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Current Carbon Emission Reduction Trends for Sustainability - A Review

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Abstract

Carbon emissions in the supply chain have been known to contribute significantly to environmental decay. These emissions are a result of carbon dioxide and other greenhouse gases released during the burning of fossil fuels. The industry is a well-known emitter of these gases to the atmosphere. These gases end up trapping energy from the sun in the atmosphere. This has led to the governments of the world putting measures in place to minimize carbon emissions. In supply chain, during the manufacture, transportation and storage of a product a significant amount of these greenhouse gases are emitted into the atmosphere. Research about supply chain with respect to carbon emissions has been going on for decades. This is the perfect time to review the literature of what has been studied up to so far and also identify the gaps in the literature. A systematic literature review approach is employed, initially. Content analysis was used to categorize existing literature on the various topics and methods over time in the area of carbon emissions in the supply chain. Triangulation research technique is also used to analyze the current literature on carbon emissions research study in the supply chain. Thereafter, a quantitative bibliometric analysis is conducted. Based on a rigorous screening process, 138 papers were selected for analysis. This review will lead to significant opportunities for future research in related areas.

Keywords: bibliometric analysis, carbon emissions, content analysis, supply chain

1. Introduction

Carbon emissions have been reported to have hit a record high in the year 2017. This increase stands in stark contrast to the requirements of the Paris Climate Agreement which needs cuts in global carbon emissions. Reduction of carbon emissions is becoming more important for the countries of the world to meet the requirements of the agreement of reducing their carbon emissions. Under this Paris Agreement, countries have agreed to limit the increase in global temperatures. Carbon footprint is the total emissions caused which is expressed as carbon dioxide equivalent.

According to Environmental Protection Agency (EPA) gases that trap heat in the atmosphere are greenhouse gases. Greenhouse gases can be emitted through production of goods. Byrne et al. (2007) stated that industrialized nations have undertaken commitments to reduce emissions of greenhouse gases. They reviewed diverse policies, strategies and cooperative frameworks and they also identified environmental and economic benefits linked to such programs. Some examples of greenhouse gases are : Carbon dioxide (CO_2) which enters the atmosphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees and wood products, and also as a result of certain chemical reactions. Many researchers have done studies on burning of fossil fuels which causes release of Carbon dioxide. Tang et al. (2018) investigated three approaches on the effects of controlling carbon emissions in the transportation and inventory management. The first one adds a constraint to represent emission reduction percentage target. The second incorporates carbon taxes into inventory management. Tshivhase (2018) wrote that he policy implications of the models are examined and discussed to provide insights for practitioners and policy makers. Methane (CH_4) which is emitted during the production and transport of coal, natural gas, and oil. Nitrous oxide (N_2O) which is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste. Some researchers have also done studies to try and minimize production of gases such as nitrous oxides during agricultural processes. Patthanaissaranukool and Polprasert (2016) investigated whole-chain soybean oil productions' carbon equivalences. and the appropriate approaches for carbon emissions were also evaluated. Cultivation accounted for 63% of overall emissions. The most significant emission from

soybean oil production was found to be fuel oil used for steam production contributing to 52% of the total emissions in industrial phase. Potential reductions of carbon emissions from soybean oil production were found to be 87% as compared to existing conditions. Fluorinated gases: Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for stratospheric ozone-depleting substances

Equivalent CO_2 (CO_2e) is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas. Examples of such greenhouse gases are methane, perfluorocarbons, and nitrous oxide. CO_2e is expressed as parts per million by volume, ppmv. Most researchers relate reduction of carbon emissions with the minimization of these emissions from industry. Some energy intensive industries that have been studied are the construction industry where there are raw materials 'manufacturing. Wu et al (2014) stated that the construction industry is the largest sources of carbon emissions. The manufacturing of cement, steel and aluminum produces considerable amount of carbon emissions. This industry is now under pressure to reduce carbon emissions. Carbon labelling schemes are therefore developed as meaningful yardsticks to measure carbon emissions. Since few studies have been done to investigate the transparency requirements in carbon labelling schemes. Through a comparative study is used to identify and investigate the carbon labelling requirements.

Most researchers believe that the main factors causing climate change and global warming is the increase of global carbon emissions produced by human activities such as deforestation and burning of fossil fuels (Huisingh et al. 2015). Global warming is one of the greatest threats to human survival. Improved energy efficiency and implementation of low fossil carbon renewable energy based systems are clearly the most direct and effective approaches to reduce carbon emissions. Some authors have investigated alternative low carbon renewable energy. Speth et al. (2015) stated that black carbon emissions from gas turbines are reduced significantly with the use of alternative jet fuels that are low in aromatic content. They proposed an approximation of the reductions associated with the use of paraffinic alternative jet fuels. The proposed relationship is constrained to produce physically meaningful results and is used to explain a majority of variability in measurements across the engines and fuels that have been tested.

Mago and Luck (2017) investigated the potential carbon dioxide emissions reduction from the implementation of electric energy storage to a combined power generation unit and organic Rankine cycle relate to a conventional system. Results indicated that reductions from the operation of the proposed system are directly correlated to the ratio of the carbon dioxide emission conversion factor for the electricity to that of the fuel. It is also shown that by using the carbon emissions cap and trade programs a frame of reference to compare operational cost gains with carbon dioxide reductions. Tshivhase and Vilakazi(2018) stated that throughout a product's life cycle various ways are available for companies to cut carbon emissions. The alternative actions include selecting environmentally friendly raw materials and replacing environmentally unfriendly energies with cleaner alternatives (Tang et al, 2018). According to Chen et al. (2016), most countries have taken a series of measures to inhibit excessive carbon emissions such as administrative regulations, carbon taxes and trade restrictions. In 2007, China has overtaken the US to become the largest emitter of carbon dioxide in the world. This has attracted huge attention from policy makers and researchers (Wang et al., 2018).

The study of carbon emissions reduction highlights the importance of alternative and renewable fuels. Algae biomass can be used for the production of advanced biofuels. This biomass has emerged as a suitable for replacing fossil fuels that are known to increase carbon emissions in the atmosphere (Adeniyi et al., 2018). Supplier selection is also important since these organizations are chosen to become part of the supply chain of such organizations. These organizations are now demanding that their suppliers reduce their carbon footprints as they are also reducing their own internal carbon footprints. The non-profit Carbon Disclosure Project has cited that some organizations have even gone to the extent of dismissing certain suppliers. (Kumar et al., 2014). The construction industry is also one of the largest emitter of carbon. Manufacturing of cement, aluminum, etc. is energy intensive which causes a high amount of carbon emissions. This industry is consequently under pressure to reduce carbon emissions level. Carbon labelling schemes are therefore used to measure and compare carbon emissions (Wu et al., 2014).

Nowadays companies should address the importance of preserving the earth for future generations. Many models have been used to estimate the reduction of carbon emissions. Just in Time and Economic Order Quantity are two basic inventory modes. According to Wang and Ye (2018), environmental issues should also be considered when conducting studies with these two inventory modes. Hence the reason they studied these two inventory models with carbon emissions with one manufacture and n retailers. Abduaziz et al. (2014) assessed green logistics practices by using a hybrid simulation method. Wang and Ye (2018) stated that environmental issues are worth to be considered in both the Just in Time (JIT) and the Economic Order Quantity (EOQ). The decided to study

these two models with carbon emissions in a supply chain with one manufacturer and many retailers. The basic and carbon emission models of JIT and EOQ are presented separately for cost comparisons.

This paper focuses on the subject of carbon emission reduction in the supply chain of different industries. The research objectives of this paper are to identify any gaps in the research literature up to so far. This is because a lot of articles with respect to carbon emission reduction have been published but few papers have been written trying to identify literature gaps and possible future research.

The focus is on the reduction of carbon emissions in the supply chain. This leads to different research objectives. The research objectives are:

- What is the trend of existing research with respect to carbon emission reduction?
- Identify the existing literature gaps in carbon emission reduction and possible future research focus

To address these questions a lot of research was done by searching various databases to view and download different articles. Databases such as SCOPUS, Science Direct and Web of Science were used for the collection of data. A comprehensive analysis of the present literature on carbon emission reduction in the supply chain was then done.

Triangulation analysis was then used which is basically an indication that two or more methods were used in a study which leads us into investigating the results of one subject. In our case this subject will be carbon emission reduction in the supply chain. Bibliometric analysis and systematic literature review were also used in order for the results of these study to be as understandable as possible. Both the quantitative and quantitative analysis of previous studies have been investigated including their results.

The paper will also present an overview of the methodology used. The next step will be to classify the studied papers using content analysis. The results of the bibliometric analysis showing leading contributions are also shown. We then show potential areas for future research on this research field.

2. Methodology

To address the above research questions, a thorough review of literature relating to carbon emissions in the supply chain was conducted. This study followed the study process recommended by Krippendorff (1980). The study process includes data collection, descriptive analysis, categorization analysis, data evaluation and interpretation.

2.1 Data Collection

This study contains literature from 1995 to 2018. The 1990s. The study contains literature from 1995 to 2018. This is because in the 1990s due to improved computer models a consensus was formed that stated that greenhouses gases were deeply involved in most climate changes. The emissions were bringing discernable global warming. During the same decade, scientific research in emissions has included multiple disciplines. The review methodology process followed suggestions by Andriolo et al. (2014) in Table 1. The different articles were collected from different academic databases such as Scopus, Web of Science and Science Direct. A selection of keywords that fulfilled research objectives requirements was used to identify relevant articles from these databases. These keywords are divided into two categories:

1) Words relevant to Reduction of Carbon Emission

2) Words relevant to Supply Chain

An example of keywords combination relating to carbon emission reduction would be ‘Carbon emission reduction Green, Environment’. And, those related to supply chain would be ‘Supply Chain, Industry, Manufacturer’. Table 1 shows all the selected keywords.

Table 1. Review methodology and process steps

Review Methodology Process	**Papers Found**
Related to Carbon emission reduction: Carbon emission reduction	280 999
Related to Carbon emission reduction: Carbon emission reduction Related to Supply Chain: Supply Chain	39233
Related to Carbon emission reduction: Carbon emission reduction Related to Supply Chain: Supply Chain, Industry, Supplier	5003
Related to Carbon emission reduction: Carbon emission reduction Green, Environment Related to Supply Chain: Supply Chain, Industry,,Manufacturer	3791
Related to Carbon emission reduction: Carbon emission reduction, Green, Environment Related to Supply Chain: Supply Chain, Industry, Supplier, Manufacturer, Transportation	1267
Related to Carbon emission reduction: Carbon emission reduction, Green, Environment, Related to Supply Chain: Supply Chain, Industry, Supplier, Transportation, Manufacturer Research Fields: Operations Management, Supply Chain Management Document type: Journal Article	766
Related to Carbon emission reduction: Carbon emission reduction, Green, Environment, Carbon dioxide, Greenhouse gases Related to Supply Chain: Supply Chain, Industry, Supplier, Transportation, Manufacturer Research Fields: Operations Management, Supply Chain Management, Management Engineering Document type: Journal Article Journal Relevance /Impact Factor: 1+	325
Critical analysis of abstracts (including keywords) and conclusions of the above 325 papers	140
Skimming through the main body of the above 325 papers	138

Relevant journal articles were collected form the databases after appearing in search results. After the application of the last set of search items a total 325 papers were returned.After this, critical analysis of the abstracts and conclusions was done which eliminated 185 papers and returned only 140 papers. The last step in this process was to skim through the main bodies of these papers which resulted in 2 papers being deemed unsuitable to this research. The remaining 138 papers were used for bibliometric analysis. By systematically labeling the content of a set of texts, researchers can analyze patterns of content quantitatively using statistical methods, or use qualitative methods to analyze meanings of content within texts. Bibliometric is statistical analysis of written publications, such as books or articles. For instance, bibliometric are used to provide quantitative analysis of academic literature. Citation analysis is a commonly used bibliometric method which is based on constructing the citation graph, a network or graph representation of the citations between documents. Many research fields use bibliometric methods to explore the impact of their field.

For content analysis, the papers had to answer the following two questions:

- What type of reduction strategy was used to reduce carbon emissions?
- How did this strategy impact the supply chain?

These papers also had to state the type of greenhouse gas studied. The content analysis was targeted at 138 papers for in-depth analysis. Hence, categorization analysis included 36 papers.

2.2 Descriptive Analysis

The study started with the exploration of the growth in research publications over time. Then, the distribution of these articles in various journals was illustrated. Then, a bibliometric analysis using Vosviewer of authors was done. This showed which authors were contributing the most knowledge in the field. Co-author analysis reveals those researchers who are (have been) actively engaged in the related research. Co-authorship analysis also shows the kind of network relationships that exist among different authors.

2.3 Categorization Analysis

The pool of research papers was analyzed according to key research issues. This analysis included: theories used, methodologies used, industry studied, objective and conclusions. Methodologies showed what type of method was used for the study in each paper under categorization analysis. This included mathematical modelling, case studies, surveys, carbon labelling scheme, etc. For example, Zhao et al. (2017) allocated carbon dioxide emissions to industries. They proposed an integrated method based on input-output analysis for the allocation. The results showed that the production and distribution of electric power needed to take largest shares with carbon dioxide emission reductions of about 1900 million tons. They also proposed a carbon labelling scheme to decimate against the emissions reduction obligations. And, Du and Lin (2018) state that the energy concentration and consumption of the industry accounts for a large proportion of the total consumption and hence carbon emissions. A mathematical model was used to analyze the change in carbon dioxide emissions. It was found out that the factors that affect carbon dioxide emissions are labour productivity, energy intensity and industry size. The paper proposed policy recommendations for the future emission reduction.

The objectives and conclusions served to answer the research objectives.

2.4 Research Process

The validity of the results was ensured by following systematic processes for each step of the paper.

3. Results

This a section summarizes the trend in the literature in terms of the distribution of relevant publications over time, the journals where these papers were published, and the kind of carbon emission reduction strategies explored through those papers' research. Through content analysis, the most frequently studied issues with respect to carbon emission reduction strategies were explored through the papers. These papers considered sustainability. Cowan et al. (2010) studied sustainability. They collected information on sustainability programs of the largest US companies. They found that amongst others Household and personal products industries had the most comprehensive environmental sustainability programs. They also found that many companies shaped their own definition of sustainability and developed their associated sustainability programs based on their sector, stakeholder interests, products and services and business model.

3.1 Descriptive Analysis

3.1.1 Literature

The number of published articles during different time periods were plotted in a 'Number of Articles' versus 'Year of Publication'. This was done to establish a trend of research interest. In the 1990s, there were improved computer models and during this time a consensus was formed that greenhouse gases were the main culprit in climate change. Literature related to carbon emissions started in 1995. There were a few publications up to 2012. The related publications during this period of 1995-2012 mainly consisted of either 1 or 0 publications. There were however, a few exceptions such as the year 2007,2010, 2011 and 2012. The research in this field has been growing from the year 2013. The number of publications has been mainly increasing exponentially from 6 publications in 2013 to 15, 30 and 48 publications in the years 2016, 2017 and 2018. This is depicted in Figure 1. This shows that interest in carbon emission reduction studies has grown rapidly in recent years.

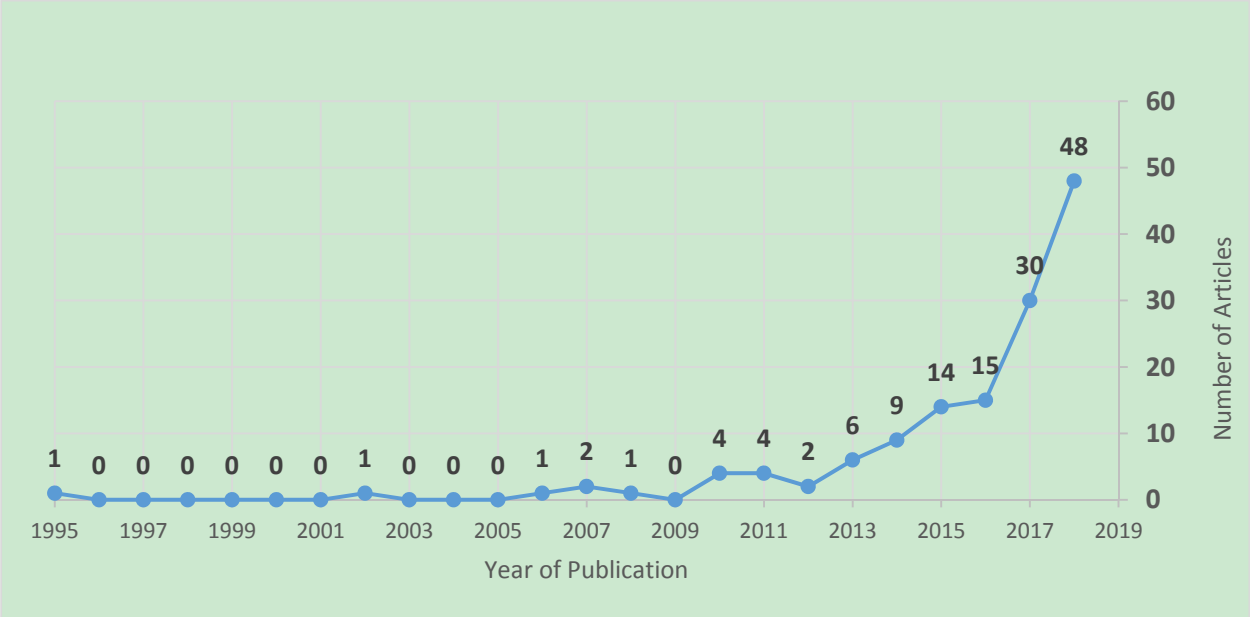

Figure 1. Distribution of relevant articles over time

3.1.2 Publications by Journal

To assess the extent of journal influence in the field of carbon emission reduction, the number of journal articles per journal were summed up from the 138 papers that were investigated. The top five journals had over 54% article contribution. The analysis shows these top five journals were the Journal of Cleaner Production, Renewable and Sustainable Energy Reviews, Energy Policy, the European Journal of Operational Research and Applied Energy with 47,10,9, 5 and 4 articles respectively. The 138 journal articles in the review were published in 35 different journals. Of these 138 journal articles, 134 articles were published in 31 journals and only 4 articles were in 4 other journals. This s shown in Table 2.

Table 2. Distribution of articles per journal

Journal	**Number of Articles**
Journal of Cleaner Production	**47**
Renewable and Sustainable Energy Reviews	**10**
Energy Policy	**9**
European Journal of Operational Research	**5**
Applied Energy	**4**
Energy Procedia	**3**
Atmospheric Environment.	**3**
Procedia Engineering	**3**
Energy Economics	**3**
Science of the Total Environment	**3**
Atmospheric Environment	**3**
Procedia Engineering	**3**
Energy Conversion and Management	**2**
Journal of Environmental Management	**2**
Transportation Research	**2**
Regulatory Toxicology and Pharmacology	**2**

Greenhouse Gas Control	**2**
International Journal of Production Economics	**2**
Resources, Conversation & Recycling	**2**
Procedia CIRP	**2**
Chemical Engineering Journal	**2**
Land Use Policy	**2**
Environmental Impact Assessment Review	**2**
Procedia Computer Science	**2**
Ecological Indicators	**2**
Environmental Science and Policy	**2**
Advances in Climate Change Research	**2**
Procedia Manufacturing	**2**
Omega	**2**
Procedia Economics and Finance	**2**
Waste Management	**2**
Others	**4**

3.1.3 Co-author Analysis

This is the analysis that is done to show the main researchers in a particular field and this also shows the kind of network connections among these main researchers. Table 3 represents the most contributing authors in the field. This table also shows the number of journal articles published by every author. This number is then converted into a percentage to just show how these publications compare to each other in terms of percentage. Most current researchers are academics in China this may be partially due to the country being the largest emitter of greenhouse gases. China's carbon emissions are on track to rise at their fastest pace in more than seven years during 2018, casting further doubt on the ability of the Paris climate change agreement to curb dangerous greenhouse gas increases. Carbon emissions in the country rose 4 per cent in the first quarter of this year, according to calculations by the environmental group based on Chinese government statistics covering coal, cement, oil and gas. If that pace continues it would be the fastest increase since 2011.

Co-author analysis reveals those researchers who are (have been) actively engaged in the related research. Co-authorship analysis also shows the kind of network relationships that exist among different authors. Table 3, shows researchers with the highest number of contributions in the field. Xu, L. is the leading author with 7 co-authored publications which makes 22.6% of the all the publications by researchers with at least 3 publications? Wang, C. has contributed to the field with 5 publications followed by Zhang, Q. with 4 co-authored publications. Wang W., Qin J., Xia L., Wang Y., and Xu J. each had 3 co-authored publications. These kind of co-authorship relations by author's name are also clearly shown in Figure 2.

Table 3. Current authors in the field

Author	No. of Publications	Percentage (%)
Xu, L.	**7**	**22.6**
Wang, C.	**5**	**16.1**
Zhang, Q.	**4**	**12.9**
Wang,W.	**3**	**9.7**
Qin, J.	**3**	**9.7**
Xia,L.	**3**	**9.7**
Wang,Y.	**3**	**9.7**
Xu,J.	**3**	**9.7**

Figure 2, is the co-authorship network analysis The circle size indicates the quantity of publications by the author. The lines between the circles indicated the co-authorship relations between two authors. The most prominent co-authorship relation is the one between Xu L. and Wang C. followed by that between Xu, L. and Wang W. and then Xu, L and Xu and finally Xia, L. and Qin, J.

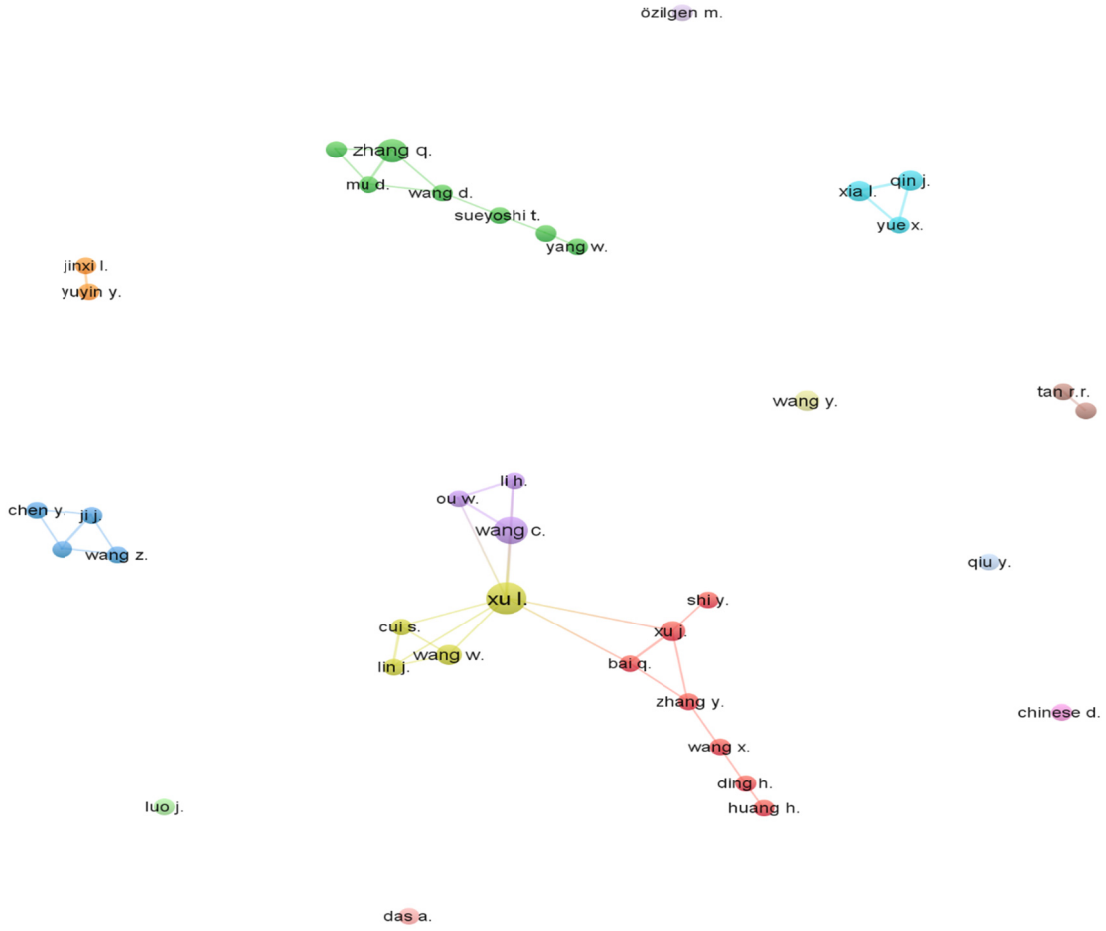

Figure 2. Co-authorship relations of authors

There were many clusters for co-authorship. The papers in this clusters looked at various areas of carbon emission reduction. According to this Vosviewer image, some of the most contributing authors to this field are Xu, L. This author has been publishing a lot of papers with various authors such as Wang, C, Wang, W. Xu, J among others. He has collaborated with 13 authors in recent years in this field. Zhang, Q. is also contributing to this field. He has collaborated with authors such as Wang, D. and Sueyoshi, T. among others. In recent years, he has collaborated with 6 different authors. Some notable authors are Wang Z., Chen Y and Ji, J. who have been collaborating with each other.

3.1.4 Citation Analysis

Table 4. Highest number of carbon emissions reduction citations per article

Author	Year of Publication	No. of Citations
Bumpus	2008	320
Suarez-Ruiz	2008	40
Chiaramonti	2014	39
Cheng	2015	32
Suopajarvi	2014	32
Vergara	2011	32
Zakeri	2014	29
Sueyoshi	2014	29

Citation analysis is a great way to investigate those papers that have highly contributed to the furthering of the relevant literature. Some of the most contributing papers were by Bumpus and Suarez-Ruiz which were both written in 2008. Table 4 summarizes the top 8 most cited articles from the list of the 138 papers analyzed for the purpose of this literature review. Bumpus (2008) has been the most cited researcher. His paper had 320 citations which are 280 times more than the second highest citations. This second highest citation of a paper by Suarez-Ruiz paper had 40 citations. This information can also be viewed with the help of Figure 3 which shows all the researchers with at least 3 citation occurrences.

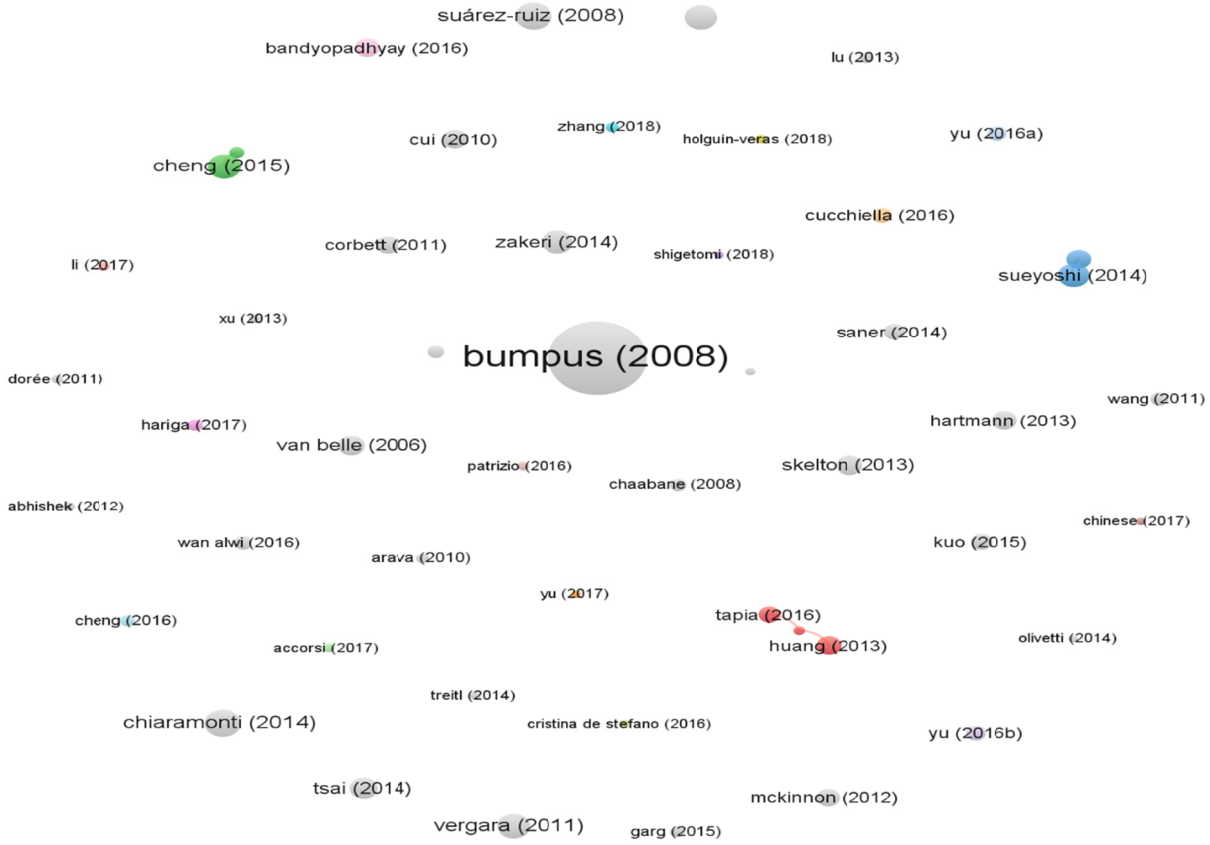

Figure 3. Articles with at least three citations

The circle size in Figure 3 also indicates the number of times an article was cited. So, the bigger the circle size the more citations that author has received. It is quite clear that Bumpus (2008) has the highest number of

citations. Suarez-Ruiz (2008) and Chiaramonti (2014) have the next bigger circle sizes after Bumpus (2008). This results support Table 4 above. It is also important to note that Figure 3 above does not show all the 138 papers since those papers includes all papers including those that have never been cited. The above figure shows all publications out of the 138 papers with at least 3 citations.

3.1.5 Keywords Analysis

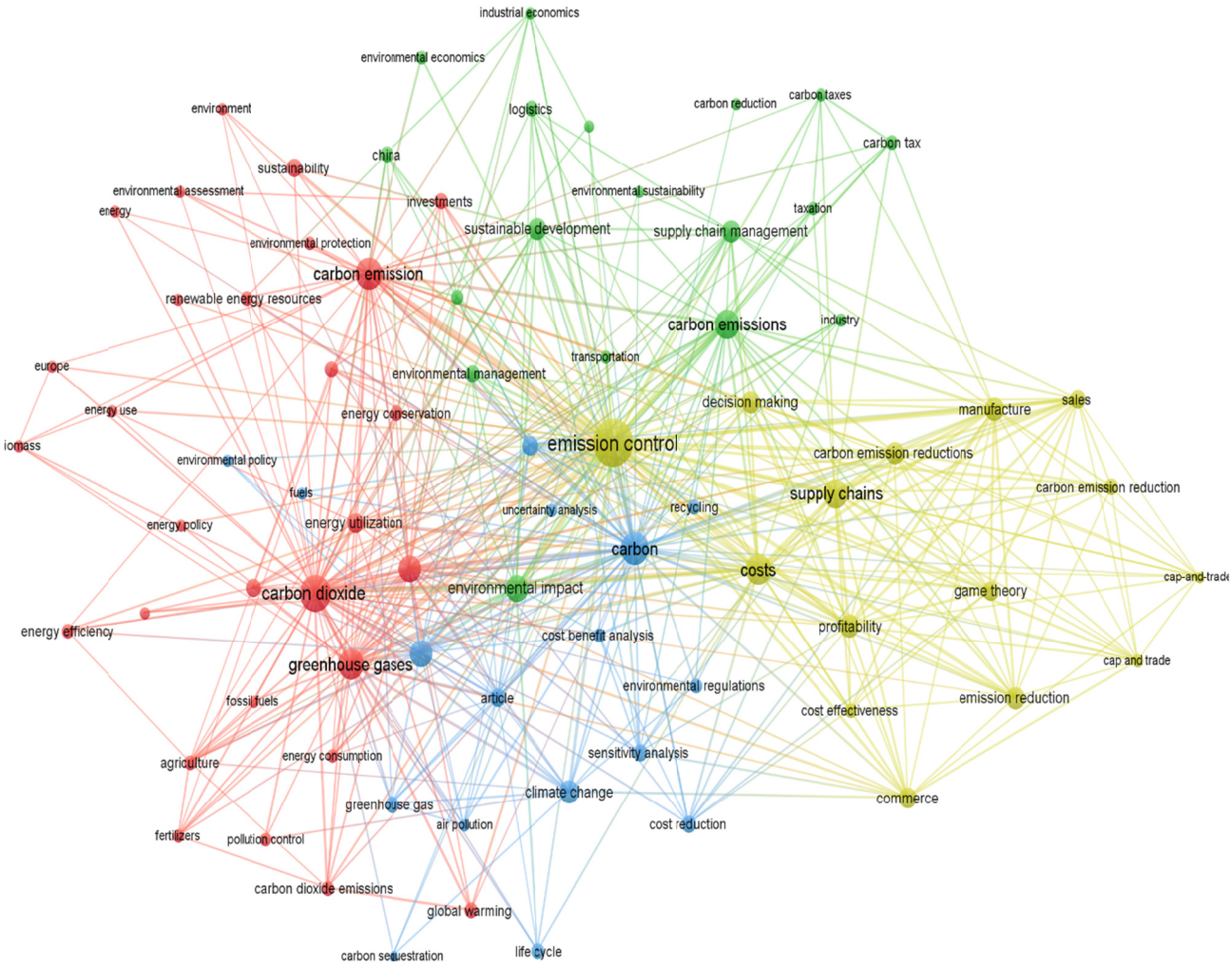

Figure 4. Carbon reduction-related keywords occurrences

From Figure 4, from the 138 papers there a lot of keywords including authors' abstract keywords. Using this knowledge, for the 138 papers with a minimum number of one occurrence/keyword, the result from the Vosviewer software produced 1553 keywords. Applying five as the minimum number of occurrence returned 79 papers meeting the threshold. Circle size implies the number of times a keyword was included in a paper. So, the bigger the circle size the more the number of appearances in the literature. Keywords such as 'emission control', 'carbon', 'carbon dioxide' 'greenhouse gases' and 'carbon emission' were the most included keywords. Because there are many keywords that are included in every single paper there tend to be connections between keywords. The links between the keywords above shows how these keywords were connected in the papers.

3.2 Categorization Analysis

This section is responsible for the review of literature with the help of categorization of the research papers' contents. The contents have been investigated under different topic names. These names are number of citations, the industry investigated, methodology employed, type of greenhouse gas studied, theory used, objective and conclusion derived. This review will allow for the identification of areas of interest and areas which have research gaps. The content analysis of the reviewed papers where derived through the methodologies proposed by Andriolo et al. (2014)**.** From Table 5, categorization analysis used only those papers focusing on the most

relevant issues. These are the papers with a minimum number of 5 citations. The result is 36 articles for content categorization. These are the papers that will be fully analyzed in the next table.

3.2.1 Greenhouse Gas Investigated

The most notable conclusion that can be drawn from table 5 is that almost all the papers that were studied further under categorization were looking at purely carbon dioxide as a greenhouse gas. Other greenhouse gases such as methane, nitrous oxides, Fluorine were hardly studied as individual gases. These three gases were mainly studied as part of all the other gases including carbon dioxide.

Table 5 shows that most papers looked at under categorization had either carbon dioxide as an individual gas or a mixture of all greenhouse gases studied. These greenhouse gases are Carbon dioxide, Methane, Nitrous oxides and Fluorinated gases. More than 47% of all the gases investigated were carbon dioxide. There papers studied under categorization had at least 5 citations The fact that these papers were cited mean that these papers have played some roles in the advancement of knowledge in the field of carbon emission reductions. One of the most cited papers was by Bumpus and Liverman which was published in 2008. This paper was cited 320 times. Another paper by Suarez-Ruiz and Crelling which was also published in 2008 had 40 citations which helped contribute to the advancement of knowledge. A lot of different industries were investigated in this categorization, heavy industries were the most investigated industries since these tend to be energy intensive which mean more electricity is used and also more fossil fuels burning is done.

Table 5. Content categorization of carbon emission reduction

Author	Citation	Industry	Study	Emission	Theory	Objective	Conclusions
Bumpus and Liverman (2008)	320	International political economy	Survey	all	the Kyoto Protocol	governance of international carbon offsets	show how carbon offsets represent capital-accumulation
Suarez-Ruiz and Crelling (2008)	40	Mining	Literature review	Methane	Organic petrology	issues concern to the general public as a whole	coal utilization
Chiaramonti et al. (2014)	39	aviation transport	Experimental testing	Carbon dioxide	bio or thermo-chemical processes	routes from biomass feedstock to sustainable paraffinic fuels,	First samples of feedstock oils were collected
Vergara et al. (2011)	32	municipal solid waste	Mathematical	all	Using two different waste LCA models, EASEWASTE	biogenic waste management	residual waste by 40% can lead to a savings of 6 Mt of CO2-e per year,
Suopajarv-i et al. (2014)	32	steelmaking	Case study	Carbon dioxide	charcoal, torrefied wood and wood-based synthetic natural gas	environmental and economic evaluation of three bioreducers	by-product credits for charcoal, torrefied wood
Cheng et al (2015).	32	Urban transportation systems	Mathematical modelling	Carbon dioxide	fuel tax, motorcycle parking	to simulate the effects of urban transportation policies and to explore their potential	Simulation results indicate that both the fuel tax and motorcycle parking management are effective.
Sueyoshi and Wang (2014)	29	energy Industry	Mathematical Modelling	Carbon dioxide	(DEA) ROA	green image is recently a very important	investigation identifies that the green investment in U.S. energy industry is useful
Zakeri et al. (2014)	29	Renewable energy	Mathematical Modelling	all	Energy PLAN tool	comprehensive modeling of the energy system	renewable energy for Finland is around 44-50% by an optimal mix of different technologies
Tsai et al. (2014)	22	the green building industry	Mathematical modelling	Carbon dioxide	(CSR) (ABC) (LCA) approach	proposes a 0-1 mixed integer programming (0-1 MIP) decision model	assist management in bidding on environmentally-friendly construction projects;

Van Belle (2006)	20	renewable electricity	Mathematical Modelling	Carbon dioxide	mean initial diameter	model to estimate CO2 emissions	CO2 emissions per MWh decreased by a factor 7.
Skelton (2013)	19	international supply chains of European companies	Mathematical Modelling	Carbon dioxide	Structural Path Analysis techniques	analysis into the maximum potential influence of European industry	found to be greater than one gigaton of carbon dioxide.
Sueyoshi and Yuan (2015)	18	energy industry	Mathematical	CO2	ROA or Tobin's q ratio	discusses (DEA) for environmental assessment	corporate sustainability depends upon an amount of net income generated
Cui et al. (2010)	17	transport sector, Bus Rapid Transit (BRT) systems	Mathematical Modelling	all	life cycle assessment (LCA) approach	carbon footprint model of the BRT system with three components	could achieve reductions of approximately 25,255 tCO2e per year
Hartmann et al. (2013)	17	management accounting and control (MAC)	Mathematical	all	carbon accounting	identifying key theoretical and empirical shortcomings of academic research	guide and organize MAC research in the emerging and exciting field of carbon accounting.
Huang et al. (2013)	17	Economy	Mathematical modelling, Survey	Carbon dioxide	Carbon capture and storage, optimization models and algorithms	developments and economic analysis of carbon capture and	directions for sustainable developments of low-carbon energy economy
Bandyopa-dhyay and Desai (2016)	17	diesel based power generation	Mathematical	all	Pinch Analysis based method	allocating different energy sources	reduction in emissions from diesel generator set by about 58%.
McKinnon and Piecyk (2012)	15	logistics operations.	literature review, semi-structured interviews	all	carbon reduction targets	different approaches that companies can take to setting targets	principles applicable to the decarbonization
Corbett (2011)	15	electricity sector	Mathematics	all	(IS) embedded in the smart grid	Effectiveness of electricity demand management	information systems can play in achieving environment sustainability.
Saner et al. (2014)	14	building energy demand and supply	case study, mathematical modelling	all	regionalized LCA-based multi-objective optimization model	for the minimization of greenhouse gas emissions	greenhouse gas emissions from energy supply could be reduced by more than 75%
Kuo et al. (2015)	14	Suppliers, SCM	literature review, mathematical	all	integrating fuzzy ANP and fuzzy TOPSIS approaches.	supplier evaluating process for carbon management	evaluate suppliers in carbon management
Tapia et al. (2016)	13	Oil Recovery	Mathematical modelling, Case Study	Carbon dioxide	Carbon capture and storage (CCS)	(MILP) model address CO2 allocation	case studies are solved to illustrate the model
Cucchiella et al. (2016)	12	photovoltaic power plants	case study, mathematics	Carbon Dioxide	Net Present Value, Discounted Payback Time	photovoltaic systems in residential sector without subsidies.	suggest that small-scale photovoltaic systems can support the transition
Yu et al. (2016)	11	coal-fired power sector	Mathematical modelling	Carbon dioxide	a carbon abatement cost estimate	carbon abatement cost estimate model	the unit cost of abatement would decrease more than 64%
Yu et al. (2016)	11	electric power systems (EPS)	vector regression (SVR) and Monte Carlo simulation	Carbon dioxide	a two-stage interval-possibilistic programming (TIPP) method	for planning carbon emission trading (CET) in the EPS	cleaner production, 30.8, 33.1 % reduction of treated CO2 emissions.

Wan Alwi et al. (2016)	10	all sectors: industrial, domestic, commercial, transportation, power generation.	Theoretical	Carbon dioxide	CO2 capture, utilisation and storage technologies	solutions to achieve cleaner energy	the energy mix in many countries are shifting towards alternative energy sources
Wang et al. (2011)	9	Manufacturing and industrial processes	Mathematical modelling	all	low-carbon production scheduling system	objective of minimizing the total carbon emissions	demonstrated the proposed low-carbon production scheduling
Kraines et al. (2010)	8	supply-side and demand-side technologies and policies for (CO2) mitigation in urban areas	Case study	Carbon dioxide	photovoltaic (PV) cells in residential and commercial buildings	technologies and policies for carbon dioxide (CO2) mitigation	CO2 tax and the SOFC/GT ould result in a 50% reduction in CO2 emissions
Chaabane et al. (2008)	7	Supply chain sustainability	Mathematical modelling	all	uses mixed integer linear programming modeling technique	mathematical programming model for environmental conscious	quantitative decision support system to understand the tradeoffs
Cheng et al. (2016)	6	Inventory routing, supply chain,	Mathematical modelling	all	mixed integer nonlinear programming models	traditional (IRP), hybrid genetic algorithm	parameter sensitive analyses
Garg and Lam (2015)	6	manufacturing industry	Mathematical modelling, genetic programming (GP),	all	3-D printing technology, polymer PLA (Polyactic acid)	genetic programming (GP), support vector regression and artificial neural network in	reduction of transport costs and carbon emission.
Lu et al. (2013)	6	energy consumption	case study	all	different energy resources (i.e., coal, oil, gas, and electricity) and	analyze the consumption of different energy resources	analysis of energy consumption is helpful for emission reduction
Hariga et al. (2017)	6	SCM, transportation and storage activities	Mathematical modelling, computational experiments	all	carbon footprint minimization model and a hybrid economic minimization model	assesses the impact of accounting for carbon emissions,	determine the optimal lot sizing and shipping quantities.
Zhao et al.(2017)	6	government	Case study	all	carbon reduction labelling scheme, uses system dynamics	model enterprises' compliance with a combined government policy	inform government of possible sustainable policy design development.
Arava et al.(2010)	5	Global Industries	Mathematical	all	Game theory =mechanism design problems	carbon credit allocation (CCA), carbon credit buying (CCB),	describes in detail one specific problem, the carbon credit allocation problem.
Li et al. (2017)	5	Manufacturing	Mathematical modelling	all	centralized and decentralized game theoretic models	performance of a low-carbon (CLSC)	Vertical Nash structure is the best
Zhang et. al. (2018)	5	of logistics infrastructure investments for green transport modes	Mathematical modelling, case study	Carbon dioxide	genetic and Wolfe hybrid algorithm	proposes an optimization model that simultaneously incorporates the selection of logistics	reduction targets can significantly affect logistics infrastructure

3.2.2 Categorization Based on the Gas Investigated and Methodology

Content analysis was used to investigate the different methodologies used for the main 36 papers under categorization. The most frequently applied methodologies are shown in Table 6. The methodologies mostly applied were mathematical modelling in this field of reduction of carbon emissions. The next commonly used methodologies were case studies followed by general mathematical calculations excluding mathematical modelling. Most of these papers applied only a single methodology. There were however, a few papers that applied two methodologies at once like Huang et al. (2013) who used mathematical modelling and survey. Zhang et al. (2018) used both mathematical modelling and a case study. This is a good step forward since a combination of methodologies implies that the depth and width of the results of the study is well off in such a way that a greater contribution to the current body of knowledge is obtained.

All these methodologies have their advantages and disadvantages. In the social sciences and life sciences, a case study is a research method involving an up-close, in-depth, and detailed examination of a subject of study (the case), as well as its related contextual conditions. Case studies can be produced by following a formal research method. These case studies are likely to appear in formal research venues, as journals and professional conferences, rather than popular works. In doing case study research, the "case" being studied may be an individual, organization, event, or action, existing in a specific time and place. Case study research can mean single and multiple case studies, can include quantitative evidence, relies on multiple sources of evidence, and benefits from the prior development of theoretical propositions. A field of applied statistics of human research surveys, survey methodology studies the sampling of individual units from a population and associated techniques of survey data collection, such as questionnaire construction and methods for improving the number and accuracy of responses to surveys. Survey methodology includes instruments or procedures that ask one or more questions that may or may not be answered.

Researchers carry out statistical surveys with a view towards making statistical inferences about the population being studied, and such inferences depend strongly on the survey questions used. Polls about public opinion, public-health surveys, market-research surveys, government surveys and censuses are all examples of quantitative research that use survey methodology to answer questions about a population. Although censuses do not include a "sample", they do include other aspects of survey methodology, like questionnaires, interviewers, and non-response follow-up techniques. Surveys provide important information for all kinds of public-information and research fields.

A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical model is termed mathematical modeling. Mathematical models are used in the natural sciences (such as physics, biology, earth science, chemistry) and engineering disciplines (such as computer science, electrical engineering), as well as in the social sciences (such as economics, psychology, sociology, political science).A model may help to explain a system and to study the effects of different components, and to make predictions about behavior.

In pure mathematics, mathematicians seek and use patterns. formulate new conjectures; they resolve the truth or falsity of conjectures by mathematical proof. When mathematical structures are good models of real phenomena, then mathematical reasoning can provide insight or predictions about nature. Through the use of abstraction and logic, mathematics developed from counting, calculation, measurement, and the systematic study of the shapes and motions of physical objects.

Table 6. Categorization with respect to research methodology

Gas	Mathematical	Modelling	Case Study	Survey
Carbon Dioxide	3	8	6	3
Methane			1	
Nitrous Oxide				
Fluorine				
All	6	9	3	2
TOTAL	**9**	**17**	**10**	**5**

From Figure 5, General carbon emissions were the main gas for the papers that were studied in the categorization.

The gas was investigated 18 times which means the gas was investigated 50% of the time. And carbon dioxide was investigated 47% of the time. Methane was only investigated 6% of the time.

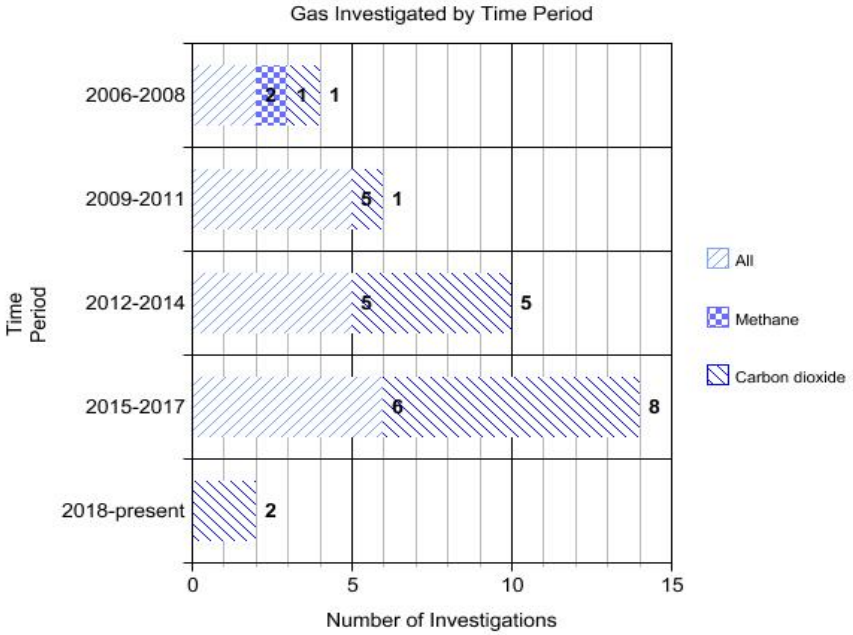

Figure 5. The greenhouse gas investigated in different time periods

The key issues investigated in the time period from 2006 to date were also examined. Earlier studies were more concentrated on carbon offsets and biomass and forest residues. From 2009 to 2011, areas such as electricity generation, inventory scheduling and photovoltaic cells. From 2012 to 2014, issues such as corporate responsibility and sustainability and carbon storage ad capture became interesting to many researchers.

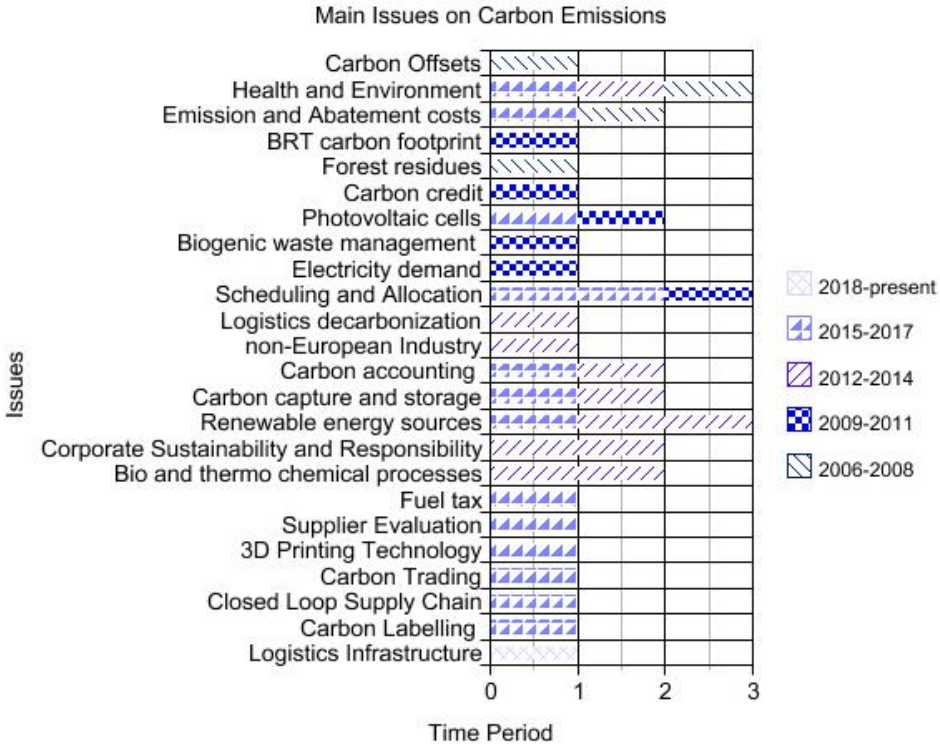

Figure 6. Main issues on carbon emissions investigated

The main issues that have been investigated in the period covered by this categorization were analyzed. The period that this categorization covered was 2006 to present. Most early researches were concerned with biomass and carbon offsetting. In the period from 2009-2011 issues of photovoltaic cells started gaining popularity. Supply chain scheduling and allocation, biogenic waste management and electricity with respect to Carbon emission reduction were starting to gain popularity with many academic researchers.

4. Conclusion and Directions for Future Research

This paper applied different techniques to explore the literature on carbon emission reduction. This technique requires that two or more methods are used to explore a subject which in this case is carbon emission reduction. Initial papers that have been written with respect to this field were written in the 1990s.Content analysis was used to categorize the existing literature based on diversified topics and methods used. In recent years there has been a rise in co-authorship of researchers. This is because certain countries have been increasing their carbon emissions in the past decades so the academics of these countries are coming together to develop strategies that can be used to reduce these emissions. Most of these early papers concentrated on issues such as measuring the effectiveness of policies, costs and electricity use. Policies such as restraining carbon emissions. Various contributions of the different factors to the restraint of energy use had to be analyzed. Some authors analyzed achievable cost-effective potential for reducing carbon emissions in various sectors. Some analyzed the impact of activity, structure and energy intensity on carbon emissions in the service sector. Some of these co-authorship examples have led to some authors collaborating with more than ten authors which is a huge step towards solving carbon emissions issues firstly in their region and subsequently in the whole world. Examples of these diversified topics that have been heavily looked at are health and environment, carbon capture and storage, scheduling and allocation, renewable energy and storage, carbon accounting and corporate sustainability and responsibility. Carbon emissions are known to impact human health by unintentionally poisoning thousands of people globally each year. The carbon capture and storage technology is estimated to capture up to 90% of carbon dioxide emissions produced from the use of fossil fuels in electricity generation and other processes. This is possible through the separation of carbon dioxide from electricity generation by means of a pre-combustion capture, post-combustion capture and oxyfuel combustion.

The area aims to identify sections that deserve further research attention and build future research areas for carbon emission reduction. From the diagrammatic representation of the most commonly used keywords with respect to carbon emission reduction, some of the most commonly used keywords were emission control, carbon, greenhouse gases which are obviously related to carbon emission reduction and which also show that currently a lot of research is being done which is relevant to the current research area. However, there are areas that have been explored on a very little basis such as cap and trade, effect of carbon emission on commerce, manufacturing and profitability, life cycle, environment, carbon taxes. These are some of the areas that can be explored with respect to carbon emission reduction.although carbon dioxide is the most commonly known cause of carbon emission, it is wise to start investigating all other greenhouse gases on an individual basis,all these gases are culprits in global warming. Some of the gases that can be studied are methane which results from the decay of organic waste in landfills.

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