we merged this kind of words into a similar form. The bibliographic data processing was performed in Microsoft Excel, and, for the keyword analysis, the data is exported to VOSviewer, a software tool that helps to visualize bibliometric visualization. Approximately 3,186 keywords are identified in the publications, and the keyword analysis was performed through VOSviewer. Only the keywords that appear more than five times are depicted in the graph to get clear visualization. We chose the lin/log modularity option for the normalization method in the VOSviewer to create the cluster (van Eck and Waltman 2018).

Content analysis is used to identify geographical locus and sectoral focus of the publication. Both are not always written in the keywords. It is conducted to make categorization in which it helps to create generalizations and information patterns by interpreting and coding textual contents (Erlingsson and Brysiewicz 2017). Four parts of the articles were examined: the abstract, the introduction, the methodology, and the conclusion. For a book title, the identification focuses on the texts written in the first chapter and the conclusion. The texts that contain information related to geographical focus and sectoral focus were condensed into meaning units, then coded, and grouped into categories. The categorization was based on codes that have similar patterns of meanings. The final step created themes (i.e., geographical locus and sectoral focus) based on the categories.

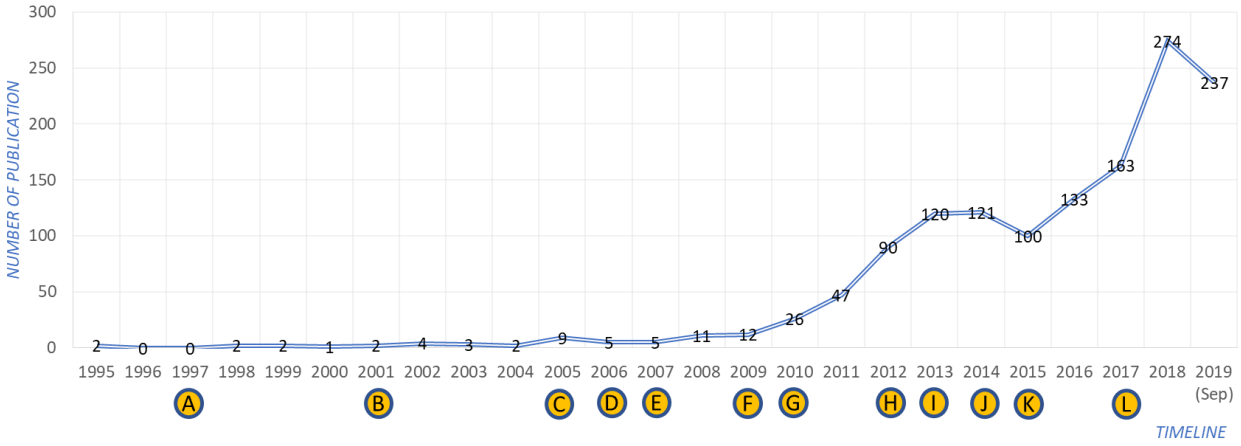
The categorization of the sectors in this data analysis follows the naming of the GHG emitting sectors in the IPCC reports (Blanco et al. 2014). The energy sectors include electricity and heat, industry, transportation, and buildings, while the non-energy sectors cover AFOLU and waste. In this review, the CO_2 emission generated from IPPU is considered as part of the industry sector because, in general, the papers related to IPPU also take into account its emission released from the energy use.

4. Results and discussion

4.1. Current Progress of the Literature

4.1.1. Annual Publication Trend: Significant increase after the Kyoto Protocol entered into force

The pursuit of net-zero CO_2 emission has grown as an emerging topic for more than two decades (Figure 2). On average, there are about 54 papers per year, and the annual publications reached its highest number (274 articles) in 2018. The first two articles were published in 1995 that Turkenburg (1995) and Ausubel (1995) use “decarbonization” in the context of climate change. About a decade later, the term “LCD” appeared in the landscape of the literature by Pan (2005) and Fulkerson et al. (2005). Meanwhile, the term “LCT” started entering the literature two years later by Mander et al. (2007).



KEY EVENTS AND POLICY							
A	COP 3 adopts Kyoto Protocol	**D**	The Government of China started aiming to cut carbon intensity through its five-year plan	**G**	Green Climate Fund was established	**J**	IPCC issued the 5th Assessment Report
B	The US Government retreat from the Kyoto Protocol	**E**	IPCC published the 4th Assessment Report	**H**	COP 18 in Doha extended the Kyoto Protocol and NAMA Facility was established	**K**	COP 21 resulted in the Paris Agreement to pursue net-zero GHG emission
C	Kyoto Protocol enters into force and EU Emission Trading was launched	**F**	COP 15 urges to limit global warming to 2°C above the pre-industrial level	**I**	COP 13 in Warsaw proposed the UNFCCC to formulate INDC	**L**	The US Government announced the withdrawal from the Paris Agreement

Figure 2 The annual number of publications and the timeline of climate change political events from 1995 to 2019 (N=1371 documents)

The annual number of publications experienced a significant increase in certain times, especially after some notable political events related to climate change actions (Table 1). By the mid of the 2000s, the annual number of publications had been very limited. It starts climbing since the Kyoto Protocol entered into force in 2005, and there have been several milestones in climate change mitigation afterward that could stimulate the trend. *First,* the establishment of the CO_2 emission reduction policy in top emitter countries in 2006. For example, the EU launched its ET scheme in 2005 and China enacted the first five-year development plan to reduce GHG emission in 2006. *Second,* the promotion of long-term temperature targets began to take place from the IPCC AR-4 (2007) and COP 15 (2009)[2]. *Third,* various financial sources were established, such as the GCF in 2010 and the NAMAs Facility in 2012. *Fourth,* the notion for accelerating and scaling up CO_2 reduction before the mid of the century has emerged in climate change negotiation. The annual number of publications has been increasing rapidly after the publication of the IPCC AR-5 on the Physical Science Basis (2013), and the Paris Agreement in 2015 urges the importance of the idea.

4.1.2. Authorship Pattern: China and UK as the leading contributors to build the knowledge

4.1.2.1 Country-based Affiliation

Since 1995, researchers from 82 different countries[3] have contributed to the body of knowledge of the three concepts in the literature. Table 3 shows the top 20 countries with the highest number of scholarly articles. The table reflects that the issue attracts researchers from major emitter countries as well as members of the G-20 (UNEP 2018). Authors from China are the most productive one as they had had more than 490 documents or 35% of the total

[2] The COP 15 introduced the idea of holding global temperature increase to 2°C above the pre-industrial level, and the parties pledged to support emission reduction with measurable targets for the first time.
[3] In this study, we include Hong Kong and Macau as part of China while England, Wales, Scotland, and Northern Ireland are part of United Kingdom.

number of publications by September 2019. The UK and the US are at the second and the third most productive countries in the scholarly publications, respectively. The domination of the EU-28 members in the list indicates their researchers' significant interest in the issue in the region. Aside from China, there are only two developing countries listed in the table, including India, Brazil, and South Africa.

While China is the most productive one to produce the publications, those affiliated to the UK organizations are the prolific ones to conduct international research collaborations. Overall, the UK has published 122 papers with 44 other countries, while China has produced 134 papers with 30 other countries (Table 3). The table also informs that UK-based scholars have a significant influence on the topic by considering their total frequency of citations, while China has lower average citation per publication.

Table 3 Top 20 productive countries to publish the articles from 1995 - 2019

Rank	Country	Number of Publication (N = 1371)	SCP	MCP (TCC)	Citation	ACP
1.	China	490 (35.3%)	355	134 (30)	4810	9.8
2.	United Kingdom	322 (23.4%)	200	122 (44)	5392	16.8
3.	United States	217 (15.8%)	107	110 (39)	3336	15.4
4.	Germany	106 (7.7%)	44	62 (34)	1642	15.5
5.	Netherlands	71 (5.1%)	11	60 (34)	1171	16.5
6.	Australia	63 (4.5%)	22	41 (27)	647	10.3
7.	Canada	51 (3.7%)	24	27 (26)	475	9.3
8.	Japan	44 (3.2%)	29	25 (25)	429	9.8
9.	Italy	43 (3.1%)	16	24 (27)	787	18.3
10.	France	38 (2.7%)	10	26 (28)	516	13.6
11.	Sweden	38 (2.7%)	14	24 (23)	457	12.0
12.	India	35 (2.5%)	18	17 (23)	289	8.3
13.	Austria	32 (2.3%)	6	17 (26)	1173	36.7
14.	Switzerland	29 (2.1%)	7	22 (11)	313	10.8
15.	Spain	27 (1.8%)	13	14 (14)	230	8.5
16.	Denmark	25 (1.9%)	4	21 (21)	259	10.4
17.	Norway	21 (1.5%)	5	16 (16)	148	7.0
18.	Greece	20 (1.4%)	10	10 (9)	277	13.9
19.	Brazil	18 (1.3%)	12	6 (21)	388	21.6
20.	South Africa	18 (1.3%)	7	11 (24)	93	5.2

Note: SCP = Single-Country Publication; MCP = Multi-Country Publication; TCC = Total Country Collaborators; ACP = Average Citation Per Publication

Figure 3 illustrates collaboration ties among the top 20 countries that study the mitigation of CO_2 emission toward the net-zero level. The nodes represent countries of the authors, and the size of the nodes means the degree of the published papers by them. The thickness of the edges connecting the nodes denotes the cooperative frequency between countries. The graph shows three clusters of country-based collaboration, and it denotes that the patterns are influenced by two factors: geographical locations and the status of CO_2 emission. China, India, Japan, and Australia under the green cluster are the major carbon emitters, and both are located in the Asia-Pacific region. However, authors affiliated with institutions in China work more closely with collaborators from the US and the UK. Strong collaboration ties between those from the US and China because there has been extensive research exchange among academia between the two in the field of climate and energy since 2009 (Lewis 2017). Meanwhile, the red cluster represents research collaborations conducted by the EU-28 members, and, as a region, it is the third major GHG emitter (UNEP 2018). In general, as shown in Table 3, most of the EU-28 members have fewer papers that the authors are from affiliated to one country only, and it shows strong collaboration ties among them. Several factors contribute to this regional collaboration, including but not limited to available funding

from the EU and similarities on economic profile, climate condition, and the energy system (European Comission 2014).

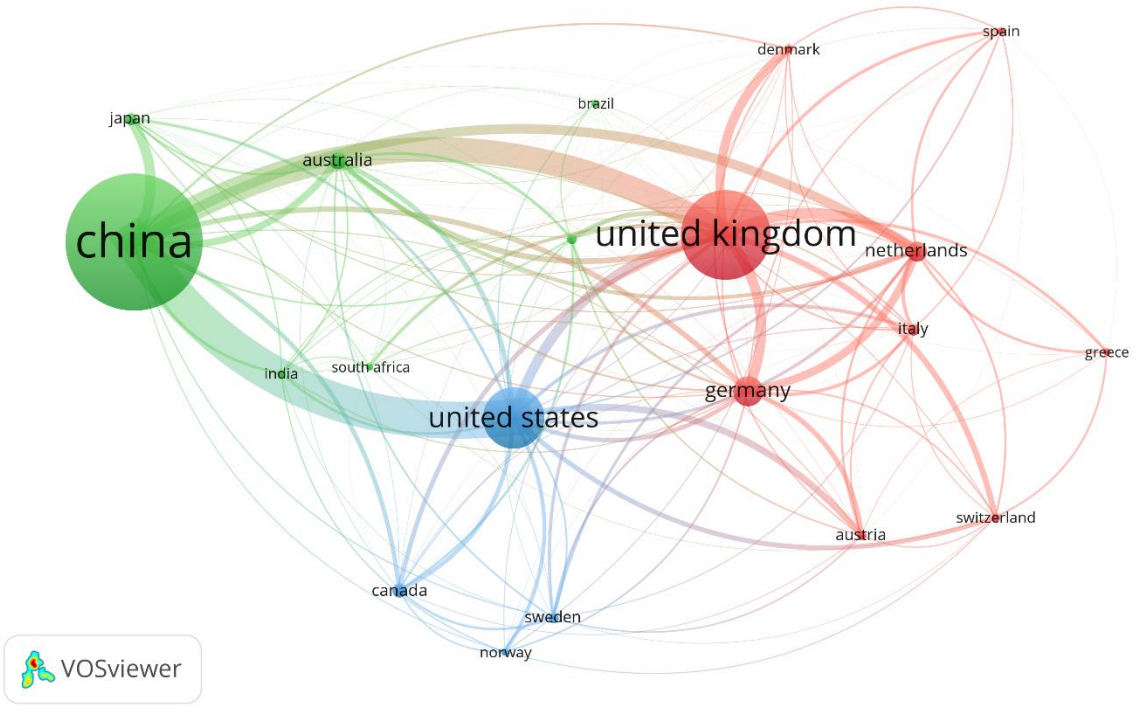


Figure 3 Cross-country co-authorship network of the research from 1995 to 2019

4.1.2.2 Institution-based Affiliation

Table provides the top 20 productive institutions among 2790 institutions that had conducted studies on the topic by September 2019. In terms of the number of institutions, nine British universities dominate the production of the knowledge, but two Chinese universities lead the list as the most productive and the most cited organizations for their scholarly papers. Tsinghua University and the Chinese Academy of Science have published 71 documents (with 1256 citations in total) and 49 documents (with 610 citations in total), respectively. Nevertheless, both had less average citation per publication than those of the University of Manchester and the University of Sussex. It indicates the limited impact of these Chinese institutions in the field. Furthermore, the table also reflects that the knowledge hub is still generally centered and conceptualized by academic institutions from industrialized countries, in particular, European countries. Interestingly, in contrast to the result of the country-based authorship, none of the US-based institutions are on the list. It indicates that, at the institutional level, they have not fully developed their interest in this topic.

Table 4 Top 20 productive organization from 1997 to 2019

R	Institution	NP	TC (ACP)	R	Institution	NP	TC (ACP)
1	Tsinghua University, China	71 (5.1%)	1256 (17.8)	*11*	Imperial College London, UK	19 (1.3%)	219 (11.5)
2	Chinese Academy of Science, China	49 (3.5%)	610 (12.4)	*12*	University of Oxford, UK	18 (1.3%)	679 (29.3)
3	University College London, UK	36 (2.6%)	596 (16.5)	*13*	Utrecht University, Netherlands	18 (1.3%)	497 (27)
4	North China Electric Power University, China	36 (2.6%)	421 (11.6)	*14*	Lund University, Sweden	18 (1.3%)	271 (0.8)
5	University of Sussex, UK	32 (2.3%)	864 (27)	*15*	International Institute for	15 (1.09%)	554 (15.1)

R	Institution	NP	TC (ACP)	R	Institution	NP	TC (ACP)
					Applied Systems Analysis, Austria		
6	University of Leeds, UK	28 (2.04%)	535 (19.1)	*16*	London School of Economics, UK	15 (1.09%)	73 (5.2)
7	University of Manchester, UK	27 (1.9%)	981 (36.3)	*17*	Australian National University, Australia	14 (1.02%)	240 (17.1)
8	Durham University, UK	25 (1.8%)	444 (17.7)	*18*	National Technical University of Athens, Greece	14 (1.02%)	168 (12)
9	National Institute for Environmental Studies, Japan	21 (1.5%)	331 (15.1)	*19*	Xiamen University, China	14 (1.02%)	365 (26)
10	Beijing Normal University, China	20 (1.4%)	157 (7.85)	*20*	University of East Anglia, UK	12 (0.8%)	91 (7.5)

Note: R = Rank; NP = Number of Publication; TC = Total of Citation; ACP = Average Citation Per Publication

4.1.2.3 Individual-authorship pattern

A total number of 4308 researchers or about three authors per article have written articles related to curbing CO_2 toward net-zero emission. About 1106 articles (80.7%) are authored by more than one scholar. Table 5 consists of the top 10 authors with the highest numbers of publications in this research domain and their scholarly profiles. Seven of them are affiliated to universities in developed countries, while the others are from China. The names are ranked by the number of their publications retrieved from the data collection. We use H-index to evaluate the significance of a scientist's contribution based on their productivity (number of publications) and impact (number of citations) (Hirsch 2005).

Based on the result, Urban is an associate professor at the Royal Institute of Technology KTH (Sweden) who publishes the highest number of papers. Urban is interested in the linkages between LCD, climate change mitigation, and energy policy (Urban and Nordensvärd 2013a). Most of Urban's works indexed in the search were published with SOAS University of London (UK) as the affiliation. However, her h-index is less than the other four scholars who have h-index more than 40. First, Bulkeley is a professor in geography from Durham University (UK) who is concerned about the governance issues at the urban level (Bulkeley, Castán Broto, and Massen 2010). Second, Geng is a professor in environmental science from Shanghai Jiao Tong University (China) who is interested in the energy-related GHG, especially from industrial activities (Geng et al. 2013). Benjamin K. Sovacool serves as a professor of politics and policy of energy transition at the University of Sussex (UK) and Aarhus Universitet (Denmark) (Sovacool and Brisbois 2019). Boqiang Lin is an energy economics professor affiliated to Xiamen University (China), and his work is devoted to modeling CO_2 emission of the energy system (Lin and Ouyang 2014).

The next five are still scholars from developed countries. Gouldson is a professor from the University of Leeds (UK) who has research on the finance dimension of LCD at the municipal level. Chen from Tsinghua University (China) investigates the CO_2 emission of the energy sector. Both Jotzo (Australian National University, Australia) and Rosenbloom (Carleton University, Canada) have similar research work on the politics and policy of energy transition. Marvin, a professor at the University of Sheffield, studies low carbon technology and infrastructure, and Marvin is also the top collaborator of Bulkeley. Overall, the table indicates that scholars from the western world are still dominant in the topic of reducing CO_2 toward net-zero emission, especially in the field of social science. Meanwhile, the prolific scholars from developing countries come mainly from China that they focus on economic modeling of CO_2 emission.

Table 5 Top 10 most productive authors

NO	Authors	Current Affiliation, Country	NP	Scopus Profile				Google Scholar Profile			Research area*
				Doc	*Cit*	*h-index*	*NoC*	*Cit*	*h-index*	*i10-index*	
1	Urban, F.	Royal Institute of Technology KTH, Sweden	14	62	749	16	50	1606	23	40	Interlinkage between LCD, climate change mitigation policy
2	Bulkeley, H.	Durham University, UK	13	139	9151	44	150	18,968	57	123	Urban governance for LCD
3	Geng, Y.	Shanghai Jiao Tong University, China	12	287	10,656	57	395	15,022	65	63	CO_2 emission of urban and industrial sector
4	Chen, W.	Tsinghua University, China	10	105	1691	20	145	N/A	N/A	N/A	Modelling low carbon economies
5	Gouldson, A.	University of Leeds, UK	10	65	1415	22	78	3939	33	59	Financing LCD at urban level
6	Lin, B.	Xiamen University, China	9	328	7693	45	109	N/A	N/A	N/A	Modelling CO_2 emission and mitigation
7	Sovacool, B.K.	University of Sussex, UK & Aarhus Universitet, Denmark	8	376	9984	49	311	20,917	73	292	Politics and policy of energy transition
8	Jotzo, F.	Australian National University	7	57	1092	17	102	4580	27	67	Policy of low carbon economies
9	Marvín, S.	University of Sheffield, UK	7	135	2600	28	57	14,549	44	102	Low carbon technology and infrastructure
10	Rosenbloom, D.	Carleton University, Canada	7	12	164	7	15	262	8	8	Politics and policy of energy transition

*Note: NP = Number of Publication; Doc = Total of Published Documents; Cit = Total citations; NoC = Number of Collaborators; * The defined research areas are based on the selected entries in the retrieved data.*

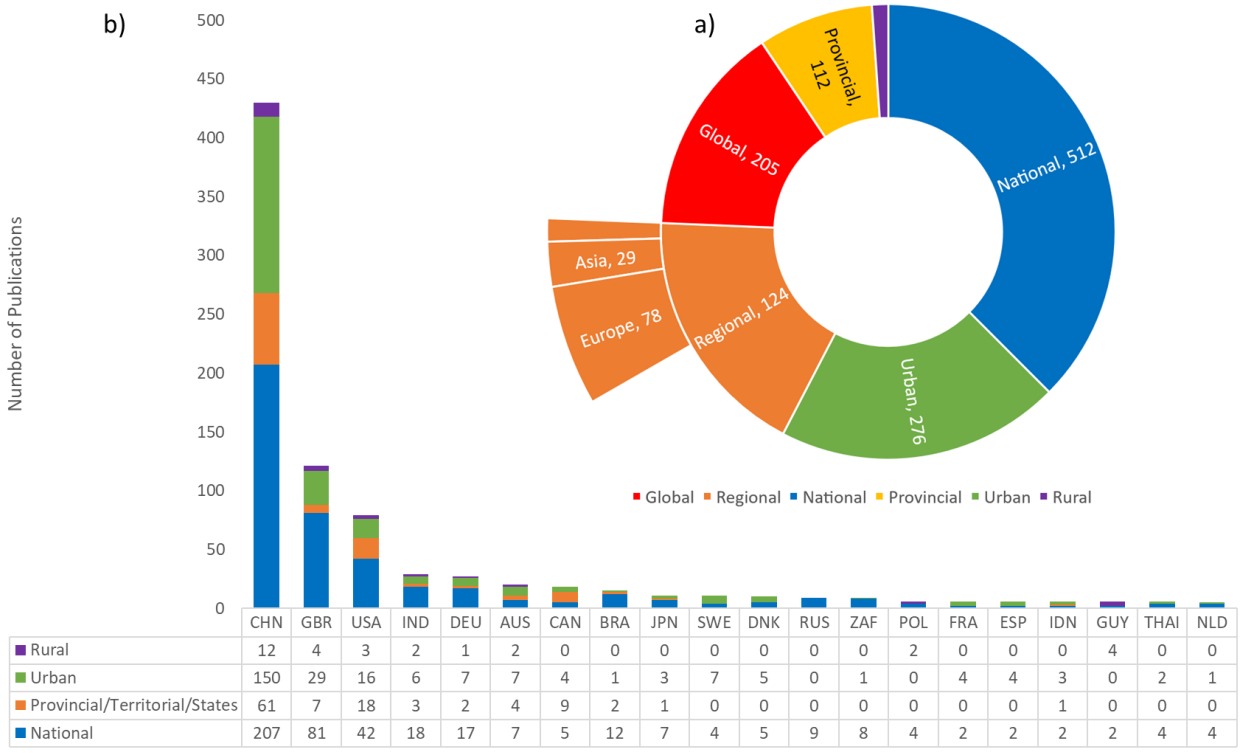
4.2. The Geographical Locus and Sectoral Focus

4.2.1. Geographical Locus: Most of the Discussion is at the National Level

The existing discussion of the CO_2 emission mitigation in the literature is divided into six different geographical levels: global, national, regional, provincial/territorial/states, urban, and rural level[4]. Of the 1371 retrieved documents, there are 1223 documents (89.6%) that mention geographical locus of their studies. Figure 4a reflects that most of the discussion is mostly related to the issues at the national level, while the urban level is the second most attractive locus of research for scholars. Figure 4b highlights that the majority of the publications captured the experience of top GHG emitters countries to deal with CO_2 emission, including China, the US, some members of EU-28 (i.e., the UK and Germany), Brazil and Japan. Both figures denote that the problem of mitigating CO_2 is still seen as national issues, but there is significant attention given to cities as hotspots of CO_2 emission. China has the most significant number of urban-related articles. However, there are still few studies capturing the experience of urban areas to move toward net-zero CO_2 emission in developing countries, such as India (6 publications) and Indonesia (3 publications). The role of rural areas remains overlooked as

[4] The publications that discuss more than four countries and they are located in different contingents are categorized in the global category

the object of the previous studies, whereas it is particularly relevant to the context of cutting CO_2 emission from the agriculture and forestry sector.



	CHN	GBR	USA	IND	DEU	AUS	CAN	BRA	JPN	SWE	DNK	RUS	ZAF	POL	FRA	ESP	IDN	GUY	THAI	NLD
Rural	12	4	3	2	1	2	0	0	0	0	0	0	0	2	0	0	0	4	0	0
Urban	150	29	16	6	7	7	4	1	3	7	5	0	1	0	4	4	3	0	2	1
Provincial/Territorial/States	61	7	18	3	2	4	9	2	1	0	0	0	0	0	0	0	1	0	0	0
National	207	81	42	18	17	7	5	12	7	4	5	9	8	4	2	2	2	2	4	4

Figure 4 The locus of the research between 1995 and 2019: a) the total number of publications for each locus level and b) the 20 most studied countries for the topic

Table 6 compares the top 10 GHG emitter countries in 2017 and the total number of publications that select them the object of the studies from national to rural level (N = 725 articles). The table shows that China and the EU-28 countries are the most studied ones on this topic. In contrast, there are still lacking studies that depict the experience of the other top GHG emitter. For instance, the publications related to the US remain limited when considering its GHG share, although the other findings show that the US-based scholars are among the ones who dominate the authorship productivity (Table 3). It indicates that most of the US-based authors either discuss the issue in the global context or investigated cases in other countries.

Table 6 The Number of Carbon Mitigation toward Net-Zero Emission Research in the Top 10 Major GHG emitters

Top 10 major GHG emitters	Share of global GHG emission in 2017*	% of publications capturing cases from national to rural level (n = 725)
China	26.8%	55.5%
USA	13.1%	2.3%
EU-28	9%	21.79%
India	7%	2.62%
Russia	4.6%	0.69%
Japan	3%	0.97%
Indonesia	1.7%	0.83%
Republic of Korea	1.6%	0.28%
Canada	1.6%	1.52%

*Source: UNEP (2018)

4.2.2. Sectoral Focus: Mostly on Multiple Sectors Followed by Electricity and Heat Sector

Figure 5 explains which sectors become the main objects of research on carbon mitigation for net-zero emission between 1995 and 2019. The graph suggests that most of the publications focus on the multi-sectoral dimension of achieving net-zero CO_2 emission. About 443 articles or 32% of them show the contents of their research, covering the examination for all sectors emitting CO_2. Scholars are also interested in explaining the issue of mitigation of CO_2 emission from the multi-sectoral perspective of the energy sectors (16% or 221 articles). Typically, the publications that cover include this multi-sectoral lens include the assessment of aggregate emission from different sectors and any discussion related to the financial, political, and policy matters of the overarching actions to achieve net-zero CO_2 emission.

The graph also suggests that more than half of the publications focus on the efforts of achieving net-zero CO_2 emission in a specific sector, especially in the energy sectors. Electricity and heat are the most frequent sector that had been studied by 2019 with 326 articles (23.8%). Meanwhile, the percentage of publications that focus on other energy sectors remains low. Nevertheless, little attention is given to explore the non-energy sectors (AFOLU and waste) are still limited to 64 articles (4.7% of the publications).

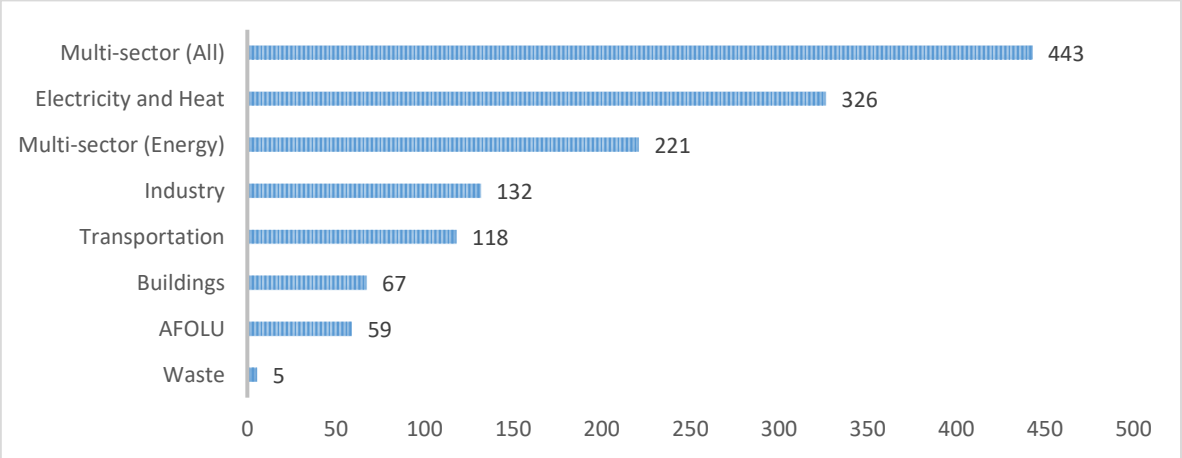


Figure 5 The characteristics of the publications based on key sectors between 1995 and 2019

4.3. Cluster research themes and their interrelationships

Figure 6 illustrates that three clusters of research streams in the discourse of CO_2 mitigation toward net-zero emission. The first cluster plotted with blue has decarbonization as the central node. The second cluster, which marked red color, has the term “LCD” as the keywords with the highest centrality. The third cluster represented with green color is led by LCT as the central node. In general, the clusters are constructed by four key themes (i.e., purposes, driving factors, research methods, and locations), and each of the themes consists of different types of categories of keywords. The following sub-sections explain the intellectual structures in each cluster.

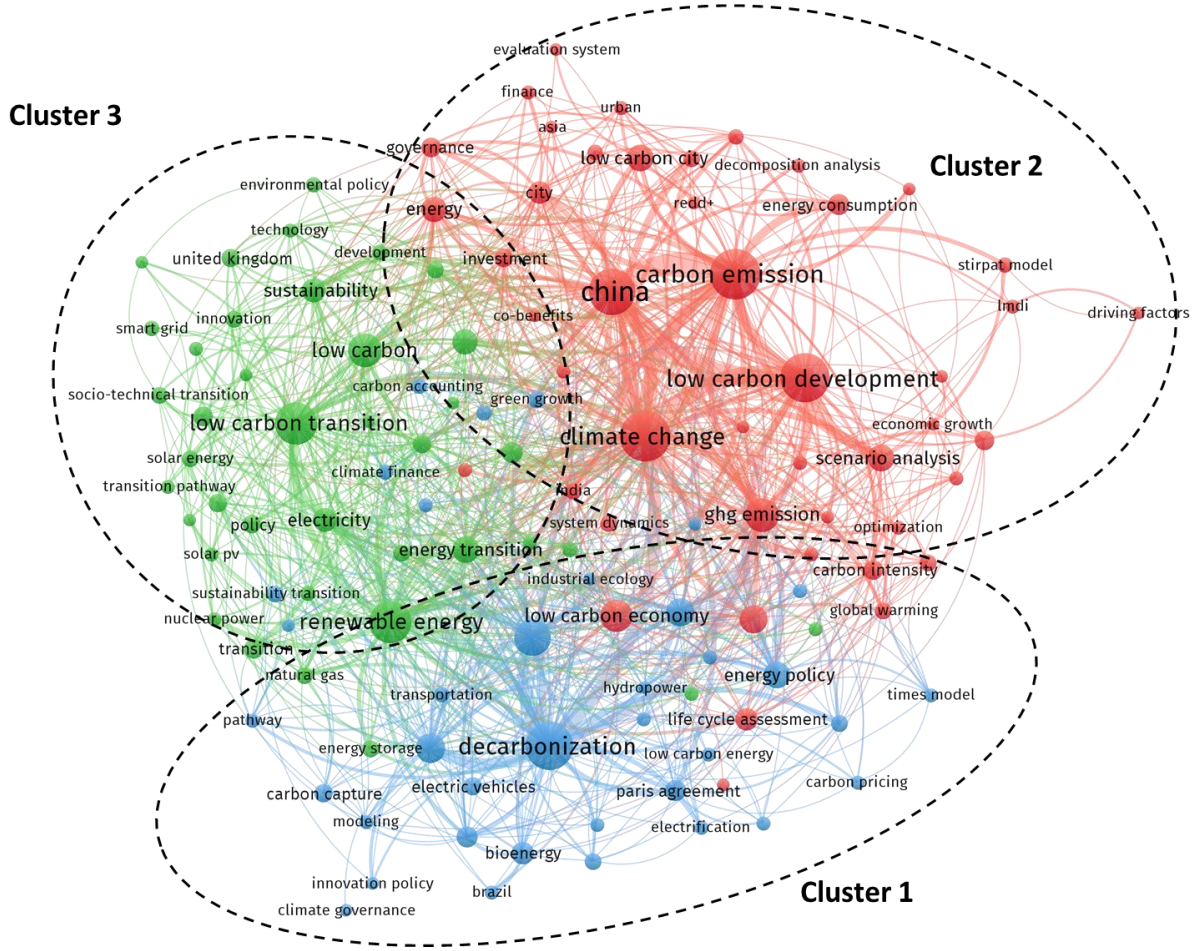


Figure 6 Clustering analysis of the studies of carbon mitigation toward net-zero emission between 1995 and 2019

4.3.1. Cluster 1: Decarbonization is expressed as an approach

About half of the identified number of keywords in the first cluster is related to the purposes of mitigating CO_2 emission. This theme is constructed by keywords representing approaches to curb the CO_2 emission and one keyword describing a vision that is green growth. The approach categories entail keywords reflecting the process or strategies to cut CO_2 emission. Decarbonization (99) is the most used keyword in the approach category, followed by low carbon energy (48), climate change mitigation (37), and energy efficiency (30). As for the vision, green growth has little attention because it is the pursuit of economic growth that emphasizes not only cutting CO_2 emission but also other environmental impacts, such as air pollution or the depletion of natural capital.

The driving factors consist of aspects that either accelerate or hamper the achievement of cutting CO_2 emission, including technology, governance, environment, and economy. In the first cluster, the main driving factors are dominated by technology and governance keywords. In the technology category, both keywords of “carbon capture and storage” and “carbon capture” share a similar emphasis on the technology to trap existing CO_2 emission in the atmosphere. The other keywords are related to technology, such as bioenergy and electric vehicles. The governance category includes keywords related to the policy and political aspects, such as climate policy, the EU, the Paris Agreement, and climate governance.

Research methods and locations contribute to small proportions in this cluster's intellectual structure. Nevertheless, both could indicate the most common methods used in the research and the geographical locations where the research of decarbonization is usually associated.

Both “modeling” and “carbon accounting” indicate the quantitative methodology used in the publications, although both do not explain further the specific name of the modeling. The others mention methods related to energy modeling (i.e., TIMES modeling and integrated assessment model). For the location, the publications related to developing countries, Africa and Brazil are listed in this research cluster.

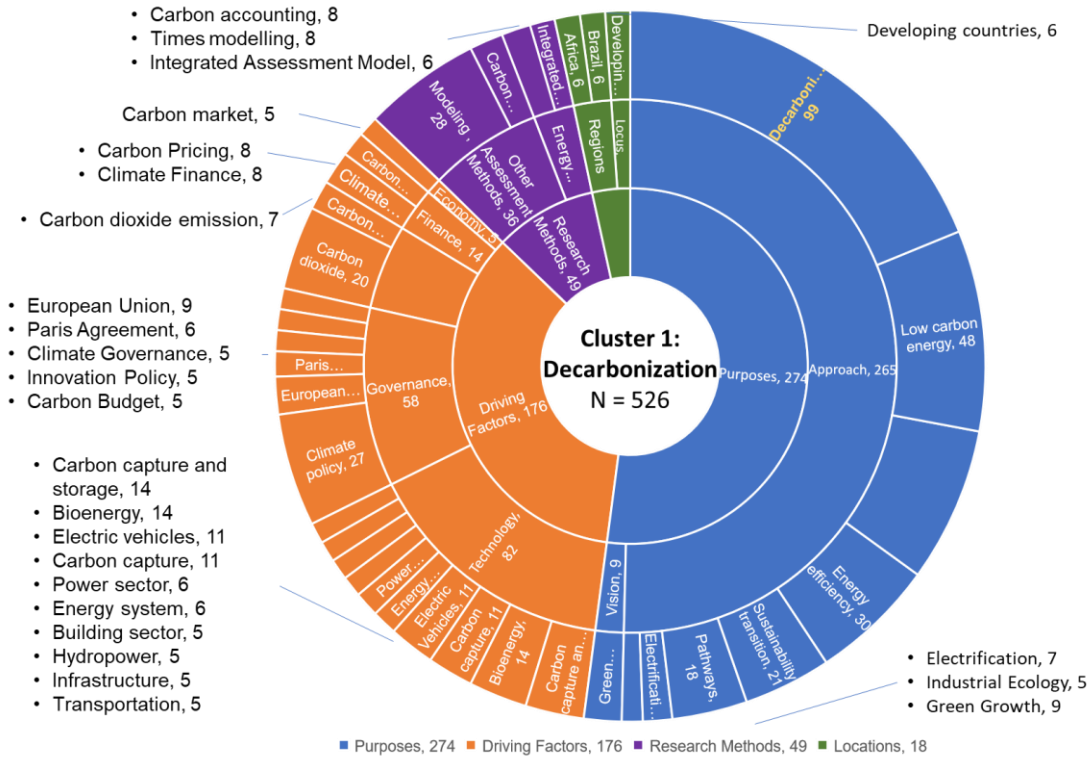


Figure 7 The Intellectual Structure of Cluster 1 “Decarbonization”

4.3.2. Cluster 2: Low Carbon Development is expressed as an economic vision

This “LCD” cluster encompasses keywords from the perspective of energy economics to curb CO_2 emission. The second cluster has more keywords that emphasize visions than the approaches (Figure 8). Scholars in this research cluster select the keywords of LCD (110), energy revolution (88), low carbon economy (43), and low carbon city (27) to describe visions for the pursuit of net-zero CO_2 emission. Those are associated with the desired state of economic activities resulting in a minimum output of CO_2 emission. The energy revolution is often linked to the shift of the dominant consumption of fossil fuel-based energy to renewables one. The keywords for the approaches of CO_2 emission mitigation that should be highlighted include decoupling and REDD+. Decoupling in this context is linked to separating the emission of CO_2 from economic activities or the energy systems. REDD+ is a program under the United Nations flagship to support action for reducing emissions from the forestry sector.

In contrast to the first cluster, the categories of locations and research methods have a more significant number of keywords that make up the intellectual structure in the second cluster. In this cluster, the environmental driving factors are the most used keywords, including climate change (116) and carbon emission (83). The keywords in the economic aspect are linked to energy consumption and production, including energy consumption, carbon intensity, energy intensity, and energy demand. In terms of locations, the term “LCD” is generally associated with case studies in China. The category of research methods in this cluster has different keywords used by scholars to indicate to assess CO_2 emission, such as scenario analysis and life-cycle assessment.

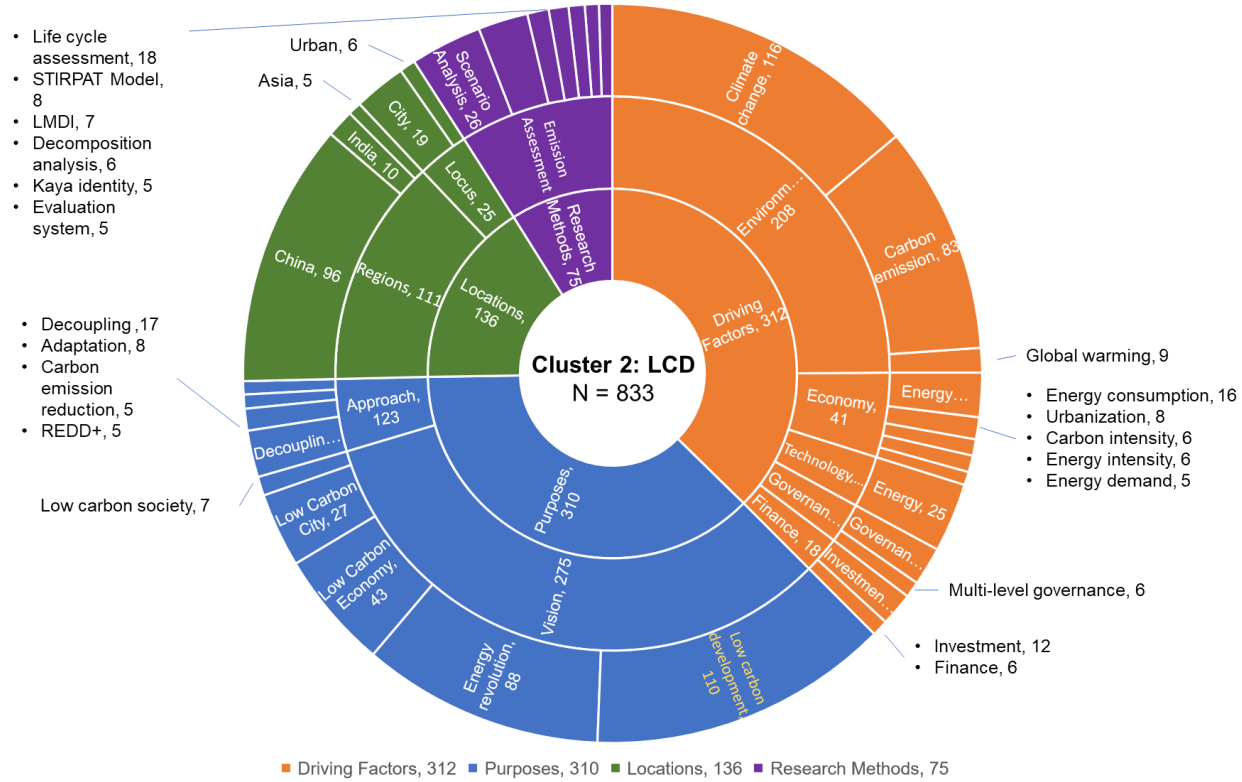


Figure 8 The Intellectual Structure of Cluster 2 "Low Carbon Development"

4.3.3. Cluster 3: Low Carbon Transition is expressed as a long-term reconfiguration process of the energy system and its pathway

Figure 9 provides the intellectual structure of the third research cluster. The keyword of "LCT" has the highest number of occurrences in the publications (78) in this cluster. It is categorized as a vision illustrating a process or a period changing toward CO_2 net-zero emission. The other identified keywords that represent visions are low carbon and energy transition. As for the energy transition, it denotes the pathways of the current energy systems to minimize its dependency from fossil-fuel-based energy sources to renewable ones (Gielen et al. 2019).

Unlike the other two clusters, the identified driving factors in this cluster only consist of two categories: technology and governance. Technology-related keywords are related to energy sectors. Renewables energy (80) is the most discussed foci for the technological driving factor, while the others include electricity (22) and energy sources-related keywords, such as fossil fuels, wind energy, and natural gas. The keywords of environmental policy and intermediaries are identified to the cluster under the category of governance. In the literature of LCT, intermediaries are considered as the actors or the institutions that accelerate changes for a sustainable transition (Bush et al. 2017).

The cluster's intellectual structure also contains the category of research methods and locations. The first category of the research method used in this cluster is emission assessment (38) that consists of energy scenarios, scenarios, and energy modeling. The second category is the socio-technical transition, a set of analytical frameworks to capture how technological and social regimes embrace sustainable transformation. Multi-level perspective is one of the analytical frameworks that posits transition as the outcome of the interaction between niches, regimes, and socio-technical landscapes. The location category comprises two European countries, including the UK and Germany. It indicates that the

research of LCT takes the experience of this region to cut CO_2 emission toward the net-zero level.

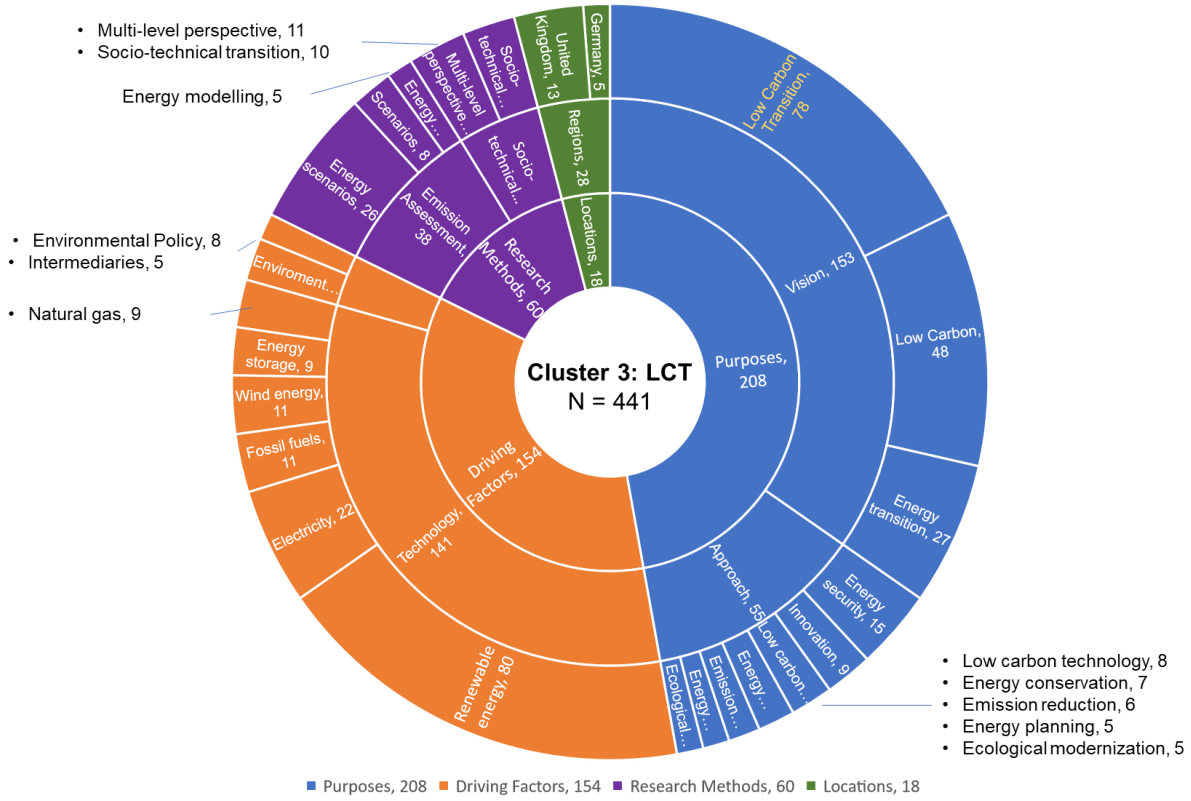


Figure 9 The Intellectual Structure of Cluster 3 "Low Carbon Transition"

4.3.4. The Interrelationships among Decarbonization, Low Carbon Development, and Low Carbon Transition

This section reveals the interrelationships of decarbonization, LCD, and LCT that they could be interchangeably used in the literature to explain the process of moving toward net-zero carbon emission. Figure 10 illustrates the relationship by comparing three bi-dimensional network diagrams for the three keywords. A bi-dimensional network diagram helps to clarify the relationship between one particular keyword and other keywords. In our case, the graph shows which keywords that are often included in a paper alongside those three selected keywords.

The first picture posits that decarbonization becomes part of the discussion related to LCD and LCT. Decarbonization is primarily linked to keywords in the two research clusters. In particular, it is mainly connected to China, CO_2 emission and climate change in the second cluster and renewable energy and energy transition in the third cluster. This relationship is also depicted in the other two diagrams that LCD and low transition become the primary nodes. Nevertheless, both keywords of LCT and LCD are not connected in their bi-dimensional network diagrams.

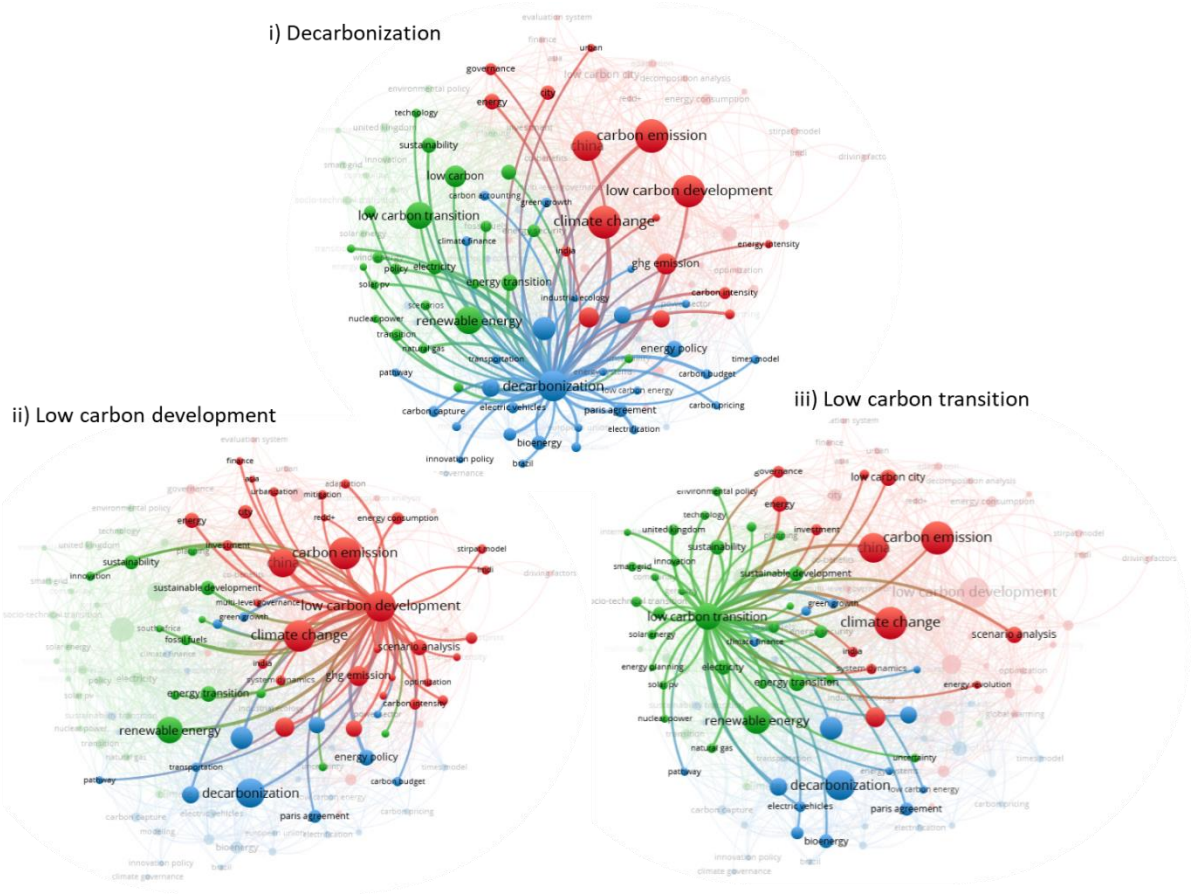


Figure 10 Bi-dimensional network diagram of (i) decarbonization, (ii) LCD, and (iii) LCT

5. Discussion

This review unveils important discoveries on the conceptual structure of mitigating CO_2 emission toward the net-zero level. We mapped that it comprises of three different research clusters: decarbonization, LCD, and LCT. Each contains a similar structure with a group of keywords representing different foci to support the notion, including purposes (i.e., vision and approach), driving factors (i.e., technology, economy, governance, environment, and finance), research methods, and locations. Nevertheless, our results settle that LCD and LCT must be considered as visional notions of moving toward net-zero emission while decarbonization is an approach to achieve it. Their interrelationships are described through the bi-dimensional keyword network that LCT and LCD are separated notions while decarbonization is identified as part of both themes.

Thus, that result implies that there are only two existing research themes in this issue: LCT and LCD. LCT comprises predominantly by two sub-categories: technology and governance. Those researchers in the domain of LCT might often use the socio-technical transition framework for the analysis. It can capture the evolution process of both technological and social systems that intrinsically connected to embrace the sustainable pathway toward net-zero level CO_2 emission. Hence, some keywords describe some elements of energy and its infrastructure (e.g., renewable energy and wind energy) and governance (e.g., intermediaries and environmental policy). Meanwhile, LCD has more emphasis on environmental and economic factors. Studies that fall under this category investigate the interrelationships between the scale of economic activities using fossil-fuel sources and CO_2 emission as the trade-off. Therefore, the most common method used for the researches is the emission

assessment, and the center of the discussion is more related to the economic issues, including energy consumption, urbanization, and energy demand.

The review also highlights that the conceptualization of this topic is primarily shaped by the dominant role of the energy sectors to cut CO_2 emission. Most of the identified keywords in driving factors represent technological elements of electricity and heat, transportation, industry, and buildings. Somewhat surprisingly, the contribution of the AFOLU sectors is very limited in the composition of the three clusters' intellectual structures. Traditionally, it is widely recognized for its central role in climate change mitigation for carbon sequestration (Canadell and Raupach 2008). The result might be affected by the possibility that scholars working in the AFOLU sectors do not always put their research under the themes of LCD or LCT. Furthermore, the use of the term "decarbonization" as the only approach-related term for the data collection limits the search result that is more relevant to the context of the energy system. If we selected specific terms such as carbon sinks or carbon sequestration, the results could have resulted in more publications from the AFOLU sectors. In spite of this limitation, the results still show that mitigating CO_2 emission toward the net-zero level includes both energy sectors and the AFOLU sectors.

In terms of scientific progress, this review paper suggests that the conceptualization of CO_2 emission mitigation toward net-zero level is mainly driven by the progress of climate change mitigation in the implementation domain. Reducing CO_2 emission is not a new notion in the discourse of climate change mitigation. However, the conceptualization has been evolving along with the dynamic of climate politics and policy over the past decade. *First,* at the global level, the increasing trend of the annual publication arises after the event of COP (i.e., COP 15 in Copenhagen and COP 21 in Paris), and the release of IPCC reports that both often suggest new directions of climate policy. *Second,* it also rises substantially after the availability of funding that motivates stakeholders to implement the mitigation and scholars to capture the problems. For example, two financial sources were launched after 2010, including the creation of the GCF in 2011 and the NAMAs Facility in 2012. *Third,* the establishment of CO_2 mitigation-related policies at the national level could also stimulate the trend. For instance, the UK launched its LCT plan in 2009 (DECC 2009), and China started calling for decarbonization in 2006 (Liu et al. 2013). Those three factors could be the triggers to the advancement of over the past decade.

The performance analysis highlights that the academia affiliated to institutions from the largest GHG emitters leads the conceptualization of reducing CO_2 emission on toward the net-zero level, especially China, the EU-28 members, and the US. Their leading role in producing and spreading the knowledge is in-line with their dominant leadership in shaping the outcome of climate change negotiations (Parker and Karlsson 2018). However, interestingly, although the US-based authors are the third most productive one to publish the knowledge, the works of literature that capture the experience of the US to cut CO_2 emission are still low if it is compared to those from China and even the UK. Moreover, there is no American-based institution listed in the top 10 productive organizations to publish the literature. These can be indications that most of the US-based authors research the topic about other countries or the global perspective, and there are still limited institutional efforts to foster the research, especially taking domestic cases. The inconsistency of the US federal government's climate politics to support climate change mitigation could contribute to diminishing long-term commitment among institutions to develop in-depth research on this topic. Under President Obama administration, the US government support the Paris Agreement while under President Trump, the government has vowed to withdraw from it (Tollefson 2017). Furthermore, President Trump's administration cut the budget for the federal research

institution on the development of clean energy proposed by the previous administration (Zhang et al. 2017).

The results of this SLR have implications for the future direction of both practices and scholarly works. For practical matters, there should be clear and defined concepts on any visional-related terms, such as LCD and LCT, for policy-making. For more than a decade, both terms have grown as visional-jargon used by policy-makers and scholars without consensus on neither parameters nor factors to measure whether the energy system has been moving toward net-zero emission. The identified intellectual structures in this SLR can be used as the basis to develop further parameters and strategies that contribute to the achievement of net-zero CO_2 emission. For future research, there should be more attention to provide knowledge of CO_2 mitigation toward net-zero emission in developing countries. The performance analysis demonstrates that the experience of the largest emitters with emerging economies, such as India, Brazil, and Indonesia, in this matter, is still overlooked, especially their contribution from the energy sectors. The number of publications taking cases for that context from those three countries remains low. As for Brazil and Indonesia, their emission sources are still generated from the AFOLU sector. Nevertheless, some recent reports urge that their emission from the energy sectors are predicted to grow substantially due to rapid urbanization, fast-growing population growth, and steady economic development (Wijaya et al. 2017, Alam et al. 2016). Hence, there is a need for more research conducted in those countries on specific energy sectors, such as electricity and transportation, and urban as the specific geographical locus.

6. Conclusion

The pursuit of net-zero CO_2 emission has emerged as an urgent global agenda to deal with climate change. Using the SLR approach, we review the key concepts that have been used in the academic literature to explain the process by taking bibliographic data from 1995 to 2019. We found that the conceptualization has been driven by the dynamic of climate politics and the interest of those coming from major emitter countries, such as China and European countries (e.g., UK and Germany). The number of annual publication trend rises after some critical events in climate change negotiation (e.g., Kyoto Protocol enters into force in 2005 and the Paris Agreement in 2015) that result in significant policies, such as the establishment of financial sources and imperative climate goals. It is also in parallel to when their national governments started incorporating the agenda into their development plan (i.e., China in 2006 and UK in 2009). Hence, the experience of reducing CO_2 emission toward net-zero emission from industrialized countries has been mostly captured by scholars affiliated to institutions from these countries. Scholars from China is the most productive one for producing the body of knowledge, but those affiliated to UK-based organizations is the most influential one. Most of the articles explore the issue at the national level and the discussion for a specific sector is still limited.

Three key concepts are identified to explain the process of achieving net-zero CO_2 emission: decarbonization, LCD, and LCT. Decarbonization emphasizes on the process of decoupling CO_2 emission from the energy system that underpins the economic activities (the production and consumption of goods and services). Meanwhile, LCT and LCD as a desired state or situation that entails transformational changes in the current development system to embrace net-zero CO_2 emission. LCT should be seen as a long-term process to reconfigure the system and its pathway to support the notion while LCD is perceived as the economic development model that its economic activities are decoupled to emit a minimum amount of CO_2 emission. Therefore, both can be perceived as visional terms to achieve the net-zero level of CO_2 emission while decarbonization is considered as the approach. The intellectual structure of CO_2 mitigation toward net-zero emission consists of different foci to support the notion,

including purposes (i.e., vision and approach), driving factors (i.e., technology, economy, governance, environment, and finance), research methods, and locations. More research should be established to investigate to what extent these driving factors are currently able to respond and facilitate the achievement of net-zero CO_2 emission at different geographical levels.

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References

Agrawala, S, S. Klasen, R Acosta Moreno, L Barreto, T Cottier, D. Guan, E.E. Guiterrez-Espeleta, E. Gámez Vázquez, Leiwen Jiang, Y.G. Kim, Joanna Lewis, M. Messouli, Rauscher Michael, N. Uddin, and A. Venables. 2014. "Regional Development and Cooperation." In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. Von Stechow, T. Zwickel and Jan C. Minx. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Alam, Md Mahmudul, Md Wahid Murad, Abu Hanifa Md Noman, and Ilhan Ozturk. 2016. "Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia." *Ecological Indicators* 70:466-479. doi: https://doi.org/10.1016/j.ecolind.2016.06.043.

Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu, and K. Zickfield. 2018. Framing and Context. In *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, edited by V. Masson-Delmotte, P. Zhai, Hans-Otto Pörtner, J. Skea, Priyadarshi R. Shukla, A. Pirani, W. Moufouma-Okia, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. TIgnor and T. Waterfield. In Press.

Ausubel, J. H. 1995. "Technical progress and climatic change." *Energy Policy* 23 (4-5):411-416. doi: 10.1016/0301-4215(95)90166-5.

Bappenas. 2019. Low carbon development: a paradigm shift toward a green economy in Indonesia. Jakarta: Bappenas (The Ministiry of National Development Planning).

Barrett, Scott. 2009. "Rethinking global climate change governance." *Economics: The Open-Access, Open-Assessment E-Journal* 3:5. doi: http://dx.doi.org/10.5018/economics-ejournal.ja.2009-5.

Benevolenza, Mia A., and LeaAnne DeRigne. 2019. "The impact of climate change and natural disasters on vulnerable populations: A systematic review of literature." *Journal of Human Behavior in the Social Environment* 29 (2):266-281. doi: 10.1080/10911359.2018.1527739.

Bernstein, Steven, and Matthew Hoffmann. 2018. "The politics of decarbonization and the catalytic impact of subnational climate experiments." *Policy Sciences* 51 (2):189-211.

Berrang-Ford, Lea, Tristan Pearce, and James D. Ford. 2015. "Systematic review approaches for climate change adaptation research." *Regional Environmental Change* 15 (5):755-769. doi: 10.1007/s10113-014-0708-7.

Blanco, Gustavo, R. Gerlagh, S. Suh, J. Barrett, H.C. de Coninck, F. Diaz Morejon, R. Mathur, N. Nakicenovic, A. Ofosu Ahenkora, J. Pan, H. Pathak, J. Rice, R. Richels, S. J. Smith, D.I. Stern, F.L. Toth, and P. Zhou. 2014. "Drivers, Trends and Mitigation." In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. Von Stechow, T. Zwickel and Jan C. Minx. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Bruckner, T., I.A. Bashmakov, Y. Mulugetta, H. Chum, A. De La Vega Navarro, J. Edmonds, A. Faaij, A. Fungammasan, A. Garg, E. Hertwich, D. Honnery, D. Infield, M. Kainuma, S. Khennas, S. Kim, K. Riahi, N. Starchan, R. Wiser, and X. Zhang. 2014. "Energy System." In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. Von Stechow, T. Zwickel and Jan C. Minx. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Bulkeley, H., V. Castán Broto, and A. Maassen. 2014. "Low-carbon Transitions and the Reconfiguration of Urban Infrastructure." *Urban Studies* 51 (7):1471-1486. doi: 10.1177/0042098013500089.

Bulkeley, H., V. Castán Broto, and Anne Massen. 2010. "Governing urban low carbon transitions." In *Cities and Low Carbon Transitions*, edited by H. Bulkeley, V. C. Broto, M. Hodson and S. Marvin. London: Routledge.

Busch, Jonathan, Timothy J. Foxon, and Peter G. Taylor. 2018. "Designing industrial strategy for a low carbon transformation." *Environmental Innovation and Societal Transitions* 29:114-125. doi: 10.1016/j.eist.2018.07.005.

Bush, R. E., C. S. E. Bale, M. Powell, A. Gouldson, P. G. Taylor, and W. F. Gale. 2017. "The role of intermediaries in low carbon transitions – Empowering innovations to unlock district heating in the UK." *Journal of Cleaner Production* 148:137-147. doi: 10.1016/j.jclepro.2017.01.129.

Canadell, Josep G, and Michael R Raupach. 2008. "Managing forests for climate change mitigation." *science* 320 (5882):1456-1457.

Castán Broto, V. 2012. "Social housing and low carbon transitions in Ljubljana, Slovenia." *Environmental Innovation and Societal Transitions* 2:82-97. doi: 10.1016/j.eist.2012.01.001.

Clarke, L., Kejun Jiang, Keigo Akimoto, Mustafa Babiker, G. J. Blanford, Karen Fisher-Vanden, J. C. Hourcade, V. Krey, E. Kriegler, Andreas Löschel, D. McCollum, Sergey Paltsev, Steven Rose, Priyadarshi Shukla, M. Tavoni, B. Van der Zwaan, and D. Van Vuuren. 2014. "Assessing Transformation Pathways." In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. Von Stechow, T. Zwickel and Jan C. Minx. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Craven, Jenny, and Paul Levay. 2019. *Systematic Searching : Practical Ideas for Improving Results*. London, UNITED KINGDOM: Facet Publishing.

Davies, Dan, Divya Jindal-Snape, Chris Collier, Rebecca Digby, Penny Hay, and Alan Howe. 2013. "Creative learning environments in education—A systematic literature review." *Thinking Skills and Creativity* 8:80-91. doi: https://doi.org/10.1016/j.tsc.2012.07.004.

DECC. 2009. The UK Low Carbon Transition Plan: National Strategy for climate and strategy. edited by Department of Energy and Climate Change. London.
Dias, L. P., S. Simões, J. P. Gouveia, and J. Seixas. 2019. "City energy modelling - Optimising local low carbon transitions with household budget constraints." *Energy Strategy Reviews* 26. doi: 10.1016/j.esr.2019.100387.
Djalante, Riyanti. 2018. "Review article: A systematic literature review of research trends and authorships on natural hazards, disasters, risk reduction and climate change in Indonesia." *Natural Hazards and Earth System Sciences* 18 (6):1785-1810. doi: 10.5194/nhess-18-1785-2018.
Drucker, Aaron M., Patrick Fleming, and An-Wen Chan. 2016. "Research Techniques Made Simple: Assessing Risk of Bias in Systematic Reviews." *Journal of Investigative Dermatology* 136 (11):e109-e114. doi: https://doi.org/10.1016/j.jid.2016.08.021.
Erlingsson, Christen, and Petra Brysiewicz. 2017. "A hands-on guide to doing content analysis." *African Journal of Emergency Medicine* 7 (3):93-99. doi: https://doi.org/10.1016/j.afjem.2017.08.001.
European Comission. 2014. Sixth National Communication and First Biennial Report from the European Union under the UN Framework Convention on Climate Change (UNFCCC) (required under the United Nations Framework Convention on Climate Change and the Kyoto Protocol). Luxembourg: European Union.
Fatorić, Sandra, and Erin Seekamp. 2017. "Are cultural heritage and resources threatened by climate change? A systematic literature review." *Climatic Change* 142 (1-2):227-254. doi: 10.1007/s10584-017-1929-9.
Fisch, Christian, and Joern Block. 2018. "Six tips for your (systematic) literature review in business and management research." *Management Review Quarterly* 68 (2):103-106. doi: 10.1007/s11301-018-0142-x.
Fulkerson, W., M. D. Levine, J. E. Sinton, and A. Gadgil. 2005. "Sustainable, efficient electricity service for one billion people[1]." *Energy for Sustainable Development* 9 (2):26-34. doi: 10.1016/S0973-0826(08)60490-1.
Geels, F. W. 2018. "Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990–2016)." *Energy Research and Social Science* 46:86-102. doi: 10.1016/j.erss.2018.07.008.
Geels, F. W., F. Berkhout, and D. P. Van Vuuren. 2016. "Bridging analytical approaches for low-carbon transitions." *Nature Climate Change* 6 (6):576-583. doi: 10.1038/nclimate2980.
Geels, F. W., B. K. Sovacool, T. Schwanen, and S. Sorrell. 2017. "The Socio-Technical Dynamics of Low-Carbon Transitions." *Joule* 1 (3):463-479. doi: 10.1016/j.joule.2017.09.018.
Geng, Y., H. Zhao, Z. Liu, B. Xue, T. Fujita, and F. Xi. 2013. "Exploring driving factors of energy-related CO2 emissions in Chinese provinces: A case of Liaoning." *Energy Policy* 60:820-826. doi: 10.1016/j.enpol.2013.05.054.
Gielen, Dolf, Francisco Boshell, Deger Saygin, Morgan D. Bazilian, Nicholas Wagner, and Ricardo Gorini. 2019. "The role of renewable energy in the global energy transformation." *Energy Strategy Reviews* 24:38-50. doi: https://doi.org/10.1016/j.esr.2019.01.006.
Gough, David, Sandy Oliver, and James Thomas. 2017. "Introducing systematic reviews." In *An introduction to systematic reviews*, edited by David Gough, Sandy Oliver and James Thomas. London: Sage.
Gouldson, A., A. Sudmant, Haneen Khreis, and E. Papargyropoulou. 2018. The economic and social benefits of low carbon cities: a systematic review of the evidence. London and Washington DC: Coaliton for Urban Transition.
Hannon, M. J., T. J. Foxon, and W. F. Gale. 2013. "The co-evolutionary relationship between energy service companies and the UK energy system: Implications for a low-carbon transition." *Energy Policy* 61:1031-1045. doi: 10.1016/j.enpol.2013.06.009.
Harrison, P. A., P. M. Berry, G. Simpson, J. R. Haslett, M. Blicharska, M. Bucur, R. Dunford, B. Egoh, M. Garcia-Llorente, N. Geamănă, W. Geertsema, E. Lommelen, L.

Meiresonne, and F. Turkelboom. 2014. "Linkages between biodiversity attributes and ecosystem services: A systematic review." *Ecosystem Services* 9:191-203. doi: https://doi.org/10.1016/j.ecoser.2014.05.006.

Held, David, and Charles Roger. 2018. "Three Models of Global Climate Governance: From Kyoto to Paris and Beyond." *Global Policy* 9 (4):527-537. doi: 10.1111/1758-5899.12617.

Hirsch, Jorge E. 2005. "An index to quantify an individual's scientific research output." *Proceedings of the National academy of Sciences* 102 (46):16569-16572.

Höhne, Niklas, Takeshi Kuramochi, Carsten Warnecke, Frauke Röser, Hanna Fekete, Markus Hagemann, Thomas Day, Ritika Tewari, Marie Kurdziel, and Sebastian Sterl. 2017. "The Paris Agreement: resolving the inconsistency between global goals and national contributions." *Climate Policy* 17 (1):16-32.

Hourcade, Jean-Charles, P-R Shukla, and Christophe Cassen. 2015. "Climate policy architecture for the Cancun paradigm shift: building on the lessons from history." *International environmental agreements: politics, law and economics* 15 (4):353-367.

IPCC. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by Martin Parry, Osvaldo Canziani, Jean Palutikof, Paul van der Linden and Clair Hanson. Cambridge, United Kingdom: Cambridge University Press.

IPCC. 2014a. "Annex II: Glossary." In *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing eam, R.K. Pachauri and L.A. Meyer (eds.)]*, edited by K.J. Mach, S. Planton and C. Von Stechow, 117-130. Geneva, Switzerland: IPCC.

IPCC. 2014b. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M Mastrandrea, D,, T.E. Bilir, M. Chatterjee, Krities L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC. 2018. "Summary for Policymakers." In *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, edited by V. Masson-Delmotte, P. Zhai, Hans-Otto Pörtner, J. Skea, Priyadarshi R. Shukla, A. Pirani, W. Moufouma-Okia, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. TIgnor and T. Waterfield. In Press.

Keough, N., and G. Ghitter. 2019. "Pathways to sustainable low-carbon transitions in an auto-dependent Canadian city." *Sustainability Science*. doi: 10.1007/s11625-019-00698-5.

Kolajo, Taiwo, Olawande Daramola, and Ayodele Adebiyi. 2019. "Big data stream analysis: a systematic literature review." *Journal of Big Data* 6 (1):47. doi: 10.1186/s40537-019-0210-7.

Lau, Lee Chung, Keat Teong Lee, and Abdul Rahman Mohamed. 2012. "Global warming mitigation and renewable energy policy development from the Kyoto Protocol to the Copenhagen Accord—A comment." *Renewable and Sustainable Energy Reviews* 16 (7):5280-5284. doi: https://doi.org/10.1016/j.rser.2012.04.006.

Lewis, Joanna. 2017. The U.S.-China Climate and Energy Relationship. In *Parallel Perspectives on the Global Economic Order: A U.S.-China Essay Collection*, edited by Daniel Remler and Ye Yu. Washington, DC: CSIS Simon Chair in Political Economy and the Shanghai Institutes for International Studies

Lin, B., and X. Ouyang. 2014. "Energy demand in China: Comparison of characteristics between the US and China in rapid urbanization stage." *Energy Conversion and Management* 79:128-139. doi: 10.1016/j.enconman.2013.12.016.
Liu, W., C. Wang, X. Xie, A. P. J. Mol, and J. Chen. 2012. "Transition to a low-carbon city: Lessons learned from Suzhou in China." *Frontiers of Environmental Science and Engineering in China* 6 (3):373-386. doi: 10.1007/s11783-011-0338-y.
Liu, Z., D. Guan, D. Crawford-Brown, Q. Zhang, K. He, and J. Liu. 2013. "Energy policy: A low-carbon road map for China." *Nature* 500 (7461):143-5. doi: 10.1038/500143a.
Mahood, Quenby, Dwayne Van Eerd, and Emma Irvin. 2014. "Searching for grey literature for systematic reviews: challenges and benefits." *Research Synthesis Methods* 5 (3):221-234. doi: 10.1002/jrsm.1106.
Mander, S., A. Bows, K. Anderson, S. Shackley, P. Agnolucci, and P. Ekins. 2007. "Uncertainty and the Tyndall decarbonisation scenarios." *Global Environmental Change* 17 (1):25-36. doi: 10.1016/j.gloenvcha.2006.11.004.
Mardani, Abbas, Dalia Streimikiene, Fausto Cavallaro, Nanthakumar Loganathan, and Masoumeh Khoshnoudi. 2019. "Carbon dioxide (CO2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017." *Science of The Total Environment* 649:31-49. doi: https://doi.org/10.1016/j.scitotenv.2018.08.229.
Meltzer, J.P. 2018. Blending climate funds to finance low-carbon, climate-resilient infrastructure. Washington D.C.: The Brooking Institute.
Mirumachi, N., A. Sawas, and M. Workman. 2019. "Unveiling the security concerns of low carbon development: climate security analysis of the undesirable and unintended effects of mitigation and adaptation." *Climate and Development*. doi: 10.1080/17565529.2019.1604310.
Mongeon, Philippe, and Adèle Paul-Hus. 2016. "The journal coverage of Web of Science and Scopus: a comparative analysis." *Scientometrics* 106 (1):213-228. doi: 10.1007/s11192-015-1765-5.
Mulugetta, Y., and F. Urban. 2010. "Deliberating on low carbon development." *Energy Policy* 38 (12):7546-7549. doi: 10.1016/j.enpol.2010.05.049.
Odeku, Kola O, Alice Maveneka, and Raligilia Happy Konanani. 2013. "The Consequences of Country's Withdrawal from Climate Change Agreements: Implications for Carbon Emissions Reduction." *Journal of Human Ecology* 41 (1):1-8.
OECD. 2015. "Climate Change Mitigation: Policies and Progress." In. Paris: OECD Publishing.
Paez, Arsenio. 2017. "Gray literature: An important resource in systematic reviews." *Journal of Evidence-Based Medicine* 10 (3):233-240. doi: 10.1111/jebm.12266.
Pan, J. 2005. "Meeting human development goals with low emissions : An alternative to emissions caps for post-Kyoto from a developing country perspective." *International Environmental Agreements: Politics, Law and Economics* 5 (1):89-104. doi: 10.1007/s10784-004-3715-1.
Parker, Charles F., and Christer Karlsson. 2018. "The UN climate change negotiations and the role of the United States: assessing American leadership from Copenhagen to Paris." *Environmental Politics* 27 (3):519-540. doi: 10.1080/09644016.2018.1442388.
Piasecki, Jan, Marcin Waligora, and Vilius Dranseika. 2018. "Google Search as an Additional Source in Systematic Reviews." *Science and engineering ethics* 24 (2):809-810. doi: 10.1007/s11948-017-0010-4.
Porter, J. J., S. Dessai, and E. L. Tompkins. 2014. "What do we know about UK household adaptation to climate change? A systematic review." *Clim Change* 127 (2):371-379. doi: 10.1007/s10584-014-1252-7.
Rahman, Shaikh M, Ariel Dinar, and Donald F Larson. 2010. "Diffusion of Kyoto's clean development mechanism." *Technological Forecasting and Social Change* 77 (8):1391-1400.
Rockström, Johan, Owen Gaffney, Joeri Rogelj, Malte Meinshausen, Nebojsa Nakicenovic, and Hans Joachim Schellnhuber. 2017. "A roadmap for rapid decarbonization." *Science* 355 (6331):1269-1271.

Rogelj, Joeri, Gunnar Luderer, Robert C. Pietzcker, Elmar Kriegler, Michiel Schaeffer, Volker Krey, and Keywan Riahi. 2015. "Energy system transformations for limiting end-of-century warming to below 1.5 °C." *Nature Climate Change* 5 (6):519-527. doi: 10.1038/nclimate2572.

Rogelj, Joeri, Michiel Schaeffer, Malte Meinshausen, Reto Knutti, Joseph Alcamo, Keywan Riahi, and William Hare. 2015. "Zero emission targets as long-term global goals for climate protection." *Environmental Research Letters* 10 (10):105007. doi: 10.1088/1748-9326/10/10/105007.

Sambunjak, D., M. Cumpston, and C. Watss. 2017. *Module 1: Introduction to conducting systematic reviews. In: Cochrane Interactive Learning: Conducting an intervention review*: Cochrane.

Shaffril, H. A. M., S. E. Krauss, and S. F. Samsuddin. 2018. "A systematic review on Asian's farmers' adaptation practices towards climate change." *Sci Total Environ* 644:683-695. doi: 10.1016/j.scitotenv.2018.06.349.

Siddaway, Andy P., Alex M. Wood, and Larry V. Hedges. 2019. "How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses." *Annual Review of Psychology* 70 (1):747-770. doi: 10.1146/annurev-psych-010418-102803.

Sovacool, B. K., and M. C. Brisbois. 2019. "Elite power in low-carbon transitions: A critical and interdisciplinary review." *Energy Research and Social Science* 57. doi: 10.1016/j.erss.2019.101242.

Sweileh, Waleed M, Samah W Al-Jabi, Adham S AbuTaha, H Zyoud Sa'ed, Fathi MA Anayah, and Ansam F Sawalha. 2017. "Bibliometric analysis of worldwide scientific literature in mobile-health: 2006–2016." *BMC medical informatics and decision making* 17 (1):72.

Tollefson, Jeff. 2017. "How Trump plans to wipe out Obama-era climate rules." *Nature News*.

Turkenburg, W. C. 1995. "Assessment report on NRP subtheme "energy demand and supply options to mitigate greenhouse gas emissions"." *Studies in Environmental Science* 65 (PART B):1013-1054. doi: 10.1016/S0166-1116(06)80126-3.

UN-ESCAP. 2010. "Low-Carbon Development Path for Asia and The Pacific: Challenges And Opportunities for the Energy Sector." In. Bangkok, Thailand: UN-ESCAP. https://www.unescap.org/sites/default/files/Energy%20Resources%20Development%20Series%2041.pdf (accessed 2 October 2019).

UNEP. 2018. "Emission Gap Report 2018." In. Nairobi, Kenya: Unite Nation Environment Programme. https://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_FullReport_EN.pdf?sequence=1&isAllowed=y.

UNFCCC. 1997. Kyoto Protocol to The United Nations Framework Convention on Climate Change.

UNFCCC. 2015. Paris Agreement – Decision 1/CP.21 – Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015 Addendum Part two: Action taken by the Conference of the Parties at its twenty-first session.

United Nations. 1992. United Nations Framework Convention on Climate Change FCCC/INFORMAL/84

Urban, F. , and J. Nordensvärd. 2013a. *Low carbon development: Key issues*, *Low Carbon Development: Key Issues*. Oxon, UK, and New York, USA Taylor and Francis. Book.

Urban, F., and J. Nordensvärd. 2013b. "Low carbon development: Origins, concepts and key issues." In *Low Carbon Development: Key Issues*, 3-22. Oxon, UK, and New York, USA Taylor and Francis.

Vaidyula, Manasvini, and Marcia Rocha. 2018. Tracking progress towards NDCs and relevant linkages between Articles 4, 6 and 13 of the Paris Agreement. *Climate Change Expert Group Paper*. Accessed 9 September 2019.

van der Gaast, Wytze. 2017. "Towards a future climate policy—From the Kyoto protocol to the Paris agreement." In *International Climate Negotiation Factors*, 91-123. Springer.

van Eck, Nees Jan, and Ludo Waltman. 2018. "VOSviewer manual." *Leiden: Univeristeit Leiden* 1 (1).
van Sluisveld, M. A. E., A. F. Hof, D. P. van Vuuren, P. Boot, P. Criqui, F. C. Matthes, J. Notenboom, S. L. Pedersen, B. Pfluger, and J. Watson. 2017. "Low-carbon strategies towards 2050: Comparing ex-ante policy evaluation studies and national planning processes in Europe." *Environmental Science and Policy* 78:89-96. doi: 10.1016/j.envsci.2017.08.022.
Wang, L., L. Zhao, G. Mao, J. Zuo, and H. Du. 2017. "Way to accomplish low carbon development transformation: A bibliometric analysis during 1995–2014." *Renewable and Sustainable Energy Reviews* 68:57-69. doi: 10.1016/j.rser.2016.08.021.
Wang, N., and Y. C. Chang. 2014. "The evolution of low-carbon development strategies in China." *Energy* 68:61-70. doi: 10.1016/j.energy.2014.01.060.
Wang, T., and J. Watson. 2010. "Scenario analysis of China's emissions pathways in the 21st century for low carbon transition." *Energy Policy* 38 (7):3537-3546.
Wijaya, Arief, Hanny Chrysolite, Mengpin Ge, Clorinda Kurnia Wibowo, Almo Pradana, Andyhta Firselly Utami, and Kemen Austin. 2017. How can Indonesia achieve its climate change mitigation goal: an analysis of potential emissions reduction from energy and land-use policies. *World Resource Institute Working Paper*.
Winkler, Harald, and Navroz K. Dubash. 2016. "Who determines transformational change in development and climate finance?" *Climate Policy* 16 (6):783-791. doi: 10.1080/14693062.2015.1033674.
World Bank. 2015. State and Trends of Carbon Pricing, 2015. Washington DC: The World Bank.
Wu, Fei, Yong Geng, Xu Tian, Shaozhuo Zhong, Wei Wu, Shitong Yu, and Shijiang Xiao. 2018. "Responding climate change: A bibliometric review on urban environmental governance." *Journal of Cleaner Production* 204:344-354. doi: https://doi.org/10.1016/j.jclepro.2018.09.067.
Xiao, Yu, and Maria Watson. 2017. "Guidance on Conducting a Systematic Literature Review." *Journal of Planning Education and Research* 39 (1):93-112. doi: 10.1177/0739456X17723971.
Zhang, Yong-Xiang, Qing-Chen Chao, Qiu-Hong Zheng, and Lei Huang. 2017. "The withdrawal of the U.S. from the Paris Agreement and its impact on global climate change governance." *Advances in Climate Change Research* 8 (4):213-219. doi: https://doi.org/10.1016/j.accre.2017.08.005.

Appendix

Table Multi-stage process for the document search in Scopus

Steps	Inclusion/Exclusion	Scopus	Number of hits
1st	• **Inclusion:** Insert "*low carbon development*" OR "*low carbon transition"* OR "*decarbonization"* • **Exclusion:** Limit the time scope between 1992 and 2019	(TITLE-ABS-KEY ("low carbon development") OR TITLE-ABS-KEY ("low carbon transition") OR TITLE-ABS-KEY (decarbonization W/255 "climate change" OR "emission")) AND PUBYEAR > 1991	**2,096**
2nd	• **Exclusion:** Limit to journal articles, conference papers, review, book chapter, and book and omit	(TITLE-ABS-KEY ("low carbon development") OR TITLE-ABS-KEY ("low carbon transition") OR TITLE-ABS-KEY (decarbonization W/255 "climate change" OR "emission")) AND PUBYEAR > 1991 AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "b") OR LIMIT-TO (SRCTYPE , "k")) AND (EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (	**1,746**

Steps	Inclusion/Exclusion	Scopus	Number of hits
	those under the conference proceeding.	DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "cr") OR EXCLUDE (DOCTYPE , "tb")) AND (EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "Undefined"))	
3rd	• **Exclusion:** Limit to those written in English language only	(TITLE-ABS-KEY ("low carbon development") OR TITLE-ABS-KEY ("low carbon transition") OR c)) AND PUBYEAR > 1991 AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "b") OR LIMIT-TO (SRCTYPE , "k")) AND (EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "cr") OR EXCLUDE (DOCTYPE , "tb")) AND (EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "Undefined")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (LANGUAGE , "Italian") OR EXCLUDE (LANGUAGE , "Polish") OR EXCLUDE (LANGUAGE, “French”))	**1,651**
4th	• **Exclusion:** Limit to relevant subject areas only and exclude those not relevant	(TITLE-ABS-KEY ("low carbon development") OR TITLE-ABS-KEY ("low carbon transition") OR TITLE-ABS-KEY (decarbonization W/255 "climate change" OR "emission")) AND PUBYEAR > 1991 AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "b") OR LIMIT-TO (SRCTYPE , "k")) AND (EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "cr") OR EXCLUDE (DOCTYPE , "tb") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "Undefined")) AND (LIMIT-TO (LANGUAGE , "English") OR EXCLUDE (LANGUAGE , "Italian") OR EXCLUDE (LANGUAGE , "Polish")) AND (EXCLUDE (LANGUAGE , "French")) AND (EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "COMP") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "PSYC") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "MULT") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "IMMU"))	**1,390**
Total of entries after manual data cleaning to exclude duplication, non-English articles, systematic literature review papers, editorial papers and titles of edited books			**1,371**