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Chapter

Green Technology Innovations Development in China: Trend and Application

Xiaodong Lai

Abstract

This chapter aims to explore what subjects have been addressed in green technology innovation (GTI) in China and initiate a journey for the next generation of sustainable-oriented research. Thus, the work examined the literatures enlisted in the database of China National Knowledge Infrastructure (CNKI) on the topics of GTI from 1994 to 2019. Some critical discussion and conclusion are sighted as follows: (1) the research of GTI in China is getting mature compared to the energy-innovation related topics and the researches 10 years ago. It is becoming a dominated research subject. (2) The qualitative publications dominates the researches, the empirical researches are in a shortage. (3) The research subjects are multi-perspective and multi-disciplinary, covering environment science, management, energy and fuels, economics and social behavior. New vibrancy of advanced theoretical and methodological research is particularly needed. (4) The trend of green technology research appears an interdisciplinary research with the themes related to environmental subject, science technology, business economics, engineering and energy & fuels. (5) Different policy implementations have different effects due to the cost structure and maturity of renewable energy. (6) GTI cannot be isolated from the policy or regulation regime, and is becoming a new underpin of current sustainable development in China.

Keywords: green technology innovation, technology innovation, management, sustainable development

1. Introduction

The global warming, frequent natural disasters and resource shortage occurred in the twenty-one centuries are forcing people to excogitate a new way to save our earth. Many countries are focusing on the development of low carbon economy or green economy. The development with green technology innovation orientation and policy regulation to drive an energy evolution and the establishment of a new economy development with less GHG emission are acknowledged to prolong the climate change [1].

In order to understand the past, present and future with regard to the technology innovation in green research and practice in China, a typical emerging country

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in Asia, this chapter took the source of primary database of China National Knowledge Infrastructure (CNKI)[1] as a particular intellectual domain for analysis. The purpose of this article tries to provide with facts that help researchers and practitioners understand what issues or subjects have been addressed in green technology innovation and anchor the trends for the next generation of sustainable-oriented research.

The remaining parts of this article are divided into four sections. In section two, the methodology and search selection are presented. In the third section, the analysis of the literatures by classifying them into different types is conducted. In the fourth section, an extensive detail study on the international research themes of green technology innovation is presented, and to a further step. A brief discussion with conclusion is given in the last section.

2. Methodology and search criterion

Through our exploration of the literature reviews within the domain of social energy system and sustainable development, we found that the literature review from the perspective of low carbon-oriented green technology is very few [2]. Carbon emission problem is becoming a serious issue right now, which is threatening the welfare of human beings. The research on carbon emission problems is being the mainstream in the existing green technology research. Therefore, this paper continue the research exploration as paper [2] but focus on the development trend in China to further invest the research status of green technology innovation after 10 years.

This article employs a methodology to reviewing the articles cited in the databases "CNKI" with "green technology innovation" as the "topic." The earliest published article related to green technology innovation topic appeared in 1994 [3]. By pulling all the articles from 1994 to 2019, 2014 articles are identified that fell within the domain of our topic "green technology innovation". Eleven overlapped article has been omitted, we has an overall glanced over for all the retrieved publications, and removed the reports, notices, announcements, conference summaries, exclusive interview, laws or regulation introductions and some researches with no green technology innovation involved, we also deleted some anonymous researches or some companies' green technology introductions. In addition, by scanning the titles and the abstracts of each article published from 1994 to 2019 and using related keywords for double review, it was found that 1348 articles mainly focus on our themes of "green technology innovation", thus, 1348 articles are kept as the research sample. Considering the searching engine objective problem, some articles with such subject may not 100% be retrieved, Therefore, this paper modestly believed that this approach was likely to have presented nearly every related article in these two databases.

It should be noted that, we cannot possibly provide a truly comprehensive review for all the articles, especially for those in a particular research field, e.g. chemistry and

[1] CNKI: CNKI project started with an e-journal product and later further expand the product line to cover newspapers, dissertations, proceedings, yearbooks and reference works and etc. CNKI is a symbol of Chinese e-publishing industry, which greatly boosted the Chinese library systems to go digital and helped researchers with their work. So far CNKI academic databases have been serving more than 5500 universities, public and corporate libraries, hospitals and other institutions inside and outside of China.

eco-biology field. However, we do feel that many of the interesting insights arise through a detailed review of these articles. In our research we organized the articles with six different approaches by (1) period sequence, (2) research methods, (3) research level, (4) research subjects, (5) keywords cluster, (6) Institution, (7) Foundation, and (8) themes of articles (this is separately analyzed in the fourth section).

With the above approaches used in this article, this paper is trying to propose an indication of the trend of green technology research and help the readers to understand the milestone throughout the development of green technology innovation. It can also serve the on-site practitioners to understand the research trend in China.

3. Overview of the literatures from the database of CNKI

3.1 Publications classified by period sequence

Firstly, the raw data retrieved from the database of CNKI with timelines and publication quantity shown in **Table 1** and made a time series bar graph in **Figure 1**. It shows the yearly publication distribution in the field of green technology innovation each year. Obviously, in the period from 1994 to 2000, there were a few articles related to green technology innovation published internationally. Only 50 articles appeared per our review. However, in the period from 2001 to 2005, it was 176 articles, three times more than the previous. Late on, in the period of 2006–2010, a dramatic increase of information consisting of 251 articles, it remains a steady publication increase as well as green concept are recognized by the public, and the QTY increased by 922 publications in the period of 2011–2019 as of 7-31-2019.

It can be seen from the above trends that the academic field is paying more and more attention to the innovation of green technologies. It indicates that the new research areas of green technology innovation mainly focus on technology development and model innovation. The new trend that focuses on technology development represents the new requirements of the modern society for the innovation level, that is, the hard demand for new technology development to improve the relevant industry benefits. The combination of academic research and social production is more closely integrated.

3.2 Publications classified by research method

A further review of these articles from the research method perspective was conducted. Referring to the literature of Shi and Lai [2], we divided the research methods into four categories: conceptual, model, empirical and qualitative methods. Here we only explore the articles cited in databases "CNKI" and selected the high cited articles and hot articles from them. In this way we got 1346 articles for analyzing. **Table 2** and **Figure 2** shows the distributions of those articles across conceptual, model, empirical and qualitative methods in every 5 years and the total quantity from 1994 to 2019 per each method. It can be seen that the model articles have gained 18% and the empirical articles have gained 15%. While the conceptual account for 49%, and the qualitative method occupies 18%, both achieve 67%. It indicates that the green technology innovation in China is still at a developing stage and the method of model and empirical are not adequate. It needs to encourage researchers to use data and models for better illustrating the relationship between elements in order to adapt to the needs of green technology development.

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
QTY	2	1	3	5	12	13	14	26	32	32	37	49	26	61	53	38	73	45	64	71	82	96	164	150	172	78

The cut-off date for the above data is 7-31-2019.

Table 1.
Literatures publication status on green technology innovation from 1994 to 2019.

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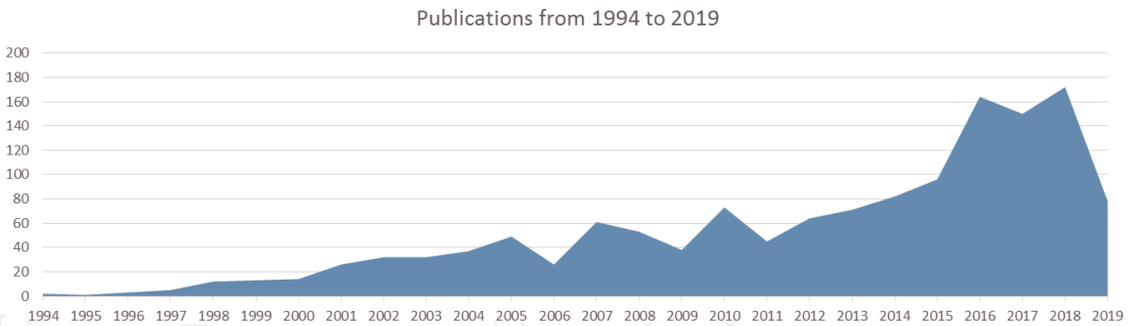


Figure 1.
Literatures on green technology innovation publication status from 1994 to 2019.

Types	1994–1998	1999–2003	2004–2008	2009–2013	2014–2019	Total	Rate
Empirical	1	2	10	35	154	202	15%
Qualitative	6	17	40	75	109	247	18%
Conceptual	26	86	188	149	210	659	49%
Model	1	6	8	35	188	238	18%
Sub-total	34	111	246	294	661	1346	

Table 2.
Percentage distribution of literatures by research methods in every 5 years.

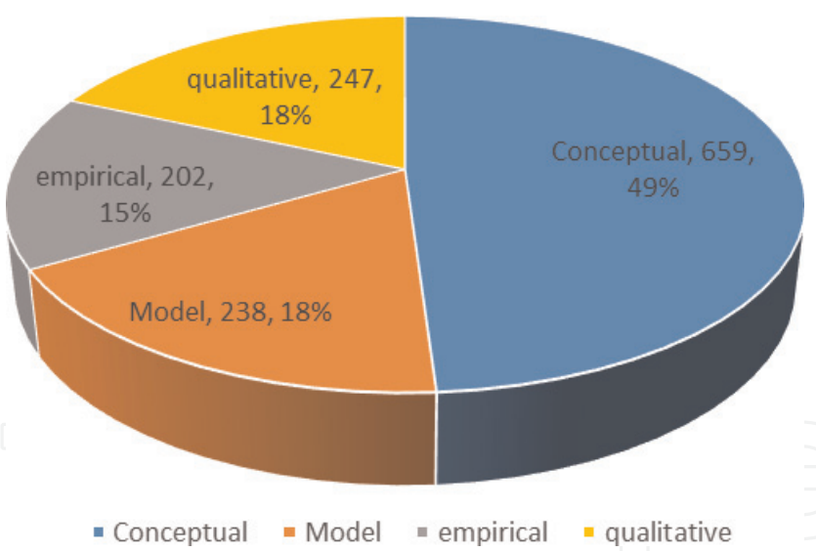


Figure 2.
Percentage distribution of literatures by research methods.

In fact, the model method can help apply the technology innovation influence on practice. The most representative publication using formal model method is Zhang and Zhu [4], the paper chooses productivity of resources and environment loads as output variables, and develops an empirical study using four-stage DEA model to analyze technological innovation efficiency of industrial enterprises, result suggest that the environmental factors are conductive to the technological innovation efficiency. It has been cited more than 162 times as of July 31, 2019. The other four publications with higher citation are Xu et al. [5] (109 times citation), Zhang and Qiu [6] (85 times citation), Qian et al. [7] (74 times citation) and Luo and Liang [8] (68 times citation).

The empirical research method is a powerful way to analyze the relation of different factor. For instance, Li. et al. [9] uses none radial and none angle SBM efficiency measurement model considering the undesirable outputs, combined with the ML productivity index to measure the efficiency of green technology and green total factor productivity of industry, which gains 283 times citation as of July 31, 2019, which is the highest citation publication so far. Another three authors [10] use empirical research method to analyze the relationship among market demand, green product innovation, and firm performance. In addition to technology adoption and field experiments in different industries, the empirical method is used to research the impact of low carbon technology policies and the application of low carbon technology in the market. There are four typical representative publications with higher citation (over 60-time citation), namely, Chen [11] (111 times citation). Chen et al. [12] (86 times citation), Li, et al. [13] (76 times citation) and Wang and Zhu [14] (64 times citation).

The qualitative research of green technology innovation focuses on the technology introduction, adoption and green path discussion. For example, Guo [15], a literature with more than 125 times citation as of the end of July, it believed that ecological industrial park is a concrete path to the realization of the sustainable development of industry economy and the most ideal model to realize the sustainable development of whole society. Dai and Liu [16] thought that green innovation in China sustainable development need the driving forces from demand, institution and technology innovation, an environmental innovation system from national perspective is needed. It gains 93 times citation as of July 31, 2019, the other representative articles are Wu and Yang [17], Chen [18] and Hua [19].

The research employed a conceptual method to introduce green technology concept from different perspectives such as innovation concept, new technology application, policy and etc. For example, the representative authors Qin and Yang [20] introduced Xi JinPing's theory of green development on the basis of the worldwide trend of green growth. It includes the following aspects: transforming the economic development mode poses the premise to realize the green growth; developing recycling economy is an important means of promoting it; improving green technology offers technical support for it; handling with the relation between developing economy and protecting ecological environment is a basic requirement for promoting it; advocating green consumption is the important way to promote it; improving the living environment for the people is the ultimate goal for China to choose it. Xi's thought of green growth is of great theoretical and realistic significance for China green development. As of July 31, 2019, this article gains more than 106-time citation. Zhong and Wang [21] thought that green technology innovation is an effective method to resolve the contradictions between enterprise economic development and environmental deterioration, and proposed related recommendation on the establishment of green technology innovation system, this article has been cited with more than 97 times as of 2019. Another two outstanding representative articles are Xu and Wang [22], Zhao [23], these articles introduce the latest development in green technology innovation.

From above analysis, we can see the green technology innovation in China is still under development stage, the conceptual and qualitative methods researches dominate in quantity for quite some time, while the model and empirical researches need more practice and employment.

3.3 Publications classified by research level

We reviewed all the articles' main contents based on the abstract descriptions. For the analysis purpose, we took the research level code scheme based on

Schumpeter's micro-meso-macroeconomics definition [24], and classified the research level as "macroscopic, mesoscopic and microscopical". For the articles regarding policies, regulations, national mechanism, national ecosystem, global comparison, concepts and sustainable development etc., we coded them as a macroscopic level. While for the articles involved with the country or territory's economy development, the country or territory's technology adoption and diffusion, national policy or technology promotion, regional economic development or technology adoption, and etc., we coded them as the mesoscopic level. For the articles involved with concept, basic research, product design, risk management, empirical research, models, entrepreneurship innovation, and technology innovation capability, we coded them as the microscopical level.

Figure 3 shows the distribution of the different research levels, macroscopic research level gains 54%, the research related to national policies, including the impact of different policies on different technological innovations, the assistance of policies to renewable energy technologies entering the market and so on, are all gained much attention by the Chinese scholars. The top five cited articles of this level are Guo [11], Zhao [25], Chen [18], Zhou [26], Li and Yang [27] mesoscopic research level are keeps 11%, the themes related to the impact of green revolution on industry and territory, including the acceptance of green economy and new technologies in society, the efficiency of new technologies in some industries and so on. For example, Lin et al. [28] analyzed the green technology innovation efficiency of China's manufacturing industries. Wang et al. [29] discussed the green development strategy in Peal River Delta of China, and Luo and Liang [8] studied the regional industrial enterprises green technology innovation efficiency and factors decode. You and Wang [30] verified the environmental regulation effectiveness on R&D bias of strengthening the green technology.

Microscopic research level are keeps 35%, this phenomenon reflects that current researches still focused on specific and concrete aspects, especially the technology innovation and most of them are about the application of new technology in the firms and environmental improvement. Most of the articles in microscopical level are about the inventions of new technology and method, including the technique of detecting chemical substances, improvements in technologies and so on. Typical representative articles are Wang et al. [31], Wang and Li [32], Zhang and Li [33], etc.

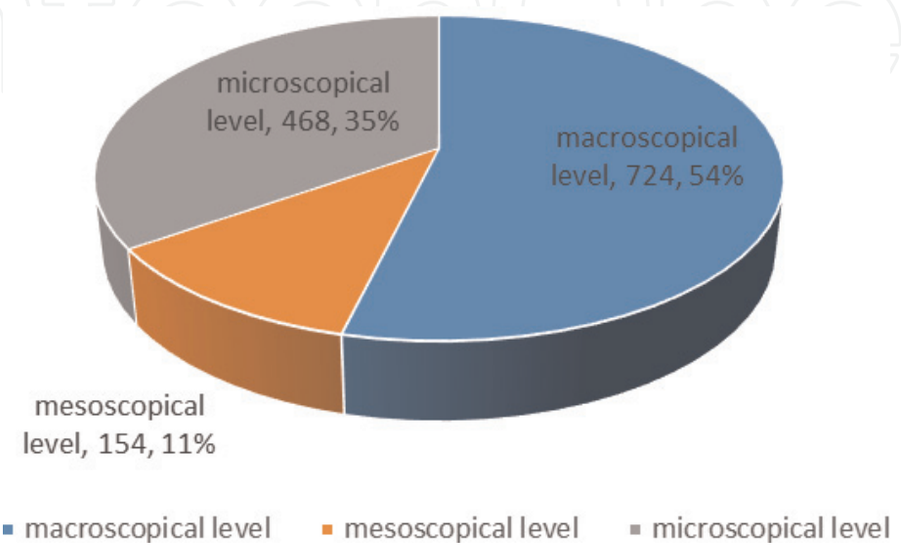


Figure 3.
Literatures on green technology classified by research level.

3.4 Publications classified by research subject area

We classified these 1346 articles per research subjects. Based on the original analysis chart downloaded from the CNKI data base, it has total 32 research subjects involved with green technologies. Some of the articles are multidisciplinary, for example, Cao and Zhang [34], Li [35], Zhang et al. [36], Zhang et al. [33]. In order to have a better understanding about the actual classification, we consolidated the overlapped research subjects. For the subject with one article, we put it into the "others" portion for the subject with less than 10 publications, we simplified and showed them in **Table 3**.

From **Table 3**, it can be seen that the distribution of research subject are: green technology innovation (301 articles, 21.41%), enterprise management (183 articles, 13.02%), green technology (111 articles, 7.89%), technology innovation (75 articles, 5.33%), sustainable development (72 articles, 5.12%), green innovation (70 articles, 4.98%), China (64 articles, 4.55%), sustainable/green consumption (58 articles, 4.13%), environmental regulation (55 articles, 3.91%), green development (51 articles, 3.63%). The rest of the articles' distribution is shown in **Table 3**.

The trend of green technology research appears an interdisciplinary research with the topics related to environmental subject, science technology, business economics, engineering and energy & fuels, which are accounting for 83% of the total. It is worth mentioning that the research articles of the top two areas–environmental sciences ecology and business economics are much more compared with other industries, the top five areas in the review of paper [2] is about for 67% of the total. In a word, the trend in the interdisciplinary field remains unchanged but with the increase in social participation, it is relatively concentrated in several subject areas (**Figure 4**).

Subject	QTY	Rate of 1346 (%)	Subject	Qty	Rate of 1346
Green technology innovation	301	21.41	Ecological civilization	39	2.77
Enterprise Management	183	13.02	Green building	25	1.78
Green technology	111	7.89	Green industry system engineering	22	1.56
Technology innovation	75	5.33	Greenization	22	1.56
Sustainable development	72	5.12	Green construction	20	1.42
Green innovation	70	4.98	Environmentally conscious products	19	1.35
China	64	4.55	Green barrier	18	1.28
Sustainable/green consumption	58	4.13	Fiscal management	18	1.28
Environmental regulation	55	3.91	Green transformation	17	1.21
Green development	51	3.63	Influence factor	15	1.07
Ecological or green economy	51	3.63	Green marketing	15	1.07
Circular economy	46	3.27	Others	39	2.77

Table 3.
Literatures on green technology classified by research subject.

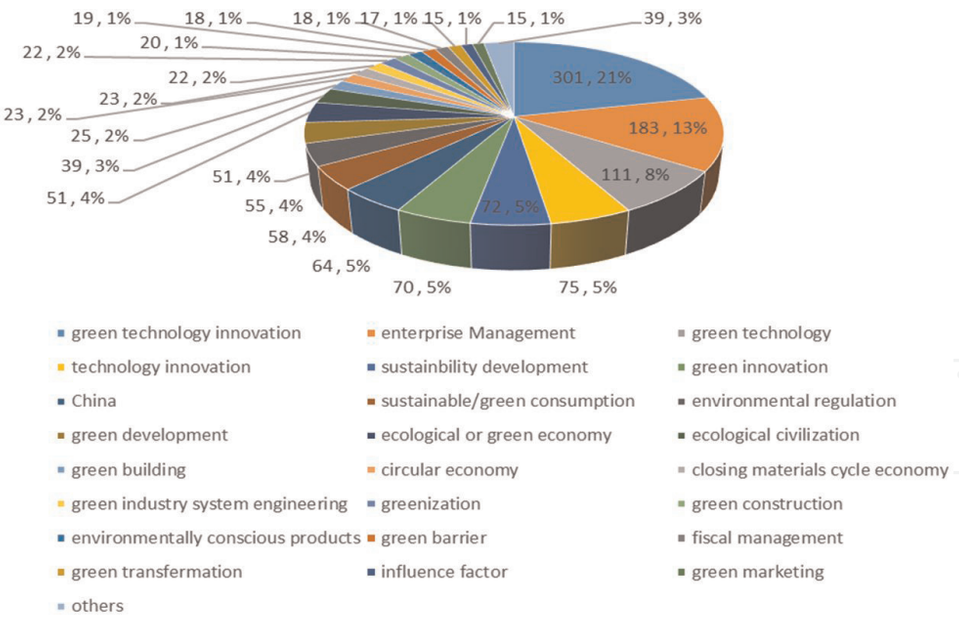


Figure 4.
Literatures on green technology classified by research subject.

3.5 Publications classified by keywords cluster

Based on the above research subject area, we seek further at the research trajectory of scholars from keywords cluster. Firstly, we searched core journals with the theme of "green technology innovation" in CNKI database and found 2014 relevant literatures[2]. Then, we imported the data into Citespace for keyword co-occurrence analysis, obtained the atlas, and sorted the keyword frequency into a table. As can be seen from **Figure 5** the keywords with high frequency are "Innovation", "Technology", "Policy", "Sustainability", "System", "Performance", "Management", "Energy", "Climate change", "Model" etc. We decided to further analyze them.

Technological innovation-related keywords gain highest occurrence frequency. In recent years, energy shortage, climate change, environmental degradation, green economy, low carbon and other phenomena have made people more aware of the

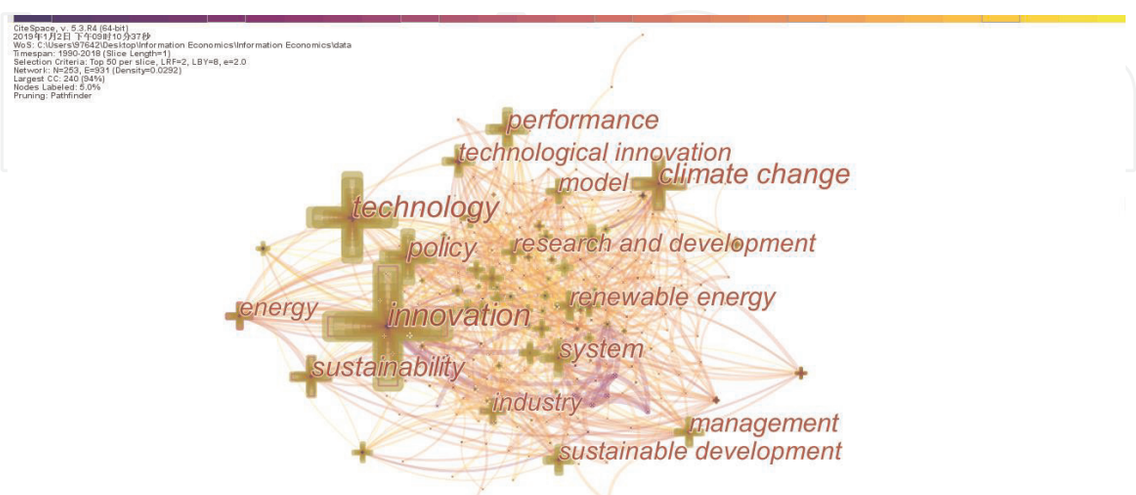


Figure 5.
Keywords cluster with occurrence frequency.

[2] Here, the authors didn't screen the publication as above mentioned 1346 article.

importance of sustainable development, and technological innovation is an important driving force for sustainable development. Chinese government conducted various policies and adjusted industrial structures to promote green innovative development of technologies, management and institutions, improve the efficiency of energy consumption, and support green innovative activities. For example, the renewable energies [37] like new energy [38, 39] biotechnology, solar energy, water and other green energy, the green innovations in process control, workmanship [40, 41] or construction method [42], those are the key areas for our researcher to explore and develop.

3.6 Publications classified by institution

We categorized the 1346 publications according the institution/organizations with a time series. Related results are shown in **Figure 6**, it can be seen that the top institution is Zhejiang University who gains 36 articles, the second one is HUST (Huazhong Science and Technology) with 35 articles, then Northeastern University, Harbin Engineering University of Science and Technology and Kunming University of Science and Technology. There are 30 institutions total with above 10 articles contribution, and most of the institutions are science and technological universities or comprehensive universities with technological and environmental subjects. Those institutions with high publication are supported by the National Nature Science Found and Social Science Found.

3.7 Researches in international journals by Chinese scholars

It is known that the setup of green technology innovation is from the western's countries like European and American counties, who dominated the technologies and energy consumption at the beginning, then turns to share market of developed countries and developing countries. Share of developing countries escalates and develops, China is one of the most powerful countries among them. However, with the high-speed development of economic and social development, technology innovation changing rapidly and increasing living standards of people, the consumption and waste of energy resources are continuously compounded as well. As the biggest developing country, China has the biggest environmental protection market in the world, thus, this paper also screened the international publications written by Chinese Scholar. **Table 4** presents 10 documents originated from Chinese scholars by browsing the theme of green technology in web of science, an international database for worldwide researchers. It can be seen that green innovation research themes of Chinese scholars mainly concentrate on fields related to

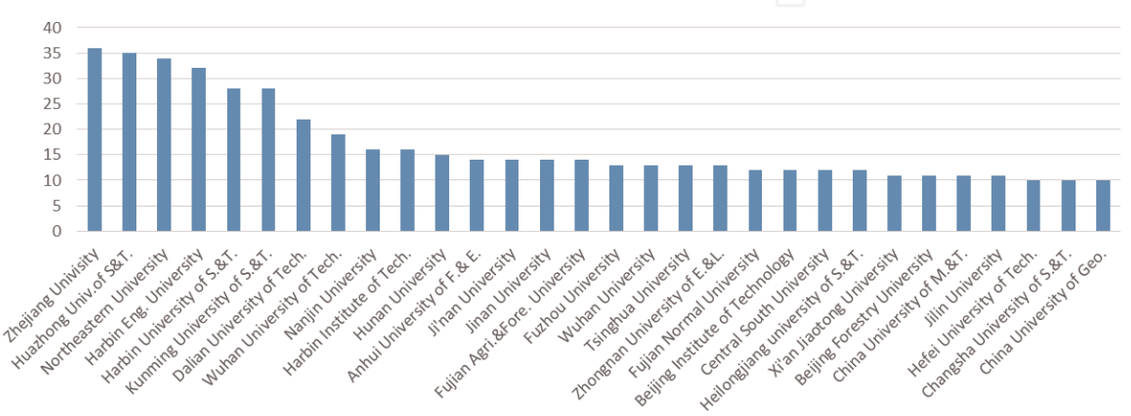


Figure 6.
Green technology publications per institution.

Code	Headline	Author	Subject theme	Method
1	Sustainable energy development and climate change in China [43]	Ren, Zeng, Zhou	Environment and ecology	Qualitative analysis
2	Integrated management for renewable energy resources and CDM resources: A case study [44]	Jing, Mingshan	Business and economy	Case method
4	Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions [45]	Ou, Zhang, Chang	Energy and fuel	Modeling method
5	Study on China's low carbon development in an Economy-Energy-Electricity-Environment framework [46]	Hu, Yuan, Hu	Energy and fuel	Qualitative analysis
6	Network Environ Perspective for Urban Metabolism and Carbon Emissions: A Case Study of Vienna, Austria [47]	Chen, Chen	Engineering	Modeling method
7	Influence of household biogas digester use on household energy consumption in a semi-arid rural region of northwest China [48]	Ding, Niu, Chen, Du, Wu	Energy and fuel	Investigation method
8	An optimization model for renewable energy generation and its application in China: A perspective of maximum utilization [47]	Cong	Energy and fuel	Literature method
9	A review of clean energy innovation and technology transfer in China [49]	Liu, Liang	Energy and fuel	Literature method
10	A review of China's approaches toward a sustainable energy future: the period since 1990 [50]	Zhu, Zhuang, Xiong	Energy and fuel	Literature method

Table 4.
Document researches in selected national journals by Chinese scholars.

energy, fuel, commercial economy, environmental sciences, engineering and so on, while researches on the theory exploration and management level of energy development have not embodied yet. The Chinese scholars' publications in international journals are less than in the developed countries or regions, but more than the publications from other developing countries.

4. Publications classified by major themes

Our main subject discussed here is for the articles related to green technology innovation, which is more specific and concise restrict in green field than the normal innovation. However, this subject also has the similar area applied to product innovation, technology innovation, technology transfer, technology diffusion, regulation or policy innovations, innovation abilities, even the innovation to the individual firms or organizations. This is a little different from the subject category Based on the characters of green technology innovation, we decompose the broader subject and code the research themes of green technology into seven themes. This is taken the reference of the article by Shane and Ulrich [51] with some modification: (1) regulation or policy innovation, (2) technology innovation adoption & diffusion, (3) technology transfer, (4) technology innovation capability, (5) basic research and advance development, and (6) Entrepreneurship innovation (see **Table 5**).

We went over all these 1346 articles' abstract contents and categorized the articles based on the above code scheme and screened some similar publications.

Major themes	Sub-themes
1. Regulation or policy innovation	1.1. Effect of innovation on economic growth
	1.2. Factors influencing the rate of innovation
	1.3. Tools used by policy maker
	1.4. Impact of specific policies
2. Technology innovation adoption and diffusion	2.1. Pure technology Introduction
	2.2. Technology adoption method introduction
	2.3. Technology diffusion introduction
3. Technology transfer	3.1. Patent
	3.2. Learning
	3.3. Technology spillover and policy impact
4. Technology innovation capability	4.1. Management innovation
	4.2. Design innovation
	4.3. Process innovation
	4.4. Organization Innovation
	4.5. Innovation assessment
5. Basic research and advance development	5.1. Conceptual/theory
	5.2. Review
	5.3. Framework/models
	5.4. Driving mechanism
	5.5. Risk innovation and management
6. Entrepreneurship innovation	6.1. Green design strategy
	6.2. Innovation efficiency
	6.3. Innovation behavior

Table 5.
Major themes and sub-themes code scheme with the domain of green technology innovation.

69% articles are discussed the theme of regulation or policy innovation, 14% articles were involved with the theme of policies. 3% percent of the articles are discussed with the theme of technology adoption and diffusion. The articles contented with the theme of technology transfer gained 6%. While the articles conducted with the theme of technology innovation capability occupied 6% either. The rest 2% fell on the theme of entrepreneurship Innovation. Detail distribution is shown in **Figure** 7. A further detail analysis by different themes category was illustrated in the Section from 4.1–4.6. For research purposes, we also extended some authors literatures involved in this type of theme from the deeper perspective and across research perspective instead of more than 1346 articles only we stated.

4.1 Regulation effect on green technology innovation

The theme of regulation or policy is one of the main and traditional research areas of technology innovation. It has a critical impact on innovation theory development. We classified the articles which related to policy into four categories the effects of innovation on economic growth, factors influencing the rate of innovation, policy tools used by policymaker and the impact of specific policies.

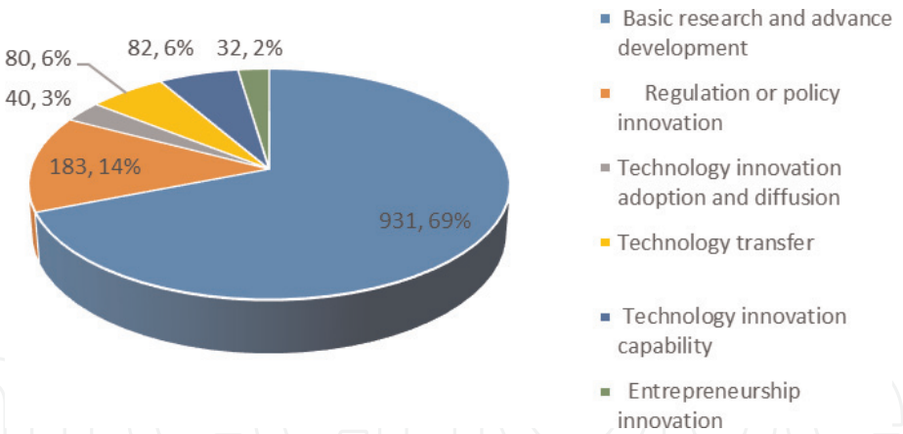


Figure 7.
Publication on green technology innovation classified by themes.

It has 48 articles involved with the effect of innovation on economic growth, there are some typical articles like Hou and Su [52], who firstly studied the green barriers effect to the exported industrial technological innovation. Peng and Sun [53] explored the challenges and strategic solution for the green economic development in China. Li et al. [9] reviewed the environmental regulation effect to the total factors of green production efficiency improvement. Feng et al. [54] discussed the relationships among the regulation difference, innovation driven and economy development in China and put forward the related recommendation regarding the effect of regulation. Xu and Zhen [55], Pei et al. [56], both publications explored the effectiveness of regulation on the economy development in Long River Belt in China. Wu and Yu [57] had a further study regarding the environmental regulation impact on the production efficiency improvement and technology innovation.

71 articles studied the factors influencing the rate of innovation. Li [58] and Gao and Wang [59] conducted the green innovation efficiency of high energy consumption industries in Jing-jin-Ji district from a special perspective for China industries development. Yang et al. [60] discussed the green innovation impacts in China and pointed that the regulation factor is one of the critical items for green development. While the rate of innovation is multiple [61, 62].

Six articles discussed the tools used by policy maker, the representative authors are Li et al. [63], Wang et al. [64], Wei [65] and Shi [66].

The theme of impact of specific policies has 59 articles, most of the publications are concentrated on the environmental regulation effect on the green innovation performance or green economic development. The most outstanding articles are Zhang et al. [67]; Li et al. [68]; Xu and Wang [69]; Francesco et al. [70]; Zhang and Qu [6]; Xu et al. [5] and Wang [71].

Throughout the above articles review, it can be seen that the effects of different policy implementations have different effects due to the different cost structure and maturity of renewable energy. The innovation of green technology can be induced by policies. The feed-in tariffs are relatively more practical. By controlling the relative price of the alternative factors, the demand factors, general scientific ability, the after controlling the relative differences in the economies, the patents tendencies, the number of patents was used as a measure of innovation ability.

4.2 Technology innovation adoptions and diffusion

The theme of technology innovation adoption and diffusion is the major impressive body research of green technology innovation for our researchers. A total of 93 articles explored this theme. We divided the theme into three

sub-themes: pure technology introduction, technology method or theory introduction and technology diffusion introduction.

Several articles introduced the pure green technology adoptions in different fields such as Hong Kong-Zhuhai-Macao bridge construction, green building, oil and mine industry etc. [72–79]. These articles are good representative example for green technology adoptions in China.

Technology innovation and diffusion theories are discussed and extended. Yun and Lee examined key factors of renewable energy systems diffusion from a socio-technological perspective [80].

The technology adoption theory with empirical application based is also one of the key research themes. E.g., Zhou et al. [81] investigated a specific example of a demonstration project in China to support the large-scale diffusion of green technology and its pilot implementations and revealed that these demonstrations face a different set of diffusion barriers. Zhu et al. [82] studied Chinese manufacturers GSCM adoption practices to see if this adoption affects their performance or not.

The themes about the technology diffusion policy were recommended with the theoretical and empirical analysis in several articles which cover innovative green procurement [83], mechanisms that can accelerate the technology diffusion [84–87].

The above exploration shows that people take great efforts on the real actual experiment and achievement in the adoption of the green technology, such as the sample survey, case study or fields study with primary data. The typical research articles are influential, for example, Zhu and Sarkis [88]. gained more than 108 times citation up to now. "The models that underlie much of the diffusion literature have their roots in physical diffusion processes". Green technology innovation diffusion takes leading the regional economic development, they save the energy with low CO_2 emission or zero-energy emission.

Furthermore, this review provides the information that the researchers' focus is within new energy introduction, renew energy development, new methods, new process improvement and even new conception or culture implantation. This is a new trend of green technology development.

4.3 Technology transfer

When introducing the technological track of the green revolution, Liu and Liang [88] explores potential policies and schemes promoting the transfer of CCS technologies to developing countries, then makes an attempt to understand technology transfer including its benefits, barriers, and definition. Ai et al. [89] studied the impact of various technological progress patterns on China's regional environmental performance using spatial econometrics and find that there are significant spatial effects of technology innovation, technology transfer on China's regional environmental performance. Liang and Luo (2019) studied the dynamic effect analysis for international R&D capital output to green technology [90].

The realization of technology transfer in green revolution is influenced by many factors. The process of green technology transfer needs to take full account of the capacity of enterprises and the policy support systems. At the same time, the increase of independent innovation capacity will play a positive role in technology transfer. From the perspective of historical development, in the environment of rapid improvement of independent innovation ability and intensified international competition, the transfer of green technology in developed countries will have a more positive impact on developing countries. Developing countries should also try their best to improve their technology adaptation level and absorptive capacity to accept the technology transfer of the green revolution in a proactive manner.

4.4 Technology innovation management and capability

The theme of technology innovation capability is a little broad. For analysis like the one cited above, we divided it into four sub-themes such as the innovation research of management capability, design capability, process control capability and organization innovation capability.

Six articles argued the innovation management concept related to green technology innovation. For example, Wu [91] discusses the relationship between green supply chain integration (GSCI) and green innovation and pointes that, in order to improve green innovation performance, managers should strive to integrate resources and capabilities among their organizations, suppliers and customers. The managers should constantly pay attention to market demand trends and maintain a close technical network between supply chain partners.

The design method innovation is also a critical research theme in technology. Six typical articles presented herein are very useful for our practitioners to study. Song and Yang [92] reviewed the relations between the financial performance and green innovation, and pointed that green capabilities are much related with the aid of finance. Han and Yan [93] explored how to the innovation capability impact the enterprises value-adding. Li et al. [68] analyzed the relationship among the environmental regulation, R&D investment and enterprises green technology ability. The rest of articles are Li et al. [94], Hua [95] and Liu et al. [96].

Regardless of the technology innovation itself, the subject of process innovation is also well-accepted by our researchers, particularly in the big construction induction of green innovation, e.g., Fu [97] proposed that environmental regulations and corporate characteristics are the most widely studied factors affecting the adoption of sustainable process technologies.

Organization innovation is another sustentation on green technology. It has three sub-themes such as the effort of organization structure, communication patterns and decision making. Only a small number of typical articles relate to the impact of organizational innovation on green technologies technology innovations.

The above analysis provides a possible direction for us that the effectiveness of innovation does not only depend on the technology but also depend on the related responsible stakeholder concept of innovation and its capability across with the management, organization and process innovation. Based on the deep research, it can be caught that, the capacity innovation, ecological innovation, leadership, and technology trajectory will all become important factors influencing green technology innovation. It is a result of core team cooperation and there are a lot of potential in this area for researching.

Through the above literatures, it was sighted that the research of green technology innovation in enterprise management gradually turns from the macro aspect to the micro aspect. After analyzing the green macro strategy of enterprises, scholars begin to pay more attention to micro factors such as enterprise organization, system design and innovation ability. Meanwhile, government policies are becoming an important influencing factor of low-carbon economy and green economy, and the direction of future research.

4.5 Basic research and advance development

The Basic research and advance development theme involved the topics of concept or theory, reviews, framework/models, driving mechanism, risk and innovation management. 697 articles discussed the basics research with the themes of conceptual or theory introduction, most of the articles discussed the concept of green technology innovation and the reason why need develop green economy in

China. [53, 98–100] but it needs to pay attention the green innovation system platform construction such as consumption mode [101], innovation system [102, 103], policy supporting system [104, 105], law system [106] and green cultural system [107, 108].

43 articles are reviews and comment on the green technology development, literatures review, trend and forecast discussion in China. Typical articles are Guo and Zhang et al. [109], it pointed out that the "environment-economy" development science and technology is a big dilemma in the process of sustainable development in various countries. It needs to clarify the impacts among the environmental regulation and governmental R&D funding and green technology innovation and study the function of promoting or suppressing. Wang [110] thinks that the technological innovation generated by environmental policy is the key for China achieving its long-term green development, the market driven force for environmental-friendly innovation activities is lacked, whereas environmental policy can provide motivation. Li and Yang [111] employed an analytical framework proposed by Astley [112], who developed a systematic, coherent analysis on the level, phase, theme and depth of domestic green technology innovation literature, and summarized the characteristics of research and calculated the trend of green technology innovation research by connecting it with the time dimension. Wang [113] summarized the external factors and internal determinants of enterprise competitive advantage from the perspective of regional innovation milieus and green technology innovation and pointed that green technology innovation is the internal factor of enterprise competitive advantage, it is an important part of enterprise internal environment. But with multi factors driving [114].

172 articles studied the theory framework and models of green technology innovation development. The main topic of the theory framework are within the scope of regulation effect to the green technology innovation [115–118], innovation system, the relationship among green technology innovation, industrial agglomeration and ecological efficiency [119, 120]; Li, Peng and Ouyang [9] thought that environmental regulation has an effect on the transformation of China's industrial development mode through green total factor productivity, but there exists the "threshold effect" of environmental regulation strength.

43 articles reviewed the driving mechanism of green technology, Vicky [121] alternative policy mechanisms based on a simulation for green technological innovation, Yu [122] proposed a combination of alliance for enterprises green innovation based on a business case study. Cao (2008) analyzed the interaction among the structure mode, operation mechanism and technology from a perspective of recycling economics, then pointed that that industrial structure transformation with technological innovation is critical. Zhang and Sun [123] conducted an economic-social-recycle system to explore the innovation efficiency mechanism based on an example in Han River eco-economic belt in Hubei Province of China. Guo et al. [124] studied the incentive mechanism for enterprise's green innovation implementation.

Only five articles paid attention on the risk and innovation management for green innovation in China based on the literature review, like Xu and Gu [125] reviewed the risk management for enterprises green innovation and proposed a system risk management framework. Li [126] studied the industry transformation between the western and eastern of China; Chen and Xie [127] employed an Bayesian network model to monitor the innovation for green buildings; Fang [128] pointed that, the eco-culture development need to pay attention on the risk of eco-development; Li et al. [129] identified the risks in manufacturing industry and proposed the related suggestion as well. All these articles have a good reference for the practitioners of the green innovation execution in China [105].

35 articles implemented the theme of Innovation assessment, some the articles focus on the assessment method [130, 131], five articles discussed the innovation ability assessment, the representative authors are Sun and Cao [132], Xie et al. [133] and Jia [134]. Seven articles explored the innovation efficiency assessment like Huang et al. [135], Sun et al. [136], and Zhang et al. [137].

4.6 The role of entrepreneurship innovation

The last theme of green technology innovation is the role of entrepreneurship innovation. We divided this theme further into four sub-themes: entrepreneurship green design strategy, enterprise decision making and individual achievement. We caught five articles appeared from 1994 to 2019 involved with the role of individual. Some outstanding articles presented below.

Xu and Zhang [105], Jiang [138], found that green entrepreneur orientation has a positive impact on the environment and financial performance. Xie et al. [139] surveyed the resources enterprises' green behavior and found that benefit is one of the critical items for the green activities' participants.

Through above articles' exploration, it is known that that entrepreneurship is one of the key players in the process of green and sustainable innovation. However, the technological innovations used in the cooperation are mainly cost-oriented.

Our detailed exploration of these articles is not very extensive. However, we are witnessing green technology innovations involving many different types of topics that are more complex than our normal technological innovations because their impact has a profound impact on people's living environment and all different lines of business. And it is significant. Some topics have changed over time, leaving a lot of room for our researchers.

The themes of entrepreneurship dominates within the scope of the different type of entrepreneurs based on the previous review by Shi and Lai [2] are multiple such as the social corporate responsibility, the decision effect of entrepreneurs on enterprise's green technology innovation, and the role of entrepreneurs in green economy development or society improvement. While based on the review in China, it is not enough, noted that our selection of research is "green technology innovation", it is different. Moreover, the enterprise participant is crucial for green development, scholars are encouraging to pay attention on the role of entrepreneurship and education in cultivating entrepreneurs' green entrepreneurship, which is a critical element of sustainable development.

5. Result and discussion

5.1 Insight from our exploration

Through the analysis of the articles in CNKI from 1994 to 2019, we have identified that, although the research topics of green technology innovation are varied, the main stream is focusing on the technology adoption, diffusion, transfer, policy recommendation, or implementation, and advanced technology development currently, which can be regarded as convergence out of divergence.

Based on the overall review for the publication from 1994 to 2019, we caught out that green technology innovation is getting mature compared to the energy-innovation related topics. It is becoming a dominated research subject coupled with social energy system innovation contributing to the green and sustainable development.

In the period sequence analysis of the articles, we have initialized that China is acting as an emerging star and its publications obviously higher with the times goes, this is helpful for our researchers to have a full understanding of green development roadmap and trend in China.

Just seen from the analysis in Section 3.2, compared to the research methods of innovation, the articles with conceptual method account for 49%, and the qualitative method occupies 18%, both achieve 67%. It indicates that the green technology innovation in China is still at a developing stage and the method of model and empirical are not adequate. China's green development is still in the developing stage and need more executions. Though we know that methods should not be ignored with the extension and quick development. In addition, the actual technology adoption needs theoretical support. It assumes that the concepts and theoretical systems driving green technology development research is more welcome. Another impressive feature of these articles is that the green technology research covers 50 subjects within multi-disciplinary fields, while the majority falls on environment science, management, energy and fuels and economics.

The research level indicates that the green technology innovation in China is still under a developing stage based on the data shown in Section 3.3, herein, macroscopic research level gains 54%, mesoscopic research level are keeps 11%, microscopic research level are keeps 35%. This phenomenon reflects that more concrete studies and application from micro perspective are urgently needed, such as the specific technology innovation and application of new technology in the firms or environmental improvement.

The research subject area review in Section 3.4 shows that, the trend of green technology research appears an interdisciplinary research with the themes related to environmental subject, science technology, innovation management, which are accounting for 47.65% of the total. It is worth mentioning that the research articles of the top two areas–environmental sciences ecology and business economics are much more compared with other industries like agriculture and forest.

The keywords cluster analysis in Section 3.5, the technological innovation-related keywords gains highest occurrence frequency, such as "Innovation", "Technology", "Policy", "Sustainability", "System", "Performance", "Management", "Energy", and "Model" etc. The technological innovation is an important driving force for sustainable development. Various policies and adjusted industrial structures are introduced to promote green development of technologies, improve the efficiency of energy utilization, and support innovative development of green technologies, new and renewable energy, there are the key areas for our researcher to explore and develop.

For the review of publication based on institutions and publications in international journals in Sections 3.6 and 3.7, we can see that the most contributor in green technology innovation are science and technology university or organizations, especial for the universities from "985" and "211" project. Now China is executing a new program of Double First-Rate project[3] among the universities and reallocate the resources based on the contributions of the discipline construction and worldwide reputation. This including the national found support for the outstanding contributor or authors based on the evaluation system.

From the analysis in Section 4, one crucial phenomenon comes to our attention: besides the majority of research themes of "technology adoption and diffusion", green technology innovation cannot be isolated from the policy or regulation regime. The innovation research from multi-perspectives such as social culture,

[3] It refers the world first-class university and the first-class discipline construction.

economic management, engineering, social energy system and etc. are needed for low carbon development in China with green innovation orientation. This opens us a wider consideration that the green technology or is not just a pure technology but a cross functional activity, as a consequence, the technology becomes a low priority compared to the social innovation, such as the saving and efficiency improvement.

The review in Section 4.1 indicates that the effects of different policy implementations have different effects due to the different cost structure and maturity of technology. In fact, the green innovation can be induced by policies. The environmental regulation does the effectiveness on promoting the green technology development.

The finding in Section 4.2 shows: the technology adoption theory with empirical application based is also one of the key research themes. It covers innovative public procurement, dynamic efficiency analysis innovation activities and mechanisms design. People take great efforts on the real actual experiment and achievement in the adoption of green technology, such as the sample survey, case study or fields study with primary data. The typical research articles are influential. Green technology innovation diffusion takes leading the regional economic development. Furthermore, the researchers' focus is within new technology introduction, renewable energy development, new methods, new process improvement and even new conception or culture implantation. This is a new trend of green technology development in China.

In Section 4.3, the realization of technology transfer in green revolution is influenced by many factors. Green technology transfer needs to take full account of the capacity of absorbing countries and governments and the obstacles of intellectual property rights system. The increase of independent innovation capacity in China will play a positive role in technology transfer. From the perspective of historical development, in the environment of rapid improvement of independent innovation ability and intensified international competition, the transfer of green technology in developed countries will have a more positive impact on China's development, though China now is a second position in the world, many core technologies still need to import or transfer from the developed countries. It needs to increase the technology adaptation level and absorptive capacity to accept the technology transfer of the green revolution in a proactive manner.

While for the technological management and capability analysis in Section 4.4, it was sighted that the research of green technology innovation in enterprise management gradually turns from the macro aspect to the micro aspect, but it is not enough. After analyzing the green macro strategy of enterprises, scholars begin to pay more attention to micro factors such as enterprise organization, system design and innovation ability. Therefore, the government policies are becoming an important influencing factor of green innovation development, and the direction of future research.

In Section 4.5, the advanced technology development analysis has been explored from the concept, mechanism, technology foresight and multi-level perspective to enrich the related innovation theory. The basic research of policy instrument and mechanism among different interested group is necessary for technology innovation implementation. The basic research has covered the most areas of green technology innovation activities. It involves research of approaches policy instrument and mechanism, models, energy, environment resource industrial, biotechnology, etc. In addition, it is expected more interdisciplinary research to emerge in the future. While some publication level is not high and cannot get into the solid foundation to guide the green practice theoretically. Solving existing problems from different disciplines is also one of the directions of future research.

And at last, in Section 4.6, it was drawn that China need more entrepreneur and entrepreneurship. The scope of the different type of entrepreneurs are multiple

such as the social corporate responsibility, the decision effect of entrepreneurs on enterprise's green technology innovation, and the role of entrepreneurs in green and low carbon economy development or society improvement. But the researches in China is not big, in fact, the enterprise participant is crucial for green development, scholars are encouraging to pay attention on the role of entrepreneurship and education in cultivating entrepreneurs' green entrepreneurship, which is a critical element for sustainability.

5.2 Recommendations for future direction

Based on the exploration of the content and trend analysis by different categories analysis from the perspectives of period sequence, research methods, research level, research subjects, keywords cluster, institution, authors and themes of articles in Sections 3 and 4, we have witnessed the researchers' contribution in China and are impressed with their consummate methodology and rich theory base. While some research limitations still can be caught due to the regional development differently in China. Herein, we summarize some of our recommendations of the future research directions for our researchers and practitioners as reference and discussion.

First, we would like to see our depth of understanding of green technology innovation and enrich our studies of methodology and theory. We recommend that researchers increase the research volume of theory extension and popularization of green life. Especial for the research from economics and social perspective, the approach in a concept innovation among human and enable of the studies getting deeper.

Second, we recommend our researchers greater use of experiments, field investigation and case study, which are the more solid and concrete foundations for the sustainability in China and would be more convincing for our practitioners.

Third, we propose the cross-level studies moving forward on the green technology promotion, such as the research of cross-culture among different enterprises, regions, organizations and other different stakeholders. The research does not only depend on the scientific research organizations, but mostly comes out of practice.

Fourth, green technology innovation is a global phenomenon with many countries serving as the locations where the technological innovation occurs. Thus, researchers or practitioners are encouraged to use cross-disciplinary teams worldwide to conduct truly international research, such as the global cooperation mechanism, global eco-system research, global cross-cultural studies on inter-action on the sustainable development etc. that means to implement the "Go Out" principles to keep the most advanced and updated research achievements.

Fifth, green technology innovation is a multi-level research and covers across different subjects and multidisciplinary subjects. The research with green technology is not only including the energy saving, renewable, sustainable consumption and transition research, technology development etc. but also including the human or social behavior research, eco-service, green accounting. Herein we also encourage researchers build research teams integrating science, environment, chemistry, energy, fuels, engineering, material science, social science, management, even psychology and other scientists from different fields, who can bring multiple perspectives and methodologies to the foundation of green innovation enhancement.

Finally, from the participant perspective of green technology innovation, government is the key for sustainability development, thus, the government policies are becoming an important influencing factor of green economy development. Moreover, as the main participants, the entrepreneur factors gained lots of scholars' attention as well, the themes of entrepreneurial spirit, corporate responsibility,

effectiveness of entrepreneurs on enterprise's green technology innovation and the role of entrepreneurs becomes a new engine of green development in China.

5.3 Conclusion

This charter examined the literatures enlisted in the database of CNKI on the topics with regard to green technology innovation from 1994 to 2019 in China. Based on the literature review, some critical discussion and direction are drawn as follows: (1) green technology innovation is getting mature compared to the initial stage 10 years ago. Green technology is becoming a dominated research subject coupled with social energy system innovation contributing to the green and sustainable development. (2) The conceptual and qualitative publications dominate the overall researches; the empirical researches are in a shortage. (3) The research subjects are multi-perspective and multi-disciplinary, covering environment science, management, energy and fuels, economics and social behavior. New vibrancy of advanced theoretical and methodological research is particularly needed, especially for green technology innovation trajectory, performance evaluation, government policy instrument and multi-level cooperation among the participants. (4) The trend of green technology research appears an interdisciplinary research with the themes related to environmental subject, science technology, business economics, engineering and energy & fuels. (5) Different policy implementations have different effects due to the different cost structure and maturity of renewable energy.(6) Green technology innovation cannot be isolated from the policy or regulation regime, and is becoming a new underpin of current sustainable development coupled with social energy system contributing to eliminate the climate change.

From the most review of 25 years of the literatures within the domain of and green technology innovation it encourages us to conclude that the research is more diverse, more multi-faceted, multi-disciplinary and multi-focused than the normal technology innovation, but the publication amount is not big, most of the researchers in China still focus on the conceptual and qualitative exploration. Green innovation is a complex, multi-level and social constructed process that attract the researcher to perform in the developing fields. It shows strong evidence of the future trend on developing the new resource and renewable sources technology, new vibrancy of theoretical and methodological advance such as green technology innovation trajectory, innovation performance evaluation, government policy instrument and multi-level cooperation among enterprise, government policies etc. New and advanced theory explorations are the research themes of future directions.

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