

Article

Research Progress of Energy Utilization of Agricultural Waste in China: Bibliometric Analysis by Citespace

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Abstract: Energy utilization of agricultural waste, due to the depletion of petroleum resources and the continuous deterioration of the ecological environment, has become an increasingly important development area at present, with broad prospects. The Citespace software was used to systematically summarize the research hotspots, development, and frontiers of researches on the energy utilization of agricultural waste in China from 1999 to 2018. The results show that (1) the number of publications in this field has increased, which includes a steady development stage, a rapid development stage, and a fluctuation and decline stage. (2) Research hotspots focused on technology for energy utilization of agricultural waste, benefits analysis of energy utilization of agricultural waste, energy conversion and upgrading path of agricultural waste, and energy potential of agricultural waste. (3) Development of research hotspots go through five stages: “technology for energy utilization of straw and the disposal of livestock and poultry waste”, “exploration of energy utilization mode of agricultural waste and the disposal of by-product from energy utilization of agricultural waste”, “technology upgrading from agricultural waste to fuel ethanol and recycling of livestock and poultry waste”, “resource recycling of by-product from biogas ” and “energy utilization of livestock and slaughterhouse waste”. It has revealed the focus in this field was changing from planting waste to breeding waste, and from unprocessed waste to by-product from energy utilization. (4) Energy utilization of slaughterhouse waste and cow manure has started to be considered as the frontiers of researches.

Keywords: energy utilization of agricultural waste; citespace; research hotspots; development process; research frontier

1. Introduction

Energy utilization of agricultural waste is among the most effective methods for disposing of agricultural waste [1]. It refers to the conversion of agricultural waste into clean energy. This includes the use of crop field residues such as crop straw, crop process residues such as rice husk and corncob, livestock breeding waste such as farm bedding and manure, and slaughterhouse waste such as carcasses and wastewater. Over the last decades, remarkable improvements have been made in technology for energy utilization of agricultural wastes, including agricultural wastes gasification technologies such as straw thermal cracking gas and biogas, agricultural wastes liquefaction technologies such as hydrolysis, enzymolysis, Fischer–Tropsch synthesis, and water phase catalysis, agricultural wastes

solidification technologies such as biomass briquette technology and steam explosion pretreatment technologies, and power generation technologies from agricultural wastes, such as straw directly burning, straw–coal co-firing and biogas generate electric technologies [2,3]. In addition, with the advancing energy utilization technology of agricultural waste, the forms of energy utilization of agricultural waste have become more and more diversified, and the major types include pyrolysis gas, biogas, biomass molding fuel, fuel ethanol, bio-gasoline, bio-kerosene, bio-diesel, and electricity, and so forth. Accordingly, a great variety of by-products are generated during the process of energy utilization of agricultural waste, such as biogas residue. Of late, with the deepening of research on energy utilization of agricultural waste, scholars started to devote themselves in the study of biogas residue disposal, in order to prevent secondary pollution [4,5].

In recent years, the importance of energy utilization of agricultural waste has been widely recognized by all sectors of the community [6–8]. First, large-scale farming creates a huge amount of agricultural waste that aggravates environmental problems, widely existing in developing and developed countries [9,10]. For example, in European Union which consists a group of 28 countries (EU-28), more than 1100 Mton livestock manure is produced every year, and dairy and pig farming are the main sources of livestock manure [11]. Second, traditional and inefficient energy use methods also cause environmental problems. A study on household air pollution from cooking in 2013 showed that the highest concentrations of fine particulate matter (PM_{2.5}) in South Asia and East Asia and the Pacific are owing to combustion emissions from dung and agricultural residues. There is a difference of more than ten times in the mean concentration of PM_{2.5} between the highest population-weighted country level and the lowest population-weighted country level [12]. Therefore, the Intergovernmental Panel on Climate Change (IPCC) has put the role of agriculture on mitigating climate change at the top of the agenda. Hence, converting agricultural waste into clean energy seems to be one of the most feasible ways for agricultural waste pollution control. Various environmental policies have been carried out to reduce agricultural emissions, such as Gothenburg Protocol, EU Nitrate Directive, and European Commission: a policy framework for climate and energy in the period from 2020 to 2030.

Energy utilization of agricultural waste is helpful to the release of fossil fuel shortage. Researchers have found that agricultural wastes, including crop straw and livestock manure, will be the most perspective energy source as an alternative of nonrenewable energy in the near future [13]. For example, the 13th five-year plan for biomass energy development, released by the Chinese Government in 2016, puts forward that, in 2015, global biogas production was about 57 billion cubic meters, of which German biogas production exceeded 9 billion cubic meters, and Swedish biogas met 30% of the country's automotive gas demand. The theoretical biogas potential of farm manure from livestock and poultry was estimated at 26 billion m³ biomethane in Europe [14]. A calculation by the author on energy utilization of straw in China shows that, in 2017 (The average number of households in China in 2017 comes from the "China Population and Employment Statistics Yearbook" published in 2018, the following is the same), the energy substitution of biogas generated by energy utilization of straw in China can meet the annual household energy needs of 93.76 million families (China's 2017 annual per capita energy consumption for household is derived from the "China Statistical Yearbook" published in 2018, the following is the same). In addition, the theoretical biogas potential of manure from livestock and poultry in China can meet the annual energy needs of 58.12 million families (Calculated based on the data from "China statistical yearbook 2012" and "China population and employment statistics yearbook 2012"). Technology for energy utilization of agricultural waste has made a tremendous breakthrough during the past decades. Nowadays, straw not only can be converted into biogas, but also can be used to generate electricity by straw direct combustion or straw thermal cracking gas. A calculation by the author on energy utilization of straw in China shows that, in 2017, the power generation potential by straw direct combustion is about 6.534×10^{11} kWh (straw direct combustion power generation coefficient = 675 kWh/t) in China, which can replace 80.3 million tons of standard coal (calorific value calculation, 10,000 kWh = 1.229 tce (ton of standard coal equivalent), the following

is the same) [15], can significantly improve the national energy structure and strengthen national energy security.

Energy utilization of agricultural waste is conducive to relieve the issues of global resource waste. Great efforts have been done in resources utilization of agricultural waste in some countries, and the comprehensive utilization ratio of agricultural waste has been significantly increased. According to Chinese statistics data, in 2017, the comprehensive utilization rate of straw was 82%, increased 11.4% compared with that in 2010 [16]. In 2017, the comprehensive utilization rate of livestock and poultry manure in China was 60%, and the goal of the government is to reach 75% by 2020 [17]. However, because of the huge amount of agricultural waste in agricultural country, the improper disposal of agricultural waste cannot be ignored. Taking Chinese statistical data as an example, in 2017, the straw resource quantity was about 9.68×10^8 t (This quantity was calculated based on the output of the main crop in China, 2017. The measured varieties include wheat, corn, rice, beans, tubers, and other major food crops, and peanut, rape, sesame, and other major oil crops, and cotton and other fiber crops. As the straw output of hemp, sugar, and tobacco is less, and mainly used as industrial raw materials, they were not calculated in this paper. Crop yields were obtained from “China statistical yearbook 2018”. The percentage of field straw as fuel, Straw to Grain Ratio, and processing by-product coefficient were obtained from reference [18]), and the quantity of livestock and poultry waste resource was about 38×10^8 t [19], which means that still nearly 1.5×10^8 t of straw was either thrown away or burnt and 15.2×10^8 t of livestock and poultry manure was randomly piled up every year. Energy utilization of these discarded resources is a huge wealth.

Energy utilization of agricultural waste contributes to environmental improvement. With rapid economic development, energy consumption has gradually increased, which causes a series of serious environmental problems. At present, environmental issues have gradually become one of the biggest obstacles to economic development. Sustainable development of the economy and environment is one of the most important issues for modern society [3]. The shortage of fossil energy has restricted the sustainable development of the economy and environment. The combustion of fossil fuel (a nonrenewable resource) has been seen as a major cause of global climate change [20]. Energy utilization of agricultural waste in rural areas has obvious advantages. A study on farm anaerobic digestion of agricultural waste shows that, with anaerobic digestion, the Greenhouse Gas (GHG) emission reduction effect can be strengthened by the increased CH_4 production potential [11]. Therefore, encouraging energy utilization of agricultural wastes has been recognized as an important factor for environmental problem improvement.

Energy utilization of agricultural waste could not only conduce to solving resource and environmental problems, but also bring great economic benefits. Therefore, the energy utilization of agricultural waste has been widely developed in many countries, especially in the rural areas of developing countries. For example, as at the end of 2015, over 110.975 thousand biogas projects have been conducted in China [21]. Taking biogas made from straw as an example, in 2017, the annual theoretical potential of biogas was estimated at 159.56 billion cubic meters in China (This biogas production was calculated by the author for straw resources, using the parameters such as dry matter ratio and biogas conversion rate, which were used in the calculation in the literature [18].), which can replace 114 million tons of standard coal (1 cubic meter biogas = 0.714 kg standard coal) [22]. The annual theoretical biogas potential of manure from livestock and poultry was estimated at 75.704 billion cubic meters [23] in China, which can replace 54 million tons of standard coal, and it amounts to 38.85% of annual natural gas production in China (Calculated based on the data from “China statistical yearbook 2012”).

Energy utilization of agricultural waste not only has outstanding performance in the aspects as mentioned above, but it also has social effects as well. For example, the unpleasant odors, flies and mosquitoes bred from littering agricultural waste may spread diseases and endanger public health. Therefore, improving the energy utilization of agricultural waste proportion is one of the most effective measures to reduce its social problems from the root cause. A report, Potential Contribution

of Bioenergy to the World's Future Energy Demand, produced by the IEA Bioenergy Executive Committee in 2007, revealed that the biomass energy industry is an important means of providing employment, driving people's incomes and promoting rural development. A report released by the Asian Development Bank, in 2018, further clarifies that biogas plants contribute to the increasing incomes of the nearby farmers [24]. Moreover, biogas purification and integration into natural gas pipeline networks can be conducted to improve people's living quality and health condition [25].

In the academic circle, there has been a lot of valuable research results in the field of energy utilization of agricultural wastes. From a global perspective, the energy utilization of agricultural waste mainly shows three characteristics. First, the energy utilization of agricultural waste is still mainly traditional, inefficient and noncommercial worldwide, in contrast to the high commercialization in the European countries. For example, based on the statistical data of International Renewable Energy Agency, in 2019, bioenergy accounts for about 75% of the world's renewable energy, more than half of which is through the traditional biomass use. Second, universally speaking, the current energy utilization technology of agricultural waste is not so advanced. Modern technology for energy utilization of agricultural waste, including the technology of biogas from straw anaerobic digestion and biomass briquette, has not been utilized effectively [13]. Third, energy utilization level of agricultural waste is uneven among different countries and regions. Europe has the most developed biomass energy industry system in the world. Biogas production of Europe occupied almost 50% of the biogas production worldwide in 2015 [26]. Europe's biogas industry has developed rapidly. The installed capacity of biogas, in 2017, increased nearly three times in Europe compared with that ten years ago [27]. The utilization rates of manure in the EU and Europe were respectively 72% and 70% in 2015. The consumption share of bioenergy in China is less than one-fifth of that of the EU [28]. Therefore, it is necessary to further promote energy utilization of agricultural waste.

Many facts have shown that using straw and manure to produce biogas is a self-sufficient way, which can effectively solve energy problems in developing countries. On the global scale, the energy utilization of agricultural waste issue in China is crucial. As a big agricultural country, a huge amount of agricultural waste is produced every year in China. If such a huge amount of agricultural waste is emitted directly without any scientific processing, severe ecological environmental problems will arise. Besides, for feeding hundreds of millions of people, China will continue to be an agricultural country, both now and in a long period of future. Therefore, the output of agricultural waste will show stability and regularity. In addition, with multiple climate and geographical conditions, the species of crops and livestock are abundant. The kinds of agricultural waste and the form of energy utilization of agricultural waste all appear diverse in China. Bioenergy statistical data, released by the International Renewable Energy Agency in 2019, reveals that biomass energy has great potential in replacing fossil energy, especially in populous countries such as Brazil, India, and China [27]. The energy utilization of agricultural waste experience of China can be used for reference by other countries, especially in developing countries with large populations.

In addition, limited study is available for the use of bibliometric tools to review the published literature in the field of energy utilization of agricultural wastes in the CNKI academic journal database. In fact, a literature review on the issue of energy utilization of agricultural wastes will contribute to a better understanding of the research status, research characteristics, and evolution of the field systematically, and it is essential to explore the issue of agricultural waste energy further. Bibliometric tools have been widely used in the writing of literature review by scholars, which can largely avoid the influence of analyst's subjectivity on the research conclusions, thus enhancing the objectivity and credibility of the research conclusions. So, the Citespace bibliometric software will be used in this paper to review the literature in the field of energy utilization of agricultural waste in China, retrieved from the full-text database of academic journals of CNKI from 1999 to 2018. The following issues are concerned in the field of energy utilization of agricultural waste: (1) the research status in China as a whole; (2) the research hotspots; (3) the development process of the research hotspot; (4) the frontier and future research direction.

2. Materials and Methods

2.1. Data Sources

The sample data are the journal papers retrieved from the full-text database of academic journals of CNKI (China National Knowledge Infrastructure), ranging from January 1999 to December 2018.

Subject keywords “agricultural waste”, “straw”, “livestock and poultry manure”, “energy”, “biogas” and “fuel” were each used with fuzzy matching to retrieve relevant literature in CNKI. The searching process was conducted on 18 May 2019 and yielded a total of 4569 articles. Manual method was adopted in order to ensure the rationality of literature and eliminate the interference of irrelevant literature. Firstly, the conference notice, book review, essay solicitation, and other irrelevant literature were deleted. Secondly, the nonacademic literature about profile interview, company introduction, lab establishment newsletter, brief introduction of the research center, and so forth were removed. Thirdly, literatures on natural science experiments, mechanical equipment manufacturing, and computer software development were excluded. Our final sample included a total of 4062 relevant articles.

2.2. Research Method

Bibliometrics is a science of quantitative analysis of literature information, which can analyze the impact of academic research more objectively. Bibliometrics was first proposed by British intelligence scientist Alan Pritchard in 1969 and was widely used in various fields such as publication statistics, journal or research institution impact evaluation, track of academic hot spots, future research direction, and so forth. Word frequency analysis is a common method in bibliometrics, which can be used to identify research hotspots and research frontiers. The operation is as follows: Keywords reflect the core content in a research article. The importance of a keyword could be measured in terms of its frequency and centrality. If the centrality of a keyword is bigger than that of other keywords, it means that this keyword has more important status in the research field. Keywords with high frequency can highlight the key issues in the research field. The trend of the burst term can be used to determine the research frontier and development direction of the research area [29]. Citespace, which is an information visualization software developed by Chen C.M., was selected for the quantitative analysis of the sample literatures in this paper.

3. Results

3.1. Descriptive Statistical Analysis of the Research Literature

3.1.1. Literature Quantity Analysis

According to the search results, 4062 papers related to the energy utilization of agricultural waste were published from January 1999 to December 2018, with an average annual publication of 203 papers. The annual change is shown in Figure 1.

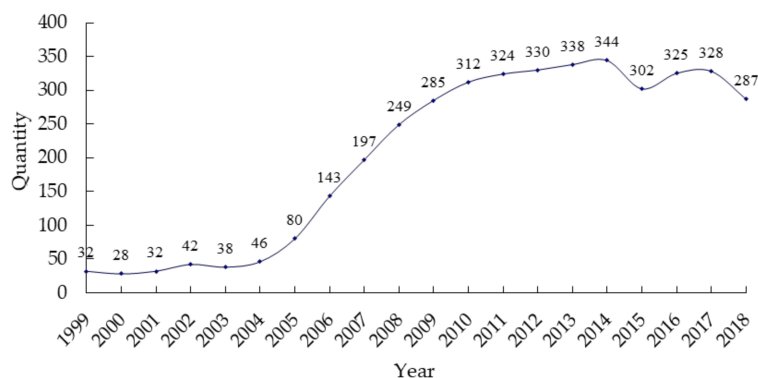


Figure 1. The number of agriculture waste energy utilization papers in 1999–2018.

According to the changing track of the number of published research papers, three stages could be identified, namely, the steady development period, the rapid development stage, and the fluctuation decline phase. During the first stage (1999–2004), steady development period, research on energy utilization of agricultural waste was just getting started and the number of published papers was relatively small, averaging around 36. In the second stage (2004–2014), research on energy utilization of agricultural waste developed rapidly. The literature number increased by 80 in 2005, and many research results were emerging during this phase. The literature number reached a peak of 344 in 2014, and between 2004 and 2014, the average annually published literature amounted to 260. In the third stage (2014–2018), the fluctuation period, research on energy utilization of agricultural waste gradually matured with rich research results. Throughout this stage, the average annual published literature was 317, and the graph of these numbers had a characteristic “S”-shaped curve, presenting a significant change.

3.1.2. Literature Distribution

The 4062 samples were distributed in 1025 journals. In 1948, British bibliologist Bradford put forward “Law of Bradford” and according to this law, if scientific journals are arranged in descending order according to the number of papers on a subject, they can be divided into core, related, and nonrelated areas, and the number of articles in each area is equal. In this paper, the samples were lined up in descending order according to the number of journal articles, and 27 journals were extracted in the core area of utilization of agricultural waste energy, as shown in Table 1.

Table 1. Top 27 journals of energy utilization of agricultural waste papers.

Ranking	Journal Name	Article Quantity
1	Transactions of the Chinese Society of Agricultural Engineering	151
2	China Biogas	148
3	Agricultural Engineering Technology (New Energy Industry)	147
4	Renewable Energy Resources	127
5	Journal of Anhui Agricultural Sciences	100
6	Modern Agricultural Science and Technology	73
7	Journal of Agricultural Mechanization Research	52
8	Agriculture of Henan	45
9	Agriculture and Technology	43
10	Nong Min Zhi Fu Zhi You	38
11	Acta Energiæ Solaris Sinica	34
12	Journal of Agricultural Resources and Environment	34
13	Modern Agriculture	32
14	Chinese Agricultural Science Bulletin	28
15	Xin Nongye	27
16	Jiangsu Agricultural Sciences	27
17	Beijing Agriculture	26
18	Transactions of the Chinese Society for Agricultural Machinery	25
19	Agriculture Machinery Technology Extension	25
20	Journal of Agro-Environment Science	24
21	Ecological Economy	23
22	Agricultural Technology & Equipment	22
23	Agricultural Engineering Technology	22
24	Agriculture of Jilin	22
25	Scientific and Technological Innovation	22
26	Agricultural Science & Technology and Equipment	19
27	Environmental Science & Technology	19

3.1.3. Group of Core Writers

Highly productive authors are the main force of research work in a field. Therefore, in order to find out the core strength in the field of agricultural waste energy research, its highly productive authors

group has been identified. In the book “Little science, Big science”, the famous scientist and historian Price pointed out that 50% of all the papers on the same subject are written by highly productive authors. The number of highly productive authors who have written half of all the papers in the field of energy utilization of agricultural waste can be obtained by formula $m = 0.749(n_{\max})^{0.5}$ [30], where $n_{\max} = 55$ refers to the number of papers published by these authors from 1999 to 2018. The value of $n_{\max}$ is equivalent to 55 after calculation. Statistically, m can be worked out to be 6. Therefore, the highly productive authors in the field of energy utilization of agricultural waste are those who have published more than 6 papers and hence, 67 authors have published 720 papers accounting for 17.7% of the total samples. There is still a big gap between 17.7% and 50% that had been expected. It means that in China, a stable core author group has not been formed in this research field [31].

Table 2 gives a general description of authors who have published nine or more papers in the field of energy utilization of agricultural waste between 1999 and 2018. Zhao L.X. topped the table with 55 published papers, which accounted for 1.35% of the total samples. Meng H.B., who had published 37 papers, ranked the second, and the third was Tian Y.S. with 36 papers. All of them were working at the Academy of Agricultural Planning and Engineering, Ministry of Agriculture and Rural Affairs of China (abbr. MARA).

Table 2. Research papers on energy utilization of agricultural waste in 1999–2018 in China.

Ranking	Author	Published Quantity	Proportion	Year
1	Zhao L.X.	55	1.35%	2006
2	Meng H.B.	37	0.91%	2009
3	Tian Y.S.	36	0.89%	2002
4	Yao Z.L.	34	0.84%	2010
5	Chang Z.Z.	21	0.52%	2011
6	Lei T.Z.	20	0.49%	2006
7	Liu S.Y.	19	0.47%	2005
8	Yang G.H.	18	0.44%	2009
9	Zhang B.L.	17	0.42%	2005
10	Zhang W.D.	16	0.39%	2001
11	Chen G.Y.	15	0.37%	2013
12	Du J.	14	0.34%	2013
14	Ye X.M.	13	0.32%	2011
14	Luo J.	13	0.32%	2010
15	Mei Z.L.	12	0.30%	2011
18	Yin F.	11	0.27%	2010
18	He X.F.	11	0.27%	2006
18	Wang F.	11	0.27%	2008
21	Bi Y.Y.	10	0.25%	2010
21	Huo L.L.	10	0.25%	2011
21	Dong R.J.	10	0.25%	2011
26	Zhu J.L.	9	0.22%	2006
26	Li Y.B.	9	0.22%	2009
26	Liu R.H.	9	0.22%	2010
26	Jiao R.L.	9	0.22%	2008
26	Ren G.X.	9	0.22%	2009

The top 10 research institutions are listed in Table 3, which are sorted out by the number of published papers in the field of energy utilization of agricultural waste in China, between 1999 and 2018. Among these are six universities and four scientific research institutes, which signifies that the research in this field was mainly carried out in universities and scientific research institutes. The top three research institutions include Chinese Academy of Agricultural Sciences, Academy of Agricultural Planning and Engineering, Ministry of Agriculture and Rural Affairs of China (MARA), and Chinese Academy of Sciences.

Table 3. Chinese research institutions in the field of energy utilization of agricultural waste in 1999–2018.

Ranking	Institution	Number of Published Papers	Proportion	Year of First Paper
1	Chinese Academy of Agricultural Sciences (Include Institute of Environment and Sustainable Development in Agriculture, Institute of Agricultural Economics and Development, Institute of Agricultural Resources and Regional Planning, Biogas Institute of Ministry of Agriculture, Nanjing Research Institute for Agricultural Mechanization Ministry of Agriculture)	87	2.14%	2006
2	Academy of Agricultural Planning and Engineering, MARA (Include Monitoring Station of Agricultural Resources, Centre for Energy and Environment Protection Technology Development, Comprehensive Laboratory for Resource Recycling Technology and Model of the Ministry of Agriculture (MOA), Key Laboratory of Energy Resource Utilization from Agricultural Waste)	69	1.70%	2002
3	Chinese Academy of Sciences (Include Institute of Geographic Sciences and Natural Resources Research, Institute of Process Engineering, Guangzhou Institute of Energy conversion, Qingdao Institute of Bioenergy and Bioprocess Technology, Chengdu Institute of Biology, Xinjiang Institute of Ecology and Geography, and University of Chinese Academy of Sciences)	65	1.60%	2002
4	China Agricultural University	55	1.35%	2009
5	Henan Agricultural University	49	1.21%	2004
6	Northwest A&F University	41	1.01%	2009
7	Henan Academy of Sciences	19	0.47%	2006
8	Anhui Agricultural University	15	0.37%	2010
9	Shenyang Agricultural University	13	0.32%	2009
10	Huazhong Agricultural University	13	0.32%	2012

3.2. Research Hot Spot and Representative Literature

The keywords of the literature in this paper were analyzed by Citespace. The parameters were set as follows: Time span was from 1999 to 2018, the slice length was 4 years, and node type selected keywords. The threshold in each time slice was to select the top 20. In order to make result interpretation easier, the map was cropped using pathfinder mode [32]. By considering the number, frequency, and the centrality of keywords, four research hotspots were selected: technology for energy utilization of agricultural waste, benefits analysis of energy utilization of agricultural waste, energy conversion and upgrading path of agricultural waste, and energy potential of agricultural waste.

3.2.1. Study on Technology for Energy Utilization of Agricultural Waste

The keywords and representative literature of the research hotspot “technology for energy utilization of agricultural waste” are listed in Table 4. The research hotspot pays more attention towards straw energy utilization technology, which includes the optimization of production technology, the improvement of production equipment, the improvement of efficiency and benefit, and the existing problems and measures. It can be divided into four main research directions: (1) Gas fuel technology of agricultural waste. For example, Yao Z.L. et al. [33] have designed a pyrolysis gas combustion equipment to solve pipe blockage caused by high tar content in straw pyrolysis gas, which can import the crude straw pyrolysis gas directly into the equipment to combust. To solve the issue of straw degrading due to the excess content of lignocellulose, Yang Q. et al. [34] put forward the optimization and improvement methods in terms of inoculum, pretreatment, mixed fermentation, and reaction equipment. Tian Y.S. et al. [35] compared the application scope, development status of household biogas technology, and biogas engineering technology in rural areas and proposed solutions

to the existing problems. (2) Liquid fuel technology of agricultural waste. The major technologies in this research direction were hydrolysis technology, Fischer–Tropsch synthesis, and aqueous phase reforming technology, which can produce cellulosic ethanol, bio-gasoline, bio-kerosene, and bio-diesel. The reduction of the production cost is the focus of this direction. For example, Cao L.Y. et al. [36] explored the key technical constraints that have led to high costs of cellulosic ethanol. (3) Solid fuel technology of agricultural waste. The research direction focused on the scientific evaluation of solid fuel technology. For example, Wang J.W. et al. [37] calculated that after agricultural waste was compressed into densified biofuel, the volume was compressed by 5.6–6.67% and the thermal efficiency was increased by 50–70%. Liu S.C. et al. [38] calculated that the combustion performance of densified biofuel can be increased by 20% on an average. Based on rough set theory, Meng H.B. et al. [39] have evaluated the densified biofuel technology objectively. (4) Power generation technology from agricultural waste. This direction focused on the development of power generation technology of agricultural waste, existing problems, and industrial development prospects, which includes three types of technologies—direct combustion power generation technology, co-combustion power generation technology, and biogas generation technology. For example, Li L.M. et al. [40] analyzed the differences in biomass power generation at home and abroad and compared the main technologies of straw direct combustion power generation in China.

Table 4. The keywords and representative literature of the research on the technology for energy utilization of agricultural waste in China.

Keywords				Representative Literature			
Year	Name	Frequency	Centrality	Author (Year)	Number of Keywords	Cited Quantity	Number of Downloads
1999	Straw gasification	77	0	Yao Z.L. (2017)	1	3	326
2007	Anaerobic digestion	299	0.07	Yang Q. (2016)	3	38	1037
1999	Biogas	478	0.13	Tian Y.S. (2011)	3	39	1366
2003	Densified biofuel	98	0.01	Cao L.Y. (2018)	4	1	681
2005	Ethanol	112	0.11	Wang J.W. (2017)	1	68	2167
2007	Pretreatment	113	0.01	Liu S.C. (2002)	1	70	462
2005	Biodiesel	9	0	Meng H.B. (2008)	2	32	338
2004	Straw power generation	111	0.01	Li L.M. (2010)	2	52	1005

3.2.2. Benefits Analysis of Energy Utilization of Agricultural Waste

Table 5 indexes the keywords and representative literature of “benefit analysis of energy utilization of agricultural waste”. The research focused on the improvement of environmental, economic, and social aspects of energy utilization of agricultural waste, trying to find the best energy utilization model of agricultural waste. This research hotspot can be divided into three main research directions. (1) The environmental benefits of energy utilization of agricultural waste. This direction focused on the benefits and estimation of greenhouse gas emission reduction from energy utilization of agricultural waste. For example, Huo L.L. et al. [41] applied the life cycle assessment (LCA) analysis principle to calculate the greenhouse gas emissions of densified biofuel made from corn straw in Beijing. Wang L. et al. [42] set up the measurement method of greenhouse gas emission mitigation based on the large-scale straw biogas centralized supply project in Cangzhou, Hebei Province of China. (2) The economic benefits of energy utilization of agricultural wastes. It focused on the prior-period investment, production costs, energy consumption, and income of energy utilization of agricultural waste. For example, Song A.D. et al. [43] estimated the production cost of cellulosic ethanol based on the demonstration line of corn straw cellulosic ethanol. Tang T. et al. [44] analyzed the cost and benefit of the biogas power generation project of Jindongtai farm, belonging to China Oil and Foodstuffs Corporation. (3) The social

benefit of energy utilization of agricultural waste. This direction focused on the changes in production and way of life caused by energy utilization of agricultural waste. For example, Yan J. et al. [45] analyzed the social benefits of household biogas systems in rural areas of western China in terms of convenience of life, leisure time, working time, and so on. Wang Y.M. et al. [46] analyzed the social benefits of the Luyi national Straw-based power generation project in Henan province of China, in terms of providing jobs and increasing the farmer's income.

Table 5. The keywords and representative literature on benefit analysis of energy utilization of agricultural waste in China.

Keywords				Representative Literature			
Year	Name	Frequency	Centrality	Author (Year)	Number of Keywords	Cited Quantity	Number of Downloads
2000	Agricultural waste	113	0.17	Huo L.L. (2011)	1	35	640
1999	Waste treatment equipment	155	0.36	Wang L. (2017)	2	4	188
2007	Ecological environment	14	0.04	Song A.D. (2010)	2	37	944
2007	Energy saving and emission reduction	34	0.00	Tang T. (2019)	2	-	17
2011	Economic benefit	9	0.01	Yan J. (2006)	1	48	547
2007	Circular agriculture	72	0.00	Wang Y.M. (2013)	1	12	514

3.2.3. Study on the Energy Conversion and Upgrading Path of Agricultural Waste

Table 6 records the keywords and representative literature of the research hotspot “energy conversion and upgrading path of agricultural waste”. The research focused on the evolution of energy forms and supply modes of agricultural waste and tries to find countermeasures to guide the energy conversion and upgrading of agricultural waste. There were three main research directions in this field. (1) The energy form evolution of agricultural waste: It has experienced the evolution from traditional energy form (straw, cow manure) to commercial energy products (biogas, bio-natural gas, electricity, etc.). For example, Zheng C. et al. [47] pointed out that livestock and poultry manure can be used to produce biogas, bio-natural gas, and other energy products with commercial properties and higher economic value. They also discussed the different techniques of commercialization of energy products from agricultural waste. (2) The evolution process of the energy supply mode of agricultural waste: It has undergone a transition from relying on the natural supply to single-family production, and then to specialized production. The current research focused on the change of production, management, and service mode. For example, Wang F. et al. [48] explored the evolution and driving factors of biogas from rural household biogas to large- and medium-scale biogas projects in China. Zhang W.D. et al. [49] discussed the invention process, patent technology, production, and development of household biogas digesters in rural China. Wang C.X. et al. [50] simulated and analyzed the sustainable operation of third-party management model of agricultural waste. (3) Optimizing the path of the energy system of agricultural waste: The direction of agricultural waste energy system optimization is more economical, environmentally friendly, and efficient. For example, Zhong S. et al. [51] analyzed that the biogas project had significant environmental benefits and scale effects, and the direction of rural energy development in China would be the medium and large-scale biogas centralized one.

Table 6. The keywords and representative literature on energy conversion and upgrading path of agricultural waste.

Keywords				Representative Literature			
Year	Name	Frequency	Centrality	Author (Year)	Number of Keywords	Cited Quantity	Number of Downloads
1999	Household biogas	193	0.15	Zheng C. (2019)	1	3	132
2003	medium and large-scale biogas projects	122	0.05	Wang C.X. (2017)	1	4	503
1999	Straw	567	0.05	Wang F. (2012)	2	181	4371
1999	Livestock and poultry manure	262	0.34	Zhong S. (2019)	2	-	98
2013	Industry	15	0.04	Zhang W.D. (2006)	4	37	843
2015	Power generation	26	0.01				

3.2.4. Study on the Energy Potential of Agricultural Waste

Table 7 mentions the keywords and representative literature of “Energy utilization potential of agricultural wastes”. This research hotspot focused on the energy utilization potential of agricultural waste, the supply and demand potential of energy products of agricultural waste, and the suitable energy utilization mode of agricultural waste for different regions in China. The research focus can be divided into three main research directions: (1) Resource quantity estimation for the energy utilization of agricultural wastes and developing countermeasures. For example, Cui M. et al. [52] worked out the quantity of the theoretical resource, collectible resource, and energy utilization resource of main crop straw in China. Geng W. et al. [53] estimated the resource quantity of ten main types of livestock and poultry manure in China and analyzed the countermeasures of energy utilization. (2) Supply potential of energy products from agricultural wastes and regional development countermeasures. For example, Jin S.Y. et al. [54] discussed the raw material type, producing area distribution, resource quantity of agricultural wastes fuel ethanol, and estimated the production potential of fuel ethanol. Qi T.Y. et al. [55] compared and analyzed the development potential of biomass direct-fired power generation in different provinces of China. Tang Y.C. et al. [56] estimated the output of household biogas. (3) Demand potential of energy products of agricultural wastes and the influencing factor analysis. For example, based on the data on provincial rural energy consumption from 2005 to 2014, Wang T.Q. et al. [57] analyzes the changing process of the Chinese household’s demand of clean energies and commodity energies and discusses the effects of the rural energy policy and the income level on the household’s demand for specific energies.

Table 7. The keywords and representative literature of Chinese research on energy utilization potential of agricultural wastes.

Keywords				Representative Literature			
Year	Name	Frequency	Centrality	Author (Year)	Number of Keywords	Cited Quantity	Number of Downloads
2011	Resource quantity	162	0	Cui M. (2008)	3	429	2835
2007	Gas output	30	0	Geng W. (2013)	1	234	2267
2008	Gas production rate	3	0	Jin S.Y. (2008)	1	33	625
2008	Energy utilization	52	0	Qi T.Y. (2011)	1	20	626
2015	Development use	41	0	Tang Y.C. (2010)	3	66	1108
2007	Countermeasure	78	0.02	Wang T.Q. (2017)	2	4	468

3.3. Development of Research Hotspots

Based on the attention (frequency of keywords ≥ 7) and influence (centrality ≥ 0.1) of the research hotspot, combined with the horizontal and vertical aggregation of keywords, by dynamic analysis, the development of research hotspots of energy utilization of agricultural waste go through five stages: “technology for energy utilization of straw and the disposal of livestock and poultry waste”, “exploration of energy utilization mode of agricultural waste and the disposal of by-product from energy utilization of agricultural waste”, “technology upgrading from agricultural waste to fuel ethanol and recycling of livestock and poultry waste”, “resource recycling of by-product from biogas”, “energy utilization of livestock and slaughterhouse waste”.

3.3.1. Stage 1 (1999–2002): Research Hotspots Were Technology for Energy Utilization of Straw and the Disposal of Livestock and Poultry Waste

According to the keywords “straw”, “biogas”, “straw gasification”, “straw gasifier”, “straw utilization”, and “biogas fermentation” in Table 8, the energy utilization technology of straw has become a hot topic in the first stage. This may have resulted from the guidance of the government’s policy. Specifically, the Chinese government launched a straw gasification project named “Bright Project” for rural areas to promote the technological upgrading of rural biomass energy utilization in 1998 [58]. Since then, crop straw gasification equipment and biomass centralized supply system has been successfully developed. The research development of energy utilization of straw was promoted by those technical breakthroughs [59,60]. In 1999, the Chinese government made “Notice on issues about further support to renewable energy development” [61] to support renewable energy projects such as biomass energy generation. Then “renewable energy” and “biomass” became the keywords in 1999. In this stage, “Agricultural Waste” was the keyword that had both the highest frequency (113) and centrality (0.17) in 2000. It shows that scholars started to study “straw” and “livestock and poultry waste” as a whole. In addition, scholars started to pay more attention towards the treatment problem of livestock and poultry waste in the following period, which may be related to the market demand and national policy. Specifically, the number and scale of livestock and poultry farms in China increased rapidly with the increase of social demand. It led to an increase in livestock and poultry wastes quantity and difficulty in management. In 2001, in order to prevent and control the pollution from livestock and poultry farms, the Chinese government promulgated “Technical Standard of Preventing Pollution for Livestock and Poultry Breeding” [62], “Management Approach for Pollution Prevention of Livestock and Poultry Farms” [63].

Table 8. The keywords of the first stage of the Chinese study in the field of energy utilization of agriculture waste.

Year	Keywords	Frequency	Centrality
1999	Straw	567	0.05
1999	Biogas	478	0.13
1999	Biomass	306	0.14
1999	Livestock and poultry waste	262	0.34
1999	Waste disposal devices	155	0.36
1999	Biogas fermentation	83	0.21
1999	Straw utilization	39	0.05
1999	Straw gasification	77	0
1999	Straw gasifier	24	0.11
1999	Pollution treatment	8	0.04
2000	Agricultural waste	113	0.17
2000	Renewable energy	51	0.03
2002	Intensive livestock and poultry farms	7	0.18

3.3.2. Stage 2 (2003–2006): The Research Focus of This Stage Lies in the Exploration of Energy Utilization Mode of Agricultural Waste and the Disposal of By-Product from Energy Utilization of Agricultural Waste

In Table 9, “densified biofuel”, “straw power generation”, “fuel ethanol”, “biomass energy”, “biodiesel”, and “straw biogas” were keywords. It meant the scholars began to explore more diverse energy utilization ways of agricultural waste at this stage. In terms of energy forms, academia not only paid attention to the gas fuel, but also extended the research field to the liquid fuel and solid fuel. One possible explanation is that the Chinese government had given priority to briquetting technology, gasification technology, liquefaction technology of agricultural waste, and straw power generation in “Outline on New and Renewable Energy Development in China (1996–2010)” [64]. Fermentation is an important step in the production of biogas and fuel ethanol, so “fermentation” became the keyword in 2003. The centrality (0.11) of “fuel ethanol”, which appeared as the keyword in 2005, was the maximum in this stage. The possible explanation includes internal and external factors. In terms of external factors, countries around the world began to explore the use of biomass energy to reduce the dependence on fossil energy and to cope with global warming actively. For example, Brazil government began to promote flex fuel vehicles (FFVs), which can use various proportions of alcohol and gas, from March 2003 [65]. The United States government issued “Roadmap for Biomass Technologies in the United States” [66]. In 2003, the Chinese government started to formulate the “Renewable Energy Law”, which mainly supported the development and utilization of renewable energy such as fuel ethanol, and this was officially issued in 2005 [67]. In addition, “medium and large-scale biogas project” and “biogas liquid” were the keywords with high frequency and high centrality in 2003. It meant that “intensive livestock and poultry farms” and “pollution treatment” in the first stage retained its influence in this stage. Scholars not only paid attention to livestock and poultry waste treatment, but also did further study in the disposal of by-product from energy utilization of agricultural waste, which may result from the effect of “Cleaner Production Promotion Law” in January 2003 [68].

Table 9. The keywords of the second stage of the Chinese study in the field of the exploration of energy utilization mode of agricultural waste and the disposal of by-product from energy utilization of agricultural waste.

Year	Keywords	Frequency	Centrality
2003	medium and large-scale biogas project	122	0.05
2003	Densified biofuel	98	0.01
2003	Fermentation	71	0.08
2003	Biogas liquid	63	0.02
2004	Straw power generation	111	0.01
2004	Biomass energy	384	0.07
2005	Fuel ethanol	112	0.11
2005	Biodiesel	9	0

3.3.3. Stage 3 (2007–2010): This Phase Focused on Technology Upgrading from Agricultural Waste to Fuel Ethanol and Recycling of Livestock and Poultry Waste

In Table 10, “pretreatment”, “anaerobic fermentation”, “fermentation raw materials”, and other keywords showed that scholars started to pay attention to the conversion of technology from agricultural waste to fuel ethanol. The possible explanation is that the technological breakthroughs and the government’s recent guidelines have made lignocellulose-rich agricultural waste an important raw material for fuel ethanol. Specifically, “pretreatment” was the core technology used to convert grain ethanol to cellulosic ethanol. Because Lignocellulose is difficult to be degraded, the key to efficient utilization of lignocellulose is to destroy the structure by pretreatment. During this stage, scholars had carried out extensive research on the pretreatment technology of fuel ethanol [69,70]. Around 2007, the Chinese government promulgated a series of policies and regulations such as “Medium- and long-term development plan for renewable energy in China” [71], “Development programming for agricultural

biological energy industry (2007–2015)” [72], “Notice Concerning Strengthening the Management of Bio-fuel Ethanol Projects and Promoting the Healthy Development of the Industry” [73], and “Circular economy promotion law” [74] to guide further development of non-grain fuel ethanol. Then, “pretreatment” and “fermentation raw materials” became the keywords in 2007. In this stage, the frequency of “livestock and poultry breeding”, “circular agriculture”, and “energy saving and emission reduction” were relatively high. It meant that “livestock and poultry manure” and “pollution treatment”, which appeared in the first stage, and “biogas slurry”, in the second stage, were kept until this stage. Scholars were concerned not only on the disposal of livestock and poultry waste and by-product from energy utilization of agricultural waste, but also on the recycling of livestock and poultry waste and energy saving and emission reduction. It may be attributed to the fact that the Chinese government promulgated a series of policies and regulations such as the “The program of China’s national climate change” [75] to improve the ecological environment, making “livestock and poultry breeding”, “circular agriculture” and “energy saving and emission reduction” become keywords in this stage.

Table 10. The keywords of the third stage of the Chinese study in the field of technology, upgrading from agricultural waste to fuel ethanol and recycling of livestock and poultry waste.

Year	Keywords	Frequency	Centrality
2007	Anaerobic fermentation	299	0.07
2007	Pretreatment	113	0.01
2007	Measure	78	0.01
2007	Livestock and poultry breeding	64	0.02
2007	Circular agriculture	72	0
2007	Fermentation raw materials	37	0.03
2007	Energy saving and emission reduction	34	0
2007	Quantity of gas production	30	0
2008	Energy utilization	52	0

3.3.4. Stage 4 (2011–2014): The Research Focus during This Stage Was the Recycling Biogas By-Products Resources

As shown in Table 11, “straw resources”, “biogas residue”, “resource utilization”, “circular economy”, and “biogas fertilizer” became keywords. It meant that “circular agriculture” in the upper stage was retained to this stage. Scholars not only paid attention to the recycling of agricultural wastes, but also took the energy utilization of agricultural wastes as an important part of the utilization of resources. The resource utilization of biogas by-products was further studied. It may result from the national policy. During this period, the Chinese government paid more attention to the problem of rural energy construction, which was under the dual constraints of resources and environment. Specifically, in order to improve resource efficiency and the development level of the recycling economy, in 2011, the Chinese government launched “The Twelfth Five-Year Guideline for National Economic and Social Development (2011–2015)” [76], promoting recycling mode of production through the acceleration of the resource utilization of agricultural wastes. In July 2012, the Chinese government stated in “The Twelfth Five-Year Plan for Biomass Energy Development” [77] that comprehensive utilization of biogas slurry and biogas residue should be promoted. Biogas residue is the biggest biogas by-product after biogas liquid. Although, “biogas liquid” became a keyword in the second stage, “biogas residue” has also become one of the concerns in the academic community in the fourth phase. In January 2013, the Chinese government issued “Circular Economy Development Strategy and Recent Action Plan” [78] to encourage the establishment of a circular economy industrial chain of “livestock and poultry manure–biogas–biogas residue–fertilizer–crop”, to accelerate the realization of the goals put forward in the twelfth five-year planning framework.

Table 11. The keywords of the fourth stage of the Chinese study in the field of recycling of biogas by-products resources.

Year	Keywords	Frequency	Centrality
2011	Resource utilization	74	0
2011	Straw resource	28	0
2011	Circular economy	29	0
2011	Biogas Fertilizer	17	0
2011	Biogas residue	15	0
2011	Combustion characteristic	14	0

3.3.5. Stage 5 (from 2015 to the present): The Research Hotspot in This Stage Was the Energy Utilization of Livestock and Slaughterhouse Waste

Based on the keywords such as “livestock and slaughterhouse waste”, “cow manure”, “combustion”, and “utilization”, mentioned in Table 12, it was not difficult to see that the academia paid more attention to livestock and slaughterhouse waste energy utilization in this stage. It may also be ascribed to the recent new policy. In recent years, sustainable and stable development of China’s animal husbandry significantly improved the scale cultivation level, and the large amount of livestock and poultry waste has become a major concern of rural environmental treatment. Chinese government promulgated a series of policies and regulations. For example, the revised “Environmental Protection Law” was implemented on 1 January, 2015 [79], and “National Agricultural Sustainable Development Plan (2015–2030)” [80], “National 13th five-year plan for rural biogas development” [81], and “2015 rural biogas project transformation and upgrading work plan” [82] were launched to reduce the impact of livestock and slaughterhouse waste on the production and living environment of rural residents. Then, large-scale biogas projects and bio-natural gas projects were established as the main disposal for livestock and slaughterhouse waste. “Livestock and slaughterhouse waste” were the keywords with the highest frequency during this stage. It meant that “livestock and poultry waste” was kept to this stage from the first stage. In the coming period, academia will not only focus on livestock and poultry waste, but also do further research in slaughterhouse wastewater, animal carcasses, and other slaughter waste [83]. “Cow manure” became the keyword in 2015. One possible explanation is that cow manure accounted for 58–81% [23] of the total quantity of livestock manure in China, which was the main source of livestock and poultry waste in China. In order to reduce the greenhouse effect and environmental pollution caused by cow manure natural fermentation, scholars would attach more importance to the disposal and resource utilization of cow manure in the next period. Based on the analysis of the keyword “combustion”, it is found that academia will pay more attention in the fields of livestock and slaughterhouse waste energy utility in the up-coming period, such as direct combustion, biogas power generation, and pyrolysis [84–86].

Table 12. Keywords used in the fifth stage of the Chinese study in the field of livestock and slaughterhouse waste energy utilization.

Year	Keywords	Frequency	Centrality
2015	livestock and slaughterhouse waste	28	0.01
2015	problem	21	0.02
2015	cow manure	18	0
2015	suggest	17	0.02
2015	Development utilization	26	0
2015	combustion	13	0.03

4. Discussion

4.1. Research Frontiers

By burst keyword analysis method (showing keywords had rapidly changed in a short period of time or dramatically increased in number, emphasizing the abrupt change of keywords [87]), the frontier analysis was made in the research of energy utilization of agricultural wastes. Through the analysis of sudden increased time nodes, the research frontiers along the timeline can be roughly determined. The burst words in the field of energy utilization of agricultural wastes are listed in Table 13. From the table, it can be noted that there are 14 burst words in the field of energy utilization of agricultural wastes in China. All their strength is above 6, and the highest of which reached 20.32.

Table 13. Top 14 literature burst words.

Keyword	Strength	Begin	End
straw gasification	17.17	1999	2007
straw gasifier	7.33	2001	2010
renewable energy	15.75	2002	2010
Power generation	9.42	2003	2007
biomass energy	8.88	2004	2006
fuel ethanol	9.19	2007	2011
agricultural wastes	6.76	2007	2015
anaerobic fermentation	9.6	2011	2015
resource utilization	20.32	2011	2015
comprehensive utilization	16.28	2011	2015
biogas fertilizer	6.61	2011	2015
cow manure	7.59	2015	2018
problem	8.86	2015	2018
livestock and slaughterhouse waste	10.92	2015	2018

From 1999 to 2002, the keyword with the highest strength was “straw gasification”, which corresponded to that in the first stage in the previous evolution path. From the technical breakthrough perspective, since the 1950s, Britain, Germany, France, Japan, United States, and former Soviet Union have already used anaerobic digestion technology to convert waste into energy. In the 1980s, Brazil and United States have begun to use liquefaction technology to convert biomass into liquid fuels to replace petroleum. In 1990, the Persian Gulf War led to the soaring of oil prices, setting off a boom in renewable energy technology development worldwide. From the policy perspective, the development of renewable energy is beneficial to the improvement of the ecological environment and the balance between energy supply and demand. Government departments of various countries have adopted a series of policies to accelerate the upgrading of rural biomass energy utilization technologies, in order to gradually change the traditional and inefficient biomass utilization methods. Hence, the technical breakthrough and released policies raised extensive concerns about “straw gasification” in 1999–2002.

Between 2003 and 2006, the keyword with the highest strength was “power generation”, which corresponded to the second stage in the previous evolution path, indicating that scholars explored the energy utilization mode of agricultural wastes such as biomass power generation during this stage. In the early 21st century, interprovincial market barriers have hindered the formation of interprovincial power markets and the optimal allocation of power resources in China. Electric institutional reform scheme, in 2002, released by the Chinese government, including the separation of plants and networks and the determination of the on-grid electricity price by market mechanisms, promoted the development of the power industry. To some extent, the institutional reform and the juristical binding helped “power generation” become burst keyword in 2003–2006.

During 2007–2010, the keyword with the highest strength was “fuel ethanol”, which corresponded to the third stage in the previous evolutionary path, indicating that the conversion from of agricultural waste to fuel ethanol was the research frontier during this stage. In order to cope with the pressure

from the sharp increase in international oil prices in 2005, many countries around the world issued laws, which required adding biofuel ethanol to vehicle fuels in a certain proportion, and ethanol subsidy policies to guide production and consumption. To a certain extent, the energy crisis and policy measures raised widespread attention about “fuel ethanol” in 2007–2010.

Between 2011 and 2014, the keyword with the highest strength was “resources utilization”, which corresponded to the fourth stage in the previous evolutionary path. In this stage, scholars made energy utilization of agricultural wastes an important component of resource utilization and conducted in-depth discussions. With environmental issues becoming increasingly prominent worldwide, the various resources on which humans depend have moved from scarcity to exhaustion, and the issue of resource recycling has begun to receive widespread attention. For example, the British Ellen McArthur Foundation was established in 2010, which is the first organization in the world to research and disseminate circular economy and carry out circular economy policy consultation. Other examples are consulting companies, such as McKinsey and Accenture, and nonprofit organizations, such as the World Economic Forum and World Resources Forum, which have systematically participated in the research and practice of circular economy. Therefore, the role of nongovernmental organizations enhanced broad interest about “resources utilization” in 2011–2014.

After 2015, the keywords with the highest strength were “livestock and slaughterhouse waste” and “cow manure”, which corresponded to the fifth stage in the previous evolution path. Overall, during this period, the focus of energy utilization of agricultural waste was changing from planting waste to livestock and poultry waste and poultry breeding waste. With the increase of food demand and changes of diet structure in recent years, greenhouse gas emissions from agriculture have caused widespread concern in the world. The amount of animal manure also increased rapidly, with the development of large-scale farming. Farm manure cleaning methods, such as water flushing and dry manure cleaning methods, and farm manure management methods, such as composting and returning to the field, or energy utilization, are the main influencing factors of greenhouse gas from the farm. Compared with composting or returning to the field, the biogas produced by anaerobic digestion can greatly reduce greenhouse gas emissions. As a result, the research focus of energy utilization of agricultural waste has turned to breeding waste. From the research scope point of view, the focus of energy utilization of livestock and poultry breeding waste was changed from “livestock and poultry waste” to “livestock and slaughterhouse waste”, and the energy utilization of cattle waste attracted more attention.

4.2. Research Conclusions

During the past 20 years, a wealth of research results have been produced in the field of energy utilization of agricultural waste in China. Especially, the number of publications has grown rapidly since 2005. The focus of Chinese researchers is mainly on four aspects: technology for energy utilization of agricultural waste, benefits analysis of energy utilization of agricultural waste, energy conversion and upgrading path of agricultural waste, and energy potential of agricultural waste. The development of research hotspots of energy utilization of agricultural waste go through five stages: “technology for energy utilization of straw and the disposal of livestock and poultry waste(1999–2002),” “exploration of energy utilization mode of agricultural waste and the disposal of by-product from energy utilization of agricultural waste(2003–2006),” “technology upgrading from agricultural waste to fuel ethanol and recycling of livestock and poultry waste(2007–2010),” “resource recycling of by-product from biogas (2011–2014),” “energy utilization of livestock and slaughterhouse waste(after 2015).” Each research topic presents different characteristics at different stages, and it continues to evolve as time progresses. The alterations of keywords have revealed the development of research hotspots on energy utilization of agricultural waste. The change of keywords, from “straw gasification” and “renewable energy” during 1999–2002 to “livestock and slaughterhouse waste” and “cow manure” after 2015, has revealed the focus of energy utilization of agricultural waste was changing from planting waste to breeding waste. The change of keywords, from “straw” and “livestock and poultry waste” during 1999–2002 to

“biogas liquid” and “biogas residue” in the latter stage, have revealed the focus of energy utilization of agricultural waste was changing from unprocessed waste to by-product from energy utilization. The change of keywords, from “livestock and poultry waste” during 1999–2002 to “livestock and slaughterhouse waste” after 2015, have revealed energy utilization of slaughterhouse waste has started to be considered as a focus of energy utilization of agricultural waste by academic circles in recent years. The above research conclusions are consistent with the research conclusions of many countries in this field during the same period [88,89].

With the increase of food demand and changes of diet structure in recent years, greenhouse gas emissions from agriculture have caused widespread concern in the world. The amount of animal manure also increased rapidly with the development of large-scale farming. The words of “livestock and slaughterhouse waste” and “cow manure” have become new burst words. Research in recent years shows that energy utilization of agricultural wastes is helpful for dealing with the shortage of fossil fuel, avoiding wasting of resource, improving the environment, and bringing great economic and social benefits. Therefore, energy utilization of slaughterhouse waste and cow manure has started to be considered as the frontiers of researches on energy utilization of agricultural wastes for dealing with resource and environmental problem.

The research focus of energy utilization of agricultural waste is affected by many factors, including technologies, laws and regulations, institutional mechanisms, policies and measures, the international situation, and the participation of nongovernmental organizations. A variety of means should be adopted to coordinate the relationship between people’s growing material and cultural needs and sustainable development of resources and the environment. Inputs to R&D in the energy utilization technologies for agricultural waste should be further increased, support to the energy utilization of large-scale farm waste should be increased, legal and policy systems about energy utilization of agricultural waste and by-product from energy utilization of agricultural waste should be improved, publicity on the energy utilization of agricultural waste should be increased, the resources of livestock breeding waste and slaughterhouse waste should be reasonably estimated, the distribution and characteristics of livestock breeding waste and slaughterhouse waste should be cleared, the subjective initiative to participate in energy utilization of agricultural waste for all society should be excited. On the global scale, the energy utilization of agricultural waste issue in China is also a typical and popular problem for countries with a large agricultural sector. Therefore, the energy utilization of agricultural waste experience of China can be used for reference by other countries, especially in the developing country with large populations.

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