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Review

Biomass Energy Technological Paradigm (BETP): Trends in This Sector

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Abstract: Renewable energy plays a significant role in the world for obvious environmental and economic reasons with respect to the increasing energy crisis and fossil fuel environmental problems. Biomass energy, one of the most promising renewable energy technologies, has drawn increasing attention in recent years. However, biomass technologies still vary without an integrated framework. Considering the theory of a technological paradigm and implementing a literature analysis, biomass technological development was found to follow a three-stage technological paradigm, which can be divided into: BETP (biomass energy technological paradigm) competition, BETP diffusion, and BETP shift. Further, the literature review indicates that waste, like municipal solid waste (MSW), has the potential to be an important future trend in the world and waste-to-energy (WTE) is designed for sustainable waste management. Among WTE, anaerobic digestion has the potential to produce energy from waste sustainably, safely, and cost-effectively. The new BETP technological framework proposed in this paper may offer new research ideas and provide a significant reference for scholars.

Keywords: biomass energy; literature analysis; technological paradigm; municipal solid waste

1. Introduction

Since the start of the 21st century, there has been continual growth in both the global economy and energy consumption. As a result, there has been more fossil energy use, which has directly led to a growth in incidences of serious environmental pollution. Greenhouse gas emissions, especially carbon dioxide (CO_2), have been increasing rapidly, which has adversely affected the environment. At the same time, these energy problems have, in turn, affected economic development and social progress. From statistical analyses, it has been estimated that world energy-related CO_2 emissions increased from 32.3 billion metric tons (2012) to 35.6 billion metric tons (2020), and this number will reach 43.2 billion metric tons (2040) [1], leading to global warming [2]. It is necessary to develop and use renewable energy, which can not only effectively control CO_2 emissions, but also improve energy efficiency. These elements are also the essence of a low-carbon society.

Compared with other renewable energies, such as solar, wind, hydroelectric, and geothermal power, biomass has been seen as a major renewable and non-fossil energy source to supplement declining fossil fuels [3]. Biomass refers to the various organisms produced by photosynthesis using air, water, and land. Energy, coming from biomass, is derived from plant and animal material, such as wood, forest waste, agricultural waste, aquatic plants, oil plants, city and industrial organic waste, and solid animal waste [4–10]. Biomass is considered an attractive feedstock for energy production because it is a renewable and widely-distributed energy resource, and can be developed sustainably in the future. Furthermore, it has positive environmental properties, such as biomass' low sulfur and nitrogen (relative to coal) content and nearly zero net CO_2 emission levels, allows biomass to offset the higher sulfur and carbon contents of fossil fuels [11]. In addition, biomass fuel is abundant, which is why biomass energy today has become the world's fourth largest energy source following coal, oil, and natural gas, indicating its significant economic, societal, and environmental potential [12].

The conversion of biomass to energy (also bioenergy) consists of a variety of different technologies, such as gasification, pyrolysis, and anaerobic digestion [13–18]. The development of bioenergy technology varies with time and will be affected by many factors, and there has not been a paradigmatic framework for biomass energy technologies. Therefore, in order to discover and develop the trends to achieve the integrity and universality of these technologies and make a contribution to the related research in bioenergy technology field, a systematic analytical framework, including a data analysis system and literature mining have been built to explore the biomass technological evolutionary paradigm and accelerate the development of this area, which can also be extended to other renewable energy and its technologies. The establishment of a technological paradigm will benefit low-carbon technological innovation and the development of a low-carbon economy.

In order to determine the progress of this biomass technological evolution, some specific foci are needed. Bibliometric analysis and visualization technology have been developed for a comprehensive literature analysis. CiteSpace, software developed by Professor Chen, is specially used to identify and visualize scientific literature as a Java application [19]. CiteSpace is a visual analysis software which is designed for scientific literature research, and its cluster analysis is used to find the foci and display it in a visual way [20,21], which can help to explore the research foci, the evolution trend, and the frontier of the field of biomass energy technology. From the visual graphs generated through CiteSpace, the trend foci which were found and expressed in the keywords and clusters are in accordance with the characteristics of technological paradigm theory [22–24].

In 1962, Kuhn first defined the paradigm in his groundbreaking work "Structure of the Scientific Revolution". In this paper, Kuhn defined the paradigm as referring to commonly accepted scientific achievements, and explained that it is able to provide questions and answers for communities of practice over a period of time [25]. In 1982, technical innovation economist Dosi combined the concept of technological innovation with that of the paradigm, and proposed the technological paradigm [26]. Due to market demand and industrial competition, the technological paradigm evolves like the gradual evolutionary process of life, that is, from birth to maturity and then to decline [27].

In the present paper, we combine the technological paradigm with biomass, and propose a new concept for the biomass energy technological paradigm (BETP), which is one of the low-carbon energy technological paradigms. As mentioned above, the evolution of the technological paradigm has distinct characteristics in each stage, which can also be verified by the foci analysis using the CiteSpace visualization tool. The changes in each stage examine the technological paradigm, which results in its evolution divided into three stages, which are shown in Figure 1, the technological revolution life trajectory.

After literature analysis and foci analysis, it can be concluded that the BETP meets the three stages for the paradigmatic pattern of development and each stage focuses on various different energy conversion technologies: namely BETP competition, BETP diffusion, and BETP shift (Figure 1). The first stage is oriented by competition with a series of different early technologies. A leading technology appears and then prevails under the influences of development and market demand, which continues to innovate and develop further. This comes to the second stage, which is diffusion. Finally, there is a need for a shift on the condition that the original leading technology becomes saturated or some problems appear, which is the third stage. Here, the main BETP technologies in the shift stage indicate the possible future trends.

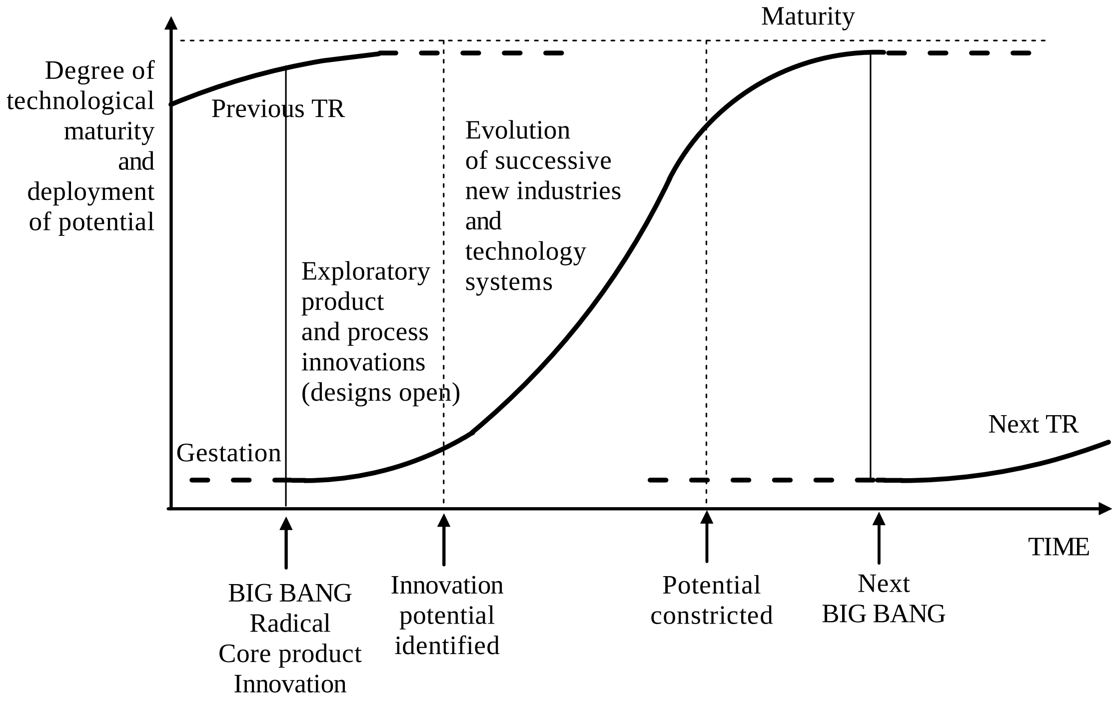

Figure 1. The evolution of the technological paradigm [28].

2. Literature Analysis

In a systematic review of the literature, the current findings are discussed in relation to a particular research question. Scientific knowledge which is based on text usually has its own evolution in the life cycle. By analyzing the evolution patterns, the foci and trends in scientific literature can be found, and it has been an important research direction in the field of text mining in recent years [29,30]. Pang put forward a research method of multi-feature co-occurrence and visualization in 2012, and through the above analysis, scientific research development in scientific literature can be discovered, to a certain extent, from multidimensional observation [31]. In the present paper, we created an advanced data analysis system (DAS) to evaluate all relevant scientific papers. First, an introduction is given to the key technology and software in this system, and then the research process and results from the analysis will be described.

2.1. The Introduction of the DAS

In this part, relevant technologies and software packages used for keyword foci trend analysis are briefly introduced. The organization of the advanced data analysis system (DAS) is shown in Figure 2, two relevant software packages are on the left, which are the Web of Science (WOS) and CiteSpace, separately, and the specific procedures used in this system are on the right. The data collection module is to obtain the most relevant information through the initial literature database. The visualization module gives a specific process description of CiteSpace.

The requirement of the data format of CiteSpace is based on the standard of the Web of Science database, and it is updated with the change of the data format in the ISI (Institute for Scientific Information) database [20]. Web of Science, a comprehensive multidisciplinary citation index database spanning manuscripts back to 1900, is the world's leading citation index database, including three libraries: the Science Citation Index Expanded (SCI-Expanded), Social Sciences Citation Index (SSCI), and Arts and Humanities Citation Index (A&HCI) [32]. The Web of Science^{TM} Core Collection Indexes was selected in this paper in order to increase the accuracy. It includes the most influential core journals which can ensure the quality of information. Web of Science has stronger coverage than

Scopus (produced by Elsevier), which goes back to 1990, and most of its journals are written in English. However, Scopus covers a superior number of journals, but with lower impact, and is limited to recent articles [33]. With a strong retrieval and analysis function, Web of Science can ensure full and accurate information retrieval, can discover the hidden trends in a research field, and can also find the latest developments [34,35].

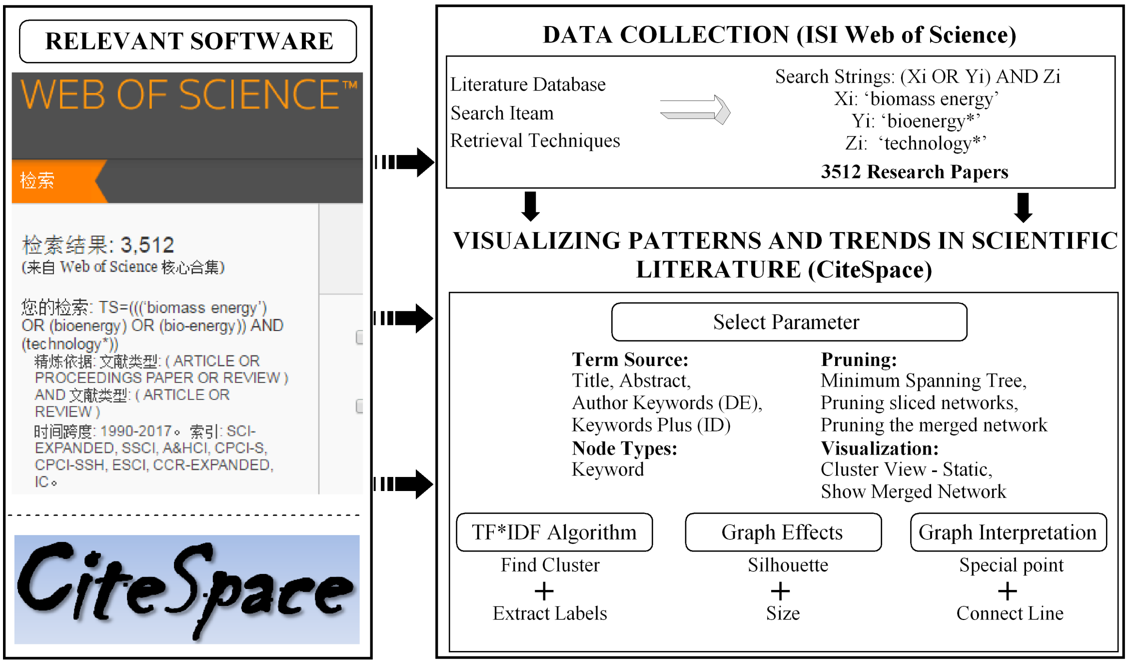

Figure 2. Data analysis system (DAS) literature mining.

Mapping knowledge domains is a kind of graph which can visually display knowledge resources and their associations [36], which helps to understand and predict the fronts and dynamics of science, and tap new frontiers. CiteSpace, a free Java application for visualizing and analyzing citations and contents in scientific literature, is applied in this paper as the main analysis tool to detect and visualize emerging trends [19]. It can be applied to the analysis of multiple, time-sharing, and dynamic complex networks, and to detect the hotspots and evolution in a certain field [37]. At present, this software has been widely used in the detection and analysis of the trends in the research frontier.

2.2. Keywords Foci Trend Analysis

In order to discover the development of biomass energy technology, and trace its research focus, we should not only retrieve relevant research articles in SCI-Expanded, SSCI, A&HCI, and other databases, but also grasp the research status to understand the current situation and development trends by some analysis methods. Therefore, it is necessary to clarify the relevant aspects of the literature to explore the research foci, for example, the keywords, abstract, publication time, and so on, which explain the research status in fields from different perspectives [38]. Foci and co-occurrence analysis of keywords can directly reflect the research hotspot and frontier in a certain field [39].

To ensure the bibliographic references and research topics were highly relevant, a variety of search strings were tried. The final search strings were ((X_i OR Y_i) AND Z_i) using topic retrieval [40,41], for which X_i represented keywords that referred to 'biomass energy', Y_i represented 'bioenergy*', and Z_i was the collection of all 'technology*' expressions. An advanced search was used, and when the search was complete, article type of ARTICLE OR PROCEEDINGS PAPER OR REVIEW were selected, then 3512 research papers were identified. These articles were downloaded directly to CiteSpace, and then relevant parameters were set. Firstly, the Time Span is 1990-2017, and the Slice Length is one year. The term source includes 'Title', 'Abstract', 'Author Keywords' and 'Keywords Plus'. Then what should be analyzed was finally selected, and here are 'Keywords'. In order to simplify the network and highlight the important structural features, the Minimal Spanning Tree is selected to prune the network. At this step, a keyword co-occurrence graph is generated. Subsequently, according to the spectral clustering algorithm for automatic clustering and by using the TF*IDF (term frequency-inverse document frequency) weighted algorithm to extract the cluster label, the keyword co-occurrence and its cluster graph are shown in Figure 3.

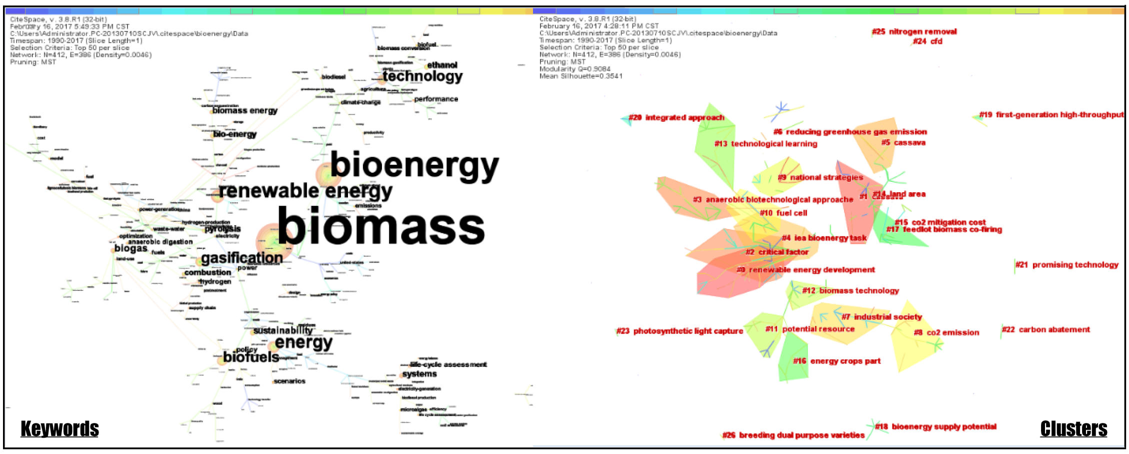

Figure 3. The keywords co-occurrence and clusters graph.

In the keyword co-occurrence graph, the circular node represents the keyword itself, and the size of the node represents the frequency of occurrence. Additionally, the label of the keyword is proportional to the frequency of its occurrence. The degree of connection between nodes reflects the cooperative relationship between the keywords. CiteSpace provides three options for visualization, in which the default is the cluster view (the right of Figure 3), which focuses on the structural features of the clusters. Through automatic labeling, 25 clusters were found, then according to the two indices-silhouette and size-also considering the relevant keywords in clusters, we chose some important clusters and their containing keywords are shown in Figure 4.

The silhouette value is used to measure the homogeneity of a cluster; the closer to 1, the higher the homogeneity. Similarly, the greater the size value, the better the cluster. Mean (year) is the average year of the formation of topic items, and label (TF*IDF) is the value of the cluster label keyword, emphasizing the mainstream of research. It is found that these three clusters are related to the development of biomass energy technology.

- ID = 2: cluster label is the 'critical factor', size = 24 and silhouette = 0.625, mean year = 1998, label (TF*IDF) = 13.23; keywords: combustion, scale boiler burner, combustion technology and modeling (Group I).
- ID = 4: cluster label is 'iea bioenergy task', size = 23 and silhouette = 0.643, mean year = 2004, label (TF*IDF) = 9.94; keywords: gasification, pyrolysis, fermentation and fluidized-bed (Group II).
- ID = 3: cluster label is 'anaerobic biotechnological approach', size = 23 and silhouette = 0.522, mean year = 2006, label (TF*IDF) = 13.23; keywords: biogas waste-water, anaerobic digestion, municipal solid wastes, landfill, land-use and residues (Group III).

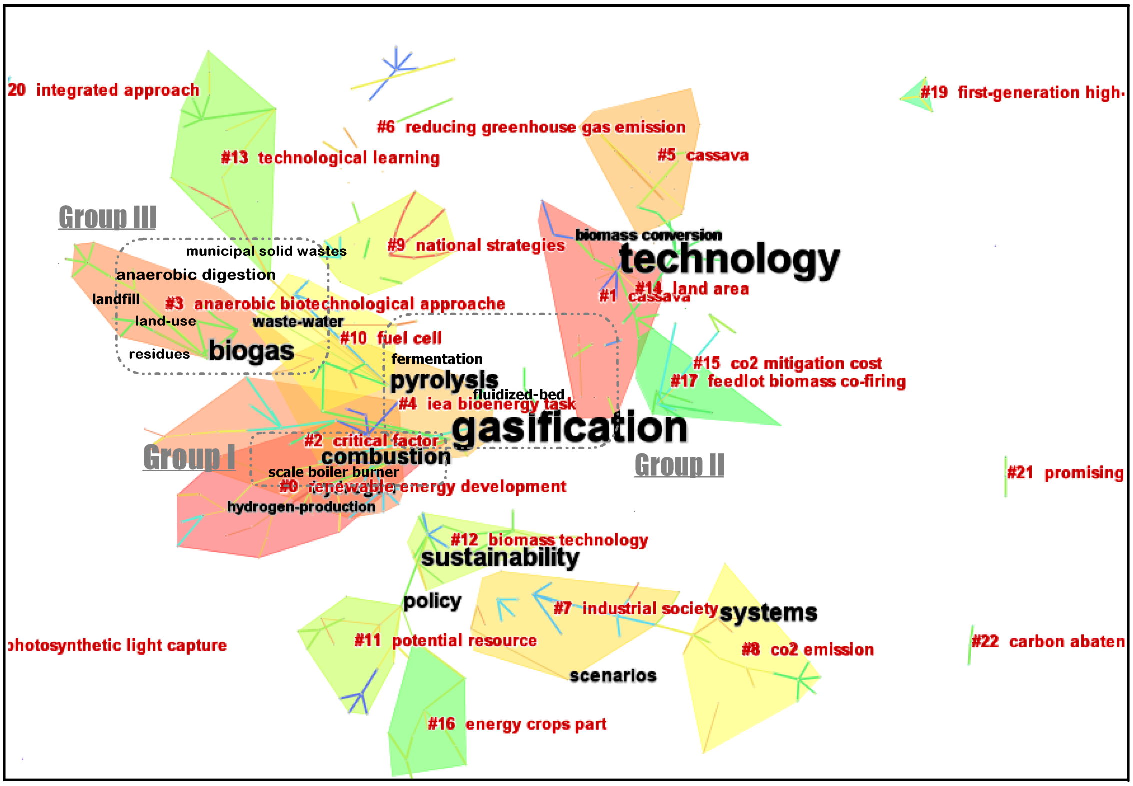

Figure 4. Clusters with keywords foci analysis graph.

2.3. Analysis Results

"The Structure of Scientific Revolution" written by Thomas Kuhn provided a philosophical foundation for CiteSpace [42]. Kuhn believes that the advancement of science is a reciprocating infinite process based on the scientific revolution, which is the alternation of the old and new scientific paradigms. The paradigm theory provides us with a framework of guidance, and the rise and fall path of a paradigm can be found in the scientific literature. The paradigm is the cluster of periods. For CiteSpace, the focus is on paradigms and paradigm shifts. Therefore, it is important to identify the key point in the paradigm and its shift. The turning point is the bridge which connects different clusters. The map in Figure 4 clearly shows three clusters, and there is a link between these clusters. In accordance with the arrangement of mean year, biomass energy technologies appeared, in turn, from cluster 2 to cluster 4, and then to cluster 3.

The evolution of the technology paradigm has significant stage characteristics along with the promotion of market demand and industrial technology competition [43]. According to the final effect of the change of each stage, the evolution of the technological paradigm can be divided into three stages: competition, diffusion, and shift. By combining the paradigm with clusters, the emergence of these three clusters is in accordance with the three stages in paradigm theory. The above analysis shows that biomass energy technologies research focus can be generally divided into three stages. From this, we can see that "direct combustion" is the main biomass technology in the first stage, which generally includes stove combustion, and boiler combustion. Thermochemical conversion and biochemical conversion are the two main biomass technologies in the second stage. The treatment and recovery of organic waste is the main path in the third stage of biomass energy technology, which includes composting, landfill, incineration, and anaerobic fermentation.

From above analysis, combining the technological paradigm with biomass energy, a new concept of the biomass energy technological paradigm (BETP) is proposed. Derived from the well-known S-curve [28], this evolution trace is shown in the above part in Figure 5. The competition stage represents the early technology development of the technological paradigm, which involves various trajectories and barriers. In the diffusion phase, a dominant path prevails in the potential market. A technological shift occurs when technology saturates and there are natural limits. The three stages in the BETP include BETP competition, BETP diffusion, and BETP shift, all of which are discussed in the following.

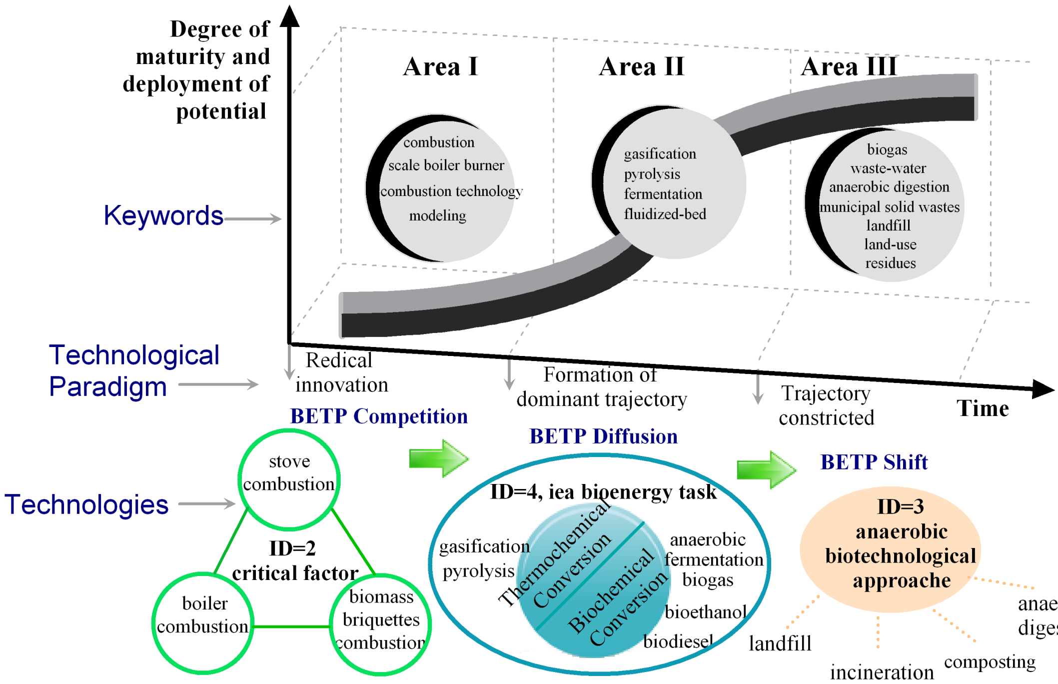

Figure 5. Biomass energy technological paradigm (BETP) evolution based on the technological paradigm.

These keywords in three stages are the results from the literature analysis, and they are strongly representative, but not totally comprehensive and accurate. Therefore, combining this with the actual situation regarding bioenergy, different technologies are summarized in the lower part in Figure 5, which transit from keywords to the technological paradigm and then to technologies. There are, mainly, direct combustion in BETP competition, thermochemical and biochemical conversion in BETP diffusion, and MSW treatment technologies in BETP shift. The review of these bioenergy technologies will be, respectively, described in detail in the next section.

3. The Three Stages of BETP

3.1. BETP Competition

From the foci trend analysis and the combination of paradigmatic evolution theory, direct combustion was the main application in the BETP competition phase. Direct combustion of biomass is a traditional method for the earliest use of biomass energy [44], and is the process of using biomass as a fuel to produce energy without the use of chemical conversion [45]. The biomass fuel combustion process involves both a strong chemical reaction process and a heat and mass transfer process between the fuel and the air. In addition to the fuel, this type of combustion requires an adequate heat and air supply. As shown in Figure 6, the biomass combustion process can be broadly divided into preheating, drying (evaporation), an analysis of volatility, and a coke (fixed carbon) combustion process [46]. BETP competition was mainly divided into three main evolutionary paths: stove combustion, boiler combustion, and biomass briquette combustion [47].

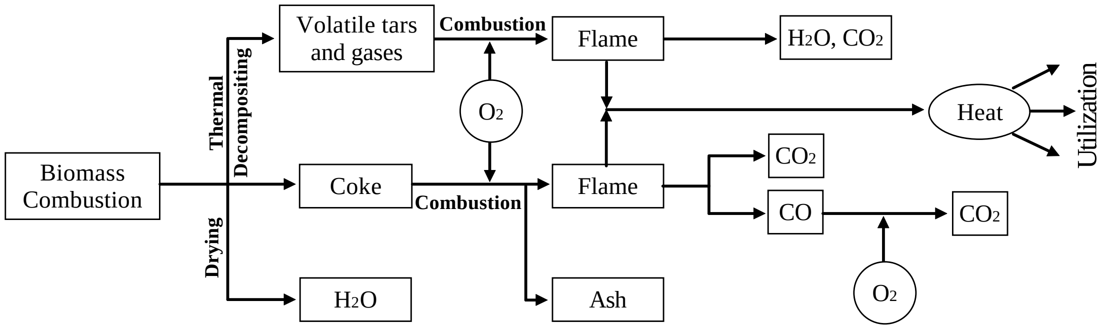

Figure 6. The combustion process of biomass fuels.

(1) Stove Combustion

Stove combustion is the most primitive method, and is commonly used for household furnaces in rural or mountainous areas. Whilst this method reduces the need for high investment, its efficiency is the lowest. This kind of old stove uses crop straw, firewood, grass, and dried animal dung as its fuel [48]. Since the supplied air is not always sufficient, fuel combustion is not always completed, and the thermal efficiency of an old wood stove (effective heat and fuel heat ratio) is very low. Biomass fuel used for stove combustion is often regarded as the only available and affordable energy source which can meet basic needs, like cooking and heating [49]. However, direct combustion for cooking and heating in rural areas typically brings indoor air pollution and the associated adverse health impacts [50,51]. Further, the relatively low thermal efficiency is a problem, as it wastes energy resources.

(2) Boiler Combustion

Boiler combustion using modern technology is suitable for the large-scale use of biomass, as it can achieve high efficiency, and is suitable for industrial production, but its high investment costs means that it is not suitable for small-scale distributed use [52]. The biomass raw materials used for boiler combustion mainly involve the burning of forestry offcuts, immature trees, wood processing and paper mill waste, rice husk, bagasse, and crop straw. There are many kinds of biomass fuel boilers depending on the type of fuel to be used, such as firewood stoves, straw furnaces, and incinerators. Depending on the different boiler combustion modes, these can be further divided into underfeed stokers, grate stokers, fluidized bed boilers [53]. The biomass boiler has been widely used in the United States, Brazil and some European countries to supply hot water and heating, with some being used for power generation and some being used for both power generation and heating [54].

(3) Biomass Briquettes Combustion

A new type of direct fuel combustion has appeared, called biomass briquettes combustion. Due to its irregular shape and size, high moisture content, and low bulk density, biomass is quite difficult to handle, transport, store, and utilize in its original form. One solution to the above problems is to increase the density of biomass materials into pellets, briquettes, or cubes [55]. Biomass briquettes combustion uses this high-density solid fuel in traditional coal-fired equipment to improve thermal efficiency. After solidification, the raw material has high volumetric energy density and high homogeneity of the fuel [56], and the pollution emissions are much lower than coal, making this technology a highly-efficient clean and renewable energy [57]. There are a variety of processes used for biomass compression molding. Depending on the technical characteristics, biomass compression molding can be divided into three basic types: wet pressure molding, hot press molding, and raw material carbonization [58]. These kinds of combustion methods use traditional coal-fired burning equipment after curing, which can reduce the biomass raw material volume needed, greatly increase the fuel energy density, and improve the utilization efficiency [59].

To conclude, in the process of BETP competition, a variety of early technologies emerged, which included the three direct combustion technologies: stove combustion, boiler combustion, and biomass briquettes combustion. A comparison of the three techniques is shown in Figure 7. The original stove combustion technology is easy to operate and requires a relatively low investment, but the combustion efficiency is also very low and there are air pollution problems. Boiler combustion has a higher efficiency, but because of its high investment, it is more suitable for large-scale production. The relatively new biomass briquettes combustion has greatly improved combustion efficiency with its greater density, but the operating costs are also very high. As society and the economy develops, there is an increasing need for energy. However, the biomass direct combustion technology in the BETP competition stages seems immature and has some problems. Therefore, according to demand-pull and technology-push theories, technological innovation of bioenergy will go to the next stage, which is BETP diffusion.

	Stove Combustion	Boiler Combustion	Biomass Briquettes Combustion
Advantages	Easy to operate and least investment.	A higher efficiency; achieving industrial production.	High volumetric energy density, high homogeneity of the fuel.
Disadvantages	The lowest efficiency and waste biomass resources; air pollution.	High investment cost.	High operating costs.
Suitable Range	Dispersing independent household stoves in rural or mountainous areas.	Large-scale utilization of biomass.	Enterprises to carry out technological transformation of the original equipment.
Types	Fuel-saving stove, etc.	Underfeed stokers, grate stokers, fluidized bed boilers.	Wet pressure molding, hot press molding, raw material carbonization.

Figure 7. A comparison of the three main evolutionary paths.

3.2. BETP Diffusion

Due to the low thermal efficiency and pollution problems of direct combustion in the competition stage, the main biomass technological developments in the phase of BETP competition need a more suitable biomass technology to encourage this evolution. Due to the increasing market demand and industrial competition, the BETP diffusion stage emerges gradually. With the transition from old to newer technologies, new biomass technological applications were developed, such as thermochemical conversion and biological conversion, which became the dominant designs in the BETP diffusion stage. Therefore, from technological paradigmatic evolutionary theory, thermochemical conversion and biological conversion matured and developed a stable product structure.

3.2.1. Thermochemical Conversion

Compared with other techniques, biomass thermochemical conversion technology has the advantages of low energy consumption, high conversion rate, and easy industrialization [60,61]. Biomass thermochemical conversion technology mainly uses gasification and pyrolysis technology, from which high grade energy products, like charcoal, tar, and combustible gas, can be obtained [62].

(1) Gasification

Gasification is the conversion of biomass into a combustible gas mixture (CO, H_2, CH_4, N_2 and C_nH_m, etc.) by the partial oxidation of biomass at high temperatures, typically in the range of 800–900 °C [63]. Biomass gasification is accomplished using a gasifier, and the reaction process is very complex. Since the gasifier type, process flow, reaction conditions, gasification agent type, raw material modification, and particle size are different, the reaction processes are not the same [64]. However, the biomass gasification process (as shown in Figure 8) basically includes the following reactions [65]:

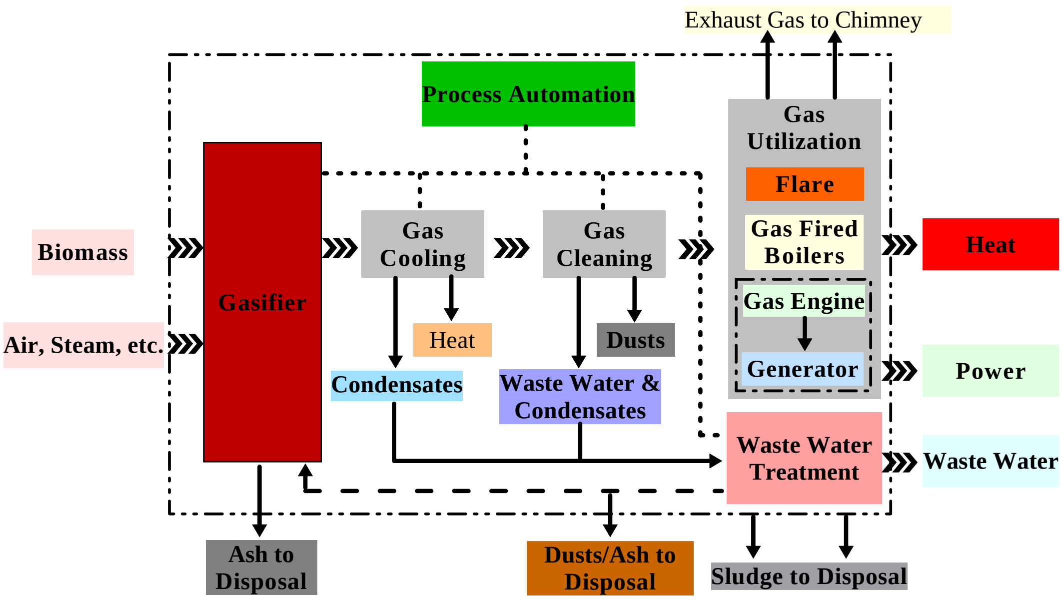

Figure 8. Typical biomass gasification process [66].

$$\begin{aligned} C + 2O_2 &\longrightarrow CO_2, \\ CO_2 + 2C &\longrightarrow 2CO, \\ 2C + O_2 &\longrightarrow 2CO, \\ 2CO + O_2 &\longrightarrow 2CO_2. \end{aligned} \tag{1}$$

Methane and hydrogen are formed simultaneously by the thermal splitting of organic material [65]:

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O. \tag{2}$$

Biomass gasification technology has two types of gasifiers: fixed bed gasifiers and fluidized bed gasifiers [67]. The fixed beds have a wide temperature distribution. This includes possibilities for hot spots with ash fusion, low specific capacity, long periods for heat-up and a limited scale-up potential [67]. However, fixed bed suffers from the disadvantage that gas flow must be stopped for cleaning [68,69]. Fluidized beds have good heat and material transfer between the gas and solid phases with the best temperature distribution, high specific capacity, and fast heat-up. Disadvantages of fluidized beds are high dust content in the gas phase and the conflict between high reaction temperatures with good conversion efficiency and low melting points of ash components [67]. Additionally, gasification is the key technology of biomass-based power generation. However, there are a number of key technological challenges that retard the commercial application of biomass gasification for power generation [70].

(2) Pyrolysis

Biomass pyrolysis is the basic thermochemical process which occurs in the absence of oxygen, or with a limited oxygen supply, that converts biomass into liquid (bio-oil or bio-crude), charcoal, and non-condensable gases, acetic acid, acetone, and methanol by the heating of the biomass to around 500 °C [71]. Pyrolysis produces energy fuels with a high fuel-to-feed in ratio, making it the most efficient biomass conversion process [72]. Biomass has three main compositions: cellulose, hemicellulose, and lignin, some extracts of which are soluble in polar or nonpolar solvents [73]. The biomass pyrolysis process is divided into four stages: drying, preheating decomposition, solid decomposition, and combustion [74]. The products produced through pyrolysis are gas (non-condensable volatile), liquids (condensable volatile), and solids (carbon), and the relative proportion of each product largely depends on the different pyrolysis methods and reaction conditions [63]. The processes for biomass pyrolysis and its products is shown in Table 1.

The conversion of biomass to liquids (namely crude oil) have an efficiency of up to 70% for flash pyrolysis processes [75]. This so-called bio-crude can be used in engines and turbines. Therefore, rapid pyrolysis for liquid production is of particular interest nowadays [76]. Bio-oil can be substituted for fuel oil or diesel in many static applications, including boilers, furnaces, engines, and turbines [77]. Further, bio-oil also has a higher density than raw biomass, which makes transportation and storage more convenient.

Table 1. Characteristics of biomass pyrolysis processes [78–80].

Process Type	Retention Period	Heating Rate	Maximum Temperature	Main Products
Slow pyrolysis				
Carbonization	Few hours~several days	Extremely low	400 °C	Charcoal
Convention	5~30 min	Low	600 °C	Gas, oil, charcoal
Fast pyrolysis				
Fast	0.5~5 s	Relatively high	650 °C	Oil
Flash (oil)	<1 s	High	<650 °C	Oil
Flash (gas)	<1 s	High	>650 °C	Gas
Extremely fast	<0.5 s	Extremely high	1000 °C	Gas
Vacuum	<2~30 s	Middle	400 °C	Oil
Reactive thermal cracking				
Hydrogenation pyrolysis	<10 s	High	500 °C	Oil
Methane pyrolysis	0.5~10 s	High	1050 °C	Chemicals

3.2.2. Biochemical Conversion

Biomass biochemical conversion technology, also called biological conversion, refers to the transformation of microbial, animal, or chemical biomass sources into a clean fuel or fertilizer [81]. Biomass biochemical transformation is divided into three kinds: technology of anaerobic fermentation biogas, bioethanol, and biodiesel [82].

(1) Anaerobic fermentation biogas

Anaerobic digestion (AD) is the process of the decomposition of biomass through bacterial action in the absence of oxygen. It is also a fermentation process and generates a mixture of gaseous products (e.g., hydrogen and carbon monoxide) [83,84]. Anaerobic fermentation is used to produce biogas, which can be directly used for cooking, heating, and as fuel for internal combustion engines [85]. Biogas fermentation is a microbiological process. Various kinds of organic matter, such as straw, livestock manure, and industrial and agricultural waste water can be converted into methane through the action of microorganisms in anaerobic or other suitable conditions [86]. The produced biogas can be utilized in several ways, either raw or upgraded. Compared with other fuels, methane generates less carbon dioxide and produces fewer atmospheric pollutants per unit of energy [87]. Since methane is a comparatively clean fuel, it is being increasingly used for power generation, vehicles, industrial applications, and so on [88].

(2) Bioethanol

Ethanol, which is produced almost entirely from food crops, is a comparatively cleaner burning fuel with high octane and fuel-extending properties [89]. Further, it is a renewable energy and can be sustainably developed from lignocellulosic biomass [90]. The production process features biological conversion and includes the following steps: feedstock handling, pretreatment, biological conversion, product recovery, utilities production, and waste treatment [91,92]. As a petrol additive/substitute, it is probable that wheat, sugar beet, straw, corn, and wood can be economically converted into bioethanol [93]. There are three main raw material types which can be used to produce bioethanol: starchy materials, sugary materials (such as molasses, sugarcane, sugar beet, and sweet sorghum), and cellulose materials (such as branches, sawdust, and plant fiber waste) [94,95]. Nowadays, however researchers and investors have become increasingly enthusiastic about another biofuel feedstock, lignocellulose, which is the most abundant biological material on Earth and which can produce both ethanol and biodiesel [96].

Essentially, bioethanol can be produced from a variety of carbohydrates which have a general formula of $(CH_2O)_n$ [97]. The chemical reaction involves an enzymatic hydrolysis of sucrose followed by a fermentation of simple sugars. First, an invertase enzyme in the yeast catalyzes the sucrose hydrolysis and convert it into glucose and fructose [12].

$$C_{12}H_{22}O_{11}\ (\text{Sucrose}) \longrightarrow C_6H_{12}O_6\ (\text{Glucose}) + C_6H_{12}O_6\ (\text{Fructose}). \tag{3}$$

Then, another enzyme, zymase, also present in yeast, converts the glucose and the fructose into ethanol (C_2H_5OH) [12].

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2. \tag{4}$$

Bioethanol can be used directly in the transport sector and vehicles can run on pure ethanol or blended with gasoline to make "gasohol" [98]. As the development of renewable energy technological applications have progressed, ethanol has become a viable alternative fuel [99]. Almost all gasoline cars can drive with fuel containing 10% ethanol (E10), flex-fuel cars can even use 85% ethanol (E85), and Brazil and the USA already include 10%–27% ethanol in their standard fuel by law [100]. Ethanol has been proved to be a promising alternative fuel for the internal combustion engine.

(3) Biodiesel

Seed crops, which contain a high proportion of oil, can be reacted with alcohols (methanol, ethanol) through a transesterification process to obtain biodiesel [101]. There are a large variety of crops that can be used for biodiesel production including rapeseed oil, palm oil, sunflower oil, soya bean oil, and recycled frying oils [102]. Biodiesel is a renewable fuel with extensive sources, which is already being utilized widely around the world. Due to its environmental benefits, biodiesel has become more attractive recently because of its low sulfur content, aromatics, and flash point [98].

At present, biodiesel production technology includes a chemical method, an enzymatic synthesis method, the recovery of glycerol, and an engineered microalgae production method [103]. The chemical method, which involves a transesterification of plant (or animal) oil, methanol or ethanol in a catalyst of acid, alkali, or biological enzyme, is the primary technology [104]. Biodiesel is better for environmental protection, which results in an overall life-cycle lowering of carbon dioxide emissions over both conventional diesel and gasoline [105,106]. Therefore, more attention should be paid to biodiesel.

In summary, because of the advantages of the thermochemical conversion and biological conversion technology, these two kinds of biomass technology play a significant role in the BETP diffusion stage. Thermochemical conversion technology not only has the advantages of low energy consumption, high conversion rates, and easy industrialization, but also has significant environmental benefits as the biomass is converted into clean biofuels (biogas, bioethanol, biodiesel), has a broad range of uses, and improves efficiency [107]. Therefore, these two kinds of biomass technology become the dominant technological trajectory. However, support for these technologies has recently been undermined due to environmental and food security concerns, including threats to forests and biodiversity, food price increases, and the competition for water resources, which are the key negative impacts of biofuel use [108]. Therefore, besides the balanced planning of land use to ensure food supplies, at the end of the BETP diffusion phase, there is a need to develop more paths, which can contribute the beginning of the next stage of the technological paradigm.

3.3. BETP Shift

The technological paradigm moves into the shift phase because of the emergence of disruptive technologies [109] and technological limitations [110]. Above, two main reasons emerge, led by full competition and market demand. Since there is an urgency to ensure environmental and societal problems, like land and food, we need to discover a new kind of biomass technology to achieve a sustainable world, which is in the BETP shift stage. From our foci trend analysis, waste, a potential biomass resource, can be used and developed in this phase. In this paper, urban organic waste is discussed because it is a serious environmental problem nowadays.

Urban organic waste refers mainly to the solid waste generated from the daily life and services of the city and its residents, which is referred to as municipal solid waste (MSW) [111]. With the rapid development of economies and the improvement in general living standards, the amount of MSW has gradually increased. In China, for example, annual generation of MSW is constantly increasing and expected to reach 172 and 200 million tons by 2013 and 2020 [112], respectively, causing harm to the ecology through the pollution of water, farmland, soil, and the atmosphere, which result in a restriction of social and economic development. However, MSW can be used as a kind of renewable energy resource [113]. MSW has been shown to contain one-third to one-half the energy of coal per tonne which is enough to power a plant with the excess being sold to the national grid [114,115]. Therefore, as an efficient new source, the development of MSW treatment technology is necessary to realize the sustainable development of cities, and it is a good alternative energy technology for the future [116,117].

There are a variety of treatment methods for biodegradable MSW. We can bury it, which means landfilling; burn it, which means incineration; and bio-digest it, which means either composting or anaerobic digestion. Others include gasification, pyrolysis, compression molding, and pouring into the sea, all of which are being promoted and used all over the world [118]. The EPA developed the non-hazardous materials and waste management hierarchy which ranks the various management strategies from most to least environmentally preferred [119,120]. The hierarchy places emphasis on reducing, reusing, and recycling as key to sustainable materials management. Combining this hierarchy framework with MSW treatment technologies, like landfill, incineration, composting, and anaerobic digestion, the comparison of the above technologies from some aspects are shown in Figure 9, and red font in figure indicates positive impact. Additionally, a schematic representation of the above four processes is shown in Figure 10, which are inputs and outputs of landfill, incineration, composting, and anaerobic digestion. A detailed description of each process is represented as follows.

Least Sustainable — Waste — Product — Most Sustainable

	Disposal	Recovery	Recycling	Recycling	Reuse	Source Reduction
Technology / Indexes	Landfill	Incineration	Composting	Anaerobic Digestion		
Sustainblility	Unsustainable waste of resources	Fertiliser loss negates any energy gain	Energy required	Carbon neutral		
Impact on the environment	Some $CH_4$to atmosphere, leachate problems	Toxic ash	Damage to ozone layer,also leachate problems	Total recovery of energy as CH_4, CO_2 & fertiliser		
Energy recovery	Partial if landfill gas extracted	Some but energy wasted	None	Maximum overall energy		
Fertiliser output	No fertiliser outputs	Some P&K output, but no destroyed	Incomplete pathogen kill	Clean NPK fertiliser and trace elements		
Water recovery	Lost in leachate	Burnt off	Lost to atmosphere	100%		
Heavy metal recovery	Not possible	Secondary waste	Not possible	Heavy metals can be recovered from digestate		

Figure 9. The comparison of municipal solid waste (MSW) treatment technologies [121,122].

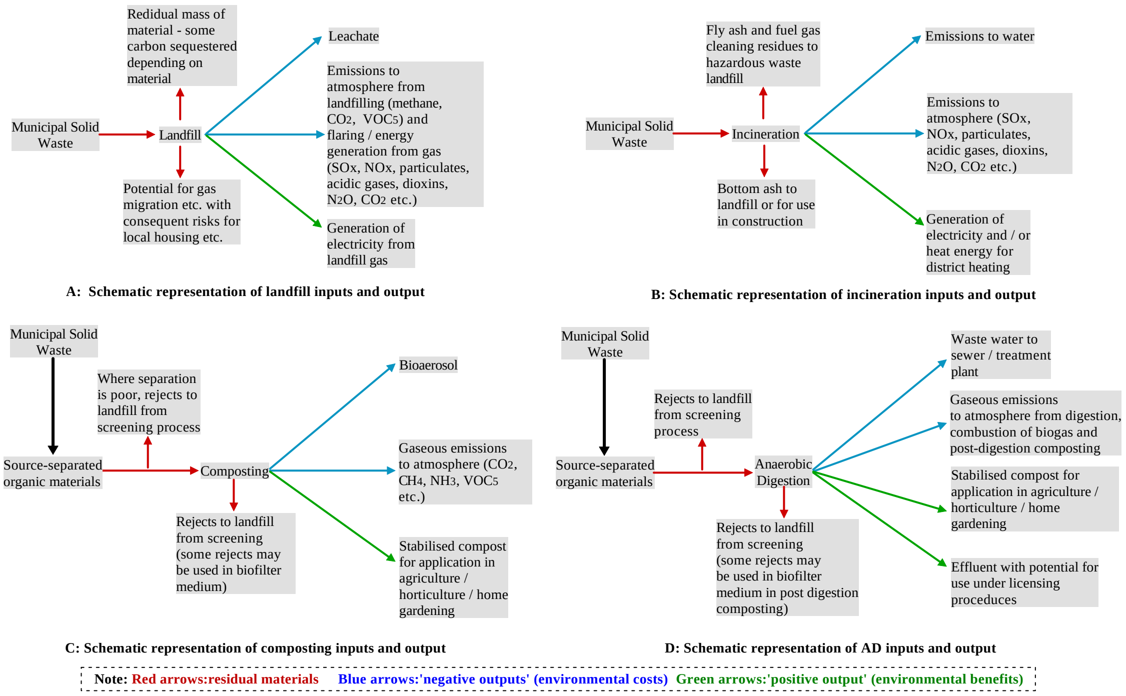

Figure 10. A schematic representation of landfill, incineration, composting, and anaerobic digestion [123].

3.3.1. Landfill

The landfill method was developed from a foundation of traditional piling and landfill treatments [124]. Landfill remains an attractive MSW disposal route because it is more economical than other technologies, such as incineration and composting in most cases [125,126]. Compared with incineration, the landfill approach requires only a relatively small investment, has more mature technology, a larger capacity, and a simpler operation [127]. However, gas and leachate generation are the inevitable consequences of MSW disposal in landfills, coming from microbial decomposition, climatic conditions, refuse characteristics, and landfill operations [128]. Serious environmental concerns at both existing and new facilities emerge when the gas and leachate migrate away from the landfill boundaries and are released into the surrounding environment [129]. Besides, there are other concerns like fires and explosions, vegetation damage, unpleasant odors, landfill settlement, ground water pollution, air pollution, and global warming [130].

There are some developments of economical and efficient technology to deal with landfill gas (LFG) problems effectively. Landfill gas can be sold as high-BTU (British Thermal Unit) pipeline-quality gas to utility companies, as medium-BTU gas to nearby businesses for use in boilers, or medium-BTU fuel for on-site electricity generation, space heating, or other applications [131]. Other newer LFG technologies include its use as an alternative vehicle fuel, for methanol production, and in fuel cells [132]. Some of the most promising technologies involve the utilization of LFG as a power generation energy source. The most common LFG energy application is in its use as an engine or turbine fuel for on-site electricity generation [133]. The reciprocating internal combustion engine is the most used technology for LFG electrical energy generation as it is economically feasible. Gas turbines (GT) are the second most used technology for LFG energy conversion, even though the number of installations is significantly lower than that of the ICEs (internal combustion engine) [134]. However, the landfill method of waste power generation has two problems: the penetration of leachate leakage can pollute groundwater and, because of the accumulation of methane, there is the danger of explosions [135].

3.3.2. Incineration

Incineration, an established means of processing combustible wastes, is the combustion of MSW under controlled conditions [136]. The objective of incineration is to reduce the volume which can eliminate the possibility of landfill gas and leachate generation by offering significant savings and destroying the organic, biodegradable waste components [137,138]. Incineration is a common technique for treating waste, as it can reduce waste mass by 70% and volume by up to 90%, as well as providing recovery of energy from waste to generate electricity [139]. Therefore, the residue is much more easily and cheaply transported and dumped than the original bulky material [140].

Waste incineration has become the main means of waste treatment in developed countries. In Japan, about 80% of MSW is incinerated and the recycling and reuse of MSW incineration ash in different ways have been described [141]. The incineration process is divided into three main parts: incineration, energy recovery, and air pollution control [142]. Further, incineration produces energy in the form of steam or electricity, if it is combined with an appropriate energy recovery system [143]. The incineration process occurs between 750 °C to 1000 °C and can be coupled with steam and electricity generation processes [143]. The incineration of MSW with electricity generation is regarded as the most reliable and economic option for the realization of a "harmless, reduction, resource-based" waste process. However, emissions from the MSW incineration contain air pollutants (SO_x, NO_x, CO_x), which may result in air pollution unless the incinerators are equipped with the appropriate pollutant control accessories [144].

3.3.3. Composting

Composting is defined as the biological decomposition and stabilization of organic substrates under the condition that allows for the development of thermophilic temperatures as a result of biologically-produced heat, and it has a final product sufficiently stable for storage and application to land without causing any environmental problems [145]. Composting increases beneficial soil biota, reduces the plant's dependence on chemical fertilizers and pesticides [146], and improves the soil's physical and biological properties, all of which can achieve effective resource recovery, and promotes a virtuous cycle of matter in nature.

Generally speaking, MSW treatment technology for composting includes: MSW classification, composting fermentation, and late treatment systems [147]. There is a new method for treating organic waste whereby three weeks of an anaerobic process is combined with a two week aerobic composting method (combined anaerobic/aerobic composting process, CCP) [148]. Compared with the traditional anaerobic and aerobic composting, CCP releases less organic gases in the anaerobic stage, such as NH_3 and reduces oxygen consumption in the aerobic phase, which saves labor costs [148].

The main objective of composting is to biologically convert putrescible organic material to a stabilized form and to destroy organisms pathogenic to humans [146]. Therefore, composting technology achieves recycling and the harmless treatment of the MSW adds an agricultural value. This technology has the ability to reduce pollution in the surrounding environment and has certain economic benefits, but the main premise is waste classification. The disadvantage of composting is the low-level production process. Compost quality is often not high, which leads to less fertilizer and re-accumulation and the formation of secondary pollution [149]. Promoting composting is also difficult where land resources and farmland are in short supply. However, with the development of modern agriculture and biotechnology, composting technology continues to improve and mature, and research and development into MSW composting will ensure this beneficial traditional technology becomes more effective in the future.

3.3.4. Anaerobic Digestion

Anaerobic digestion is a naturally-occurring biological process in which organic manures and wastes are partially decomposed by a mixed population of bacteria in the absence of oxygen [117]. The overall reaction is summarized as follows:

$$C_6H_{12}O_6(glucose) \longrightarrow 3CH_3COOH(aceticacid) \longrightarrow 3CH_4(biogas) + 3CO_2. \quad (5)$$

The main steps of AD are: pretreatment, anaerobic digestion, and post-treatment [150]. Before anaerobic digestion, pretreatment is needed to increase the digestibility, which mainly includes sorting and particle size reduction. In the AD process, organic matter decomposes and produces a biogas, which is a mixture of methane (CH_4), and carbon dioxide (CO_2), in an atmosphere without oxygen (anaerobic conditions) [151]. After digestion, the material usually needs some kind of refining before it can be used for horticulture or agriculture [150].

The AD method is popular because of its high efficiency in the degradation of organic matter. Due to the high temperature produced in the AD process, large numbers of pathogens are destroyed, and the resulting fermentation substrate can be used as high-quality fertilizer [152]. Anaerobic digestion is cost-effective, due to the high energy recovery linked to the process and its sustainable development of the environment. In the near future, it is expected that anaerobic digestion will become a popular technology for the organic part of municipal solid waste (OFMSW) [153]. The digested residue from AD is considered a stable organic matter with a very slow turnover of several decades given adequate soil conditions [18]. In this way the natural imbalance in the CO_2 can be adjusted by restoring or creating organic-rich soil. Due to this extra benefit, AD could become one of the most relevant technologies in the near future.

To summarize, from the point of view of energy requirements and environmental protection, the effective utilization of MSW can contribute significantly to sustainable development. With an adequate supply, MSW provides a major energy-saving opportunity and plays a significant role in the stage of BETP shift. Combing the results from the literature analysis, technology of MSW in the BETP shift phase can lead to effective sustainability, which is the trend of the future.

4. Discussion

Renewable energy plays a central role not only for the environment, but also for social and economic development at all levels, from families, to communities, to regional and national levels. Renewable energy sources combined with other factors can increase health equity, reduce poverty, and build societies that live within set environmental limits. According to REN21 reports, renewable energy has set up a competitive mainstream position in many countries around the world [154]. The report predicts that global renewable energy investment reached $7,800 trillion between now and 2040, and most investments in renewable energy will be concentrated in India and other emerging markets in Asia. The report also points out that with the growth of investment, technology progress, and cost reduction, the employment opportunities have increased. At present, a total of 8,100,000 people are working in the field of renewable energy, the steady increase in the rate of employment in the renewable energy industry is in sharp contrast to the sluggish labor market in the overall energy sector.

4.1. Trends from Literature Analysis

Our literature analysis has shown that a great deal of the research in this area has been focused on sustainable and environmentally-friendly energy from biomass to replace conventional fossil fuels, as biomass is considered the best alternative and has the largest potential to meet requirements and insure fuel supplies in the future. According to the report "Key World Energy Statistics 2016" from the International Energy Agency (IEA) shows that biomass energy accounts for roughly 10% (50 EJ) of the world total primary energy supply today [155]. Over the last few years, biomass and its related biofuels have gained worldwide interest because of their potential to reduce GHG (greenhouse gas) emissions, improve energy security, and enhance rural development. Further, there are significant socioeconomic advantages from the use of renewable resources for power generation compared to conventional generation technologies.

In order to alleviate the contradiction between economic development and energy and the environment, it is necessary to find the bioenergy technology which has the best potential for sustainable development. One novel method which was discussed above applies a social network analysis to determine the literature research focus. In the above literature analysis, CiteSpace also supports a timezone view to highlight temporal patterns between a research front and its intellectual base. Consisting of an array of vertical strips as time zones, the time zones are arranged chronologically from left to right so that a research front points back to its intellectual base [20]. Therefore, a timezone view is shown in Figure 11, which emphasizes the temporal relationships and make a specialty easily recognizable.

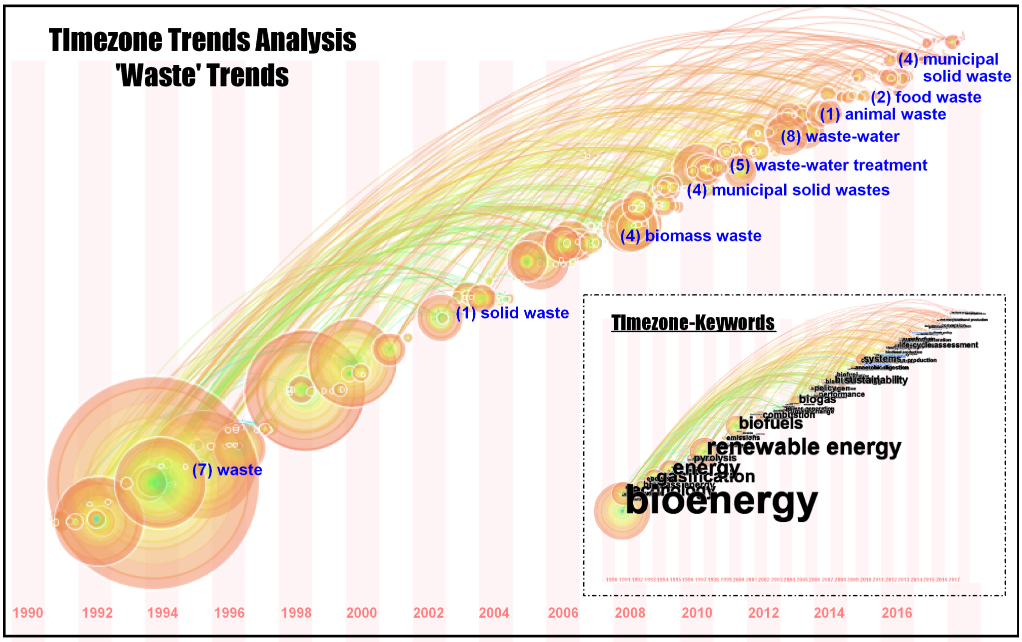

Figure 11. A timezone view of keyword foci trend analysis.

In the figure, the 'Timezone-Keywords' graph represents the keyword trends with time. From these points, we can highlight keywords about waste in blue font, which is shown in the 'Timezone Trends Analysis-Waste Trends' graph. This reveals that waste is the foci trend as time goes on, and it is the focus point in recent years, especially with respect to municipal solid waste. Therefore, from the literature analysis results, we can see that MSW is the core topic studied in most biomass literature in recent years. Recent research attention has also turned to the use of dedicated feedstocks for biofuel production, such as MSW. As a special biomass feedstock, MSW resources grow along with economic development, urbanization, and improvements in living standards. Therefore, on one hand, in order to solve this urban environmental issue, and on the other hand, to ensure enough land for food crops, problems which underline the BETP shift, MSW is expected to be have the most potential as a biomass resource. Biomass waste management as a new environmentally-friendly technology, can not only reduce environmental pollution and ease the pressure on the environment, it can also alleviate the global energy crisis, fully embodying the concept of harmonious development and sustainable development.

4.2. Sustainable MSW Management

Sustainable development includes the sustainable carrying capacity of the environment and the sustainable utilization of resources, or, more specifically, sustainable development refers to human beings who are under the conditions of not exceeding the resources and environment carrying capacity to promote economic development, sustainable supply of resources, and improve the quality of life [156]. Environmental protection is an important aspect of sustainable development, and MSW disposal is an important aspect of environmental protection. Therefore, the environment and social sustainable development are closely related to achieve MSW disposal and recovery.

In the BETP shift stage, there are four main technologies of MSW disposal. However, either MSW compost or landfill will make land resources more tense. Thus, a careful classification and sorting of municipal solid waste should be adopted. Then, according to the different properties after sorting, respectively using appropriate methods, different types of MSW can be used, so as to achieve the reduction of volume. It is necessary to treat and handle the problems of MSW with a positive attitude and the concept of sustainable development, and realize the waste to energy as soon as possible; that is, through reasonable disposal of MSW resources to prevent and control pollution, maintain the balance of the ecosystem and realize a sustainable use of resources.

Waste-to-energy (WTE) systems are designed for sustainable waste management, and generating electricity is an added benefit. A more complete life-cycle analysis would show that waste-to-energy actually reduces overall greenhouse gas emissions [157]. The idea behind WTE is that there is a lot of energy in MSW, in particular plastics, which have a high BTU value. Waste-to-energy not only solves problems with how to dispose of waste, but they are actually generating energy that would otherwise have to be generated through the use of fossil fuels [158]. Therefore, they are reducing CO_2 emissions and reducing the amount of raw materials that need to be extracted and processed in order to make electricity and power. In recent years, many studies have been done with respect to energy, the economy, and environmental evaluation (3E) of WTE [159–161]. From these evaluation, the benefits of proposed WTE from energy, economy, and environment perspectives can be summarized in Figure 12 [8,162,163], which also shows its evaluation parameters.

From the above, waste-to-energy stood out as a promising alternative to overcoming the waste generation problem and a potential renewable energy source. WTE encompasses thermal and biological conversion technologies that unlock the usable energy stored in solid waste [164]. Thermal treatment technologies mainly include incineration, gasification, and pyrolysis, while biological treatment technology mainly refers to anaerobic digestion [165]. Among above technologies, anaerobic digestion is the only form of biological treatment of MSW. It creates the least amount of waste and is the most efficient conversion technology, which has been established as a viable treatment technology for the organic fraction of municipal solid waste and will most likely play an even more important role in the future [166].

Anaerobic digestion does hold some potential to produce energy from waste sustainably, safely, and cost-effectively. The biogas produced by AD can be combusted directly to produce electricity and heat, or purified for injection into the gas grid or for use as a transport fuel [167]. In fact, anaerobic digestion is already used to create renewable energy at numerous municipal wastewater treatment plants. Anaerobic digestion is categorized as waste-to-energy because it produces energy from waste [165]. Unlike incineration and conversion technologies, AD almost exclusively runs on a separated biodegradable portion of the waste stream, not mixed solid waste [168]. It is more closely related to composting and managing organics than it is to a mixed solid waste disposal technology, and it is commonly analyzed separately from other WTE technologies. This technology has seen prolific growth throughout the EU in recent years. The main driver behind this growth are EU regulations to keep organic materials out of landfills [169,170].

Although there are some barriers, such as a lack of funding options, inexpensive landfill disposal, unable to demonstrate proven technology, and other technical problems [171,172], as with most renewables, incentives and governmental intervention are key growth drivers. Many policies that promote investment in renewable energy technologies, including WTE technology, have been put policies and taxes into place in order to decrease our dependence on fossil fuels for energy over the years. There is no single recipe for waste management. However, there are a few golden rules: start small, keep it simple, and advance step by step. The proposed WTE has shown its potential in sustainable MSW management, and there is no doubt that governments must take the first step, if only by introducing clear framework conditions.

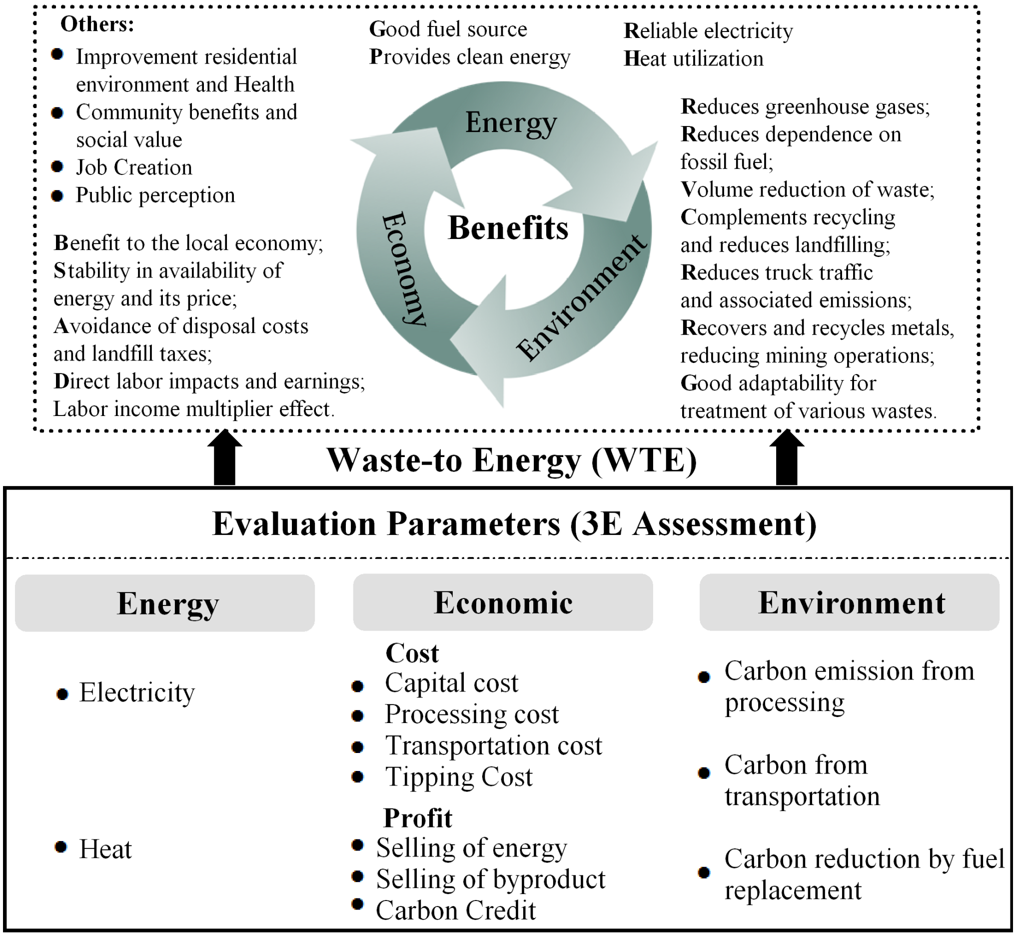

Figure 12. The benefits of WTE from 3E perspectives.

5. Conclusions

Biomass is a renewable energy source not only because the energy in it comes from the sun, but also because biomass can re-grow over a relatively short period of time compared with the hundreds of millions of years that it took for fossil fuels to form. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrate-complex compounds composed of carbon, hydrogen, and oxygen. When these carbohydrates are burned, they turn back into carbon dioxide and water and release the energy they captured from the sun. There are many types of biomass that can be used to derive fuels, chemicals, and power—such as plants, agricultural and forestry residues, organic components of garbage (municipal solid waste), and algae. This broad diversity of suitable biomass has resulted in increased research and development of technologies to produce fuels, products, and power at an industrial scale.

The development of bioenergy technology varies with time and will be affected by many factors, such as technical, environmental, economic, and social concerns, which include infrastructure, facilities, cost, price, geography, transportation, competitors, and so on. Up to now, there has not been a paradigmatic framework for biomass energy technologies, though various works have been conducted on a low-carbon economy. Therefore, in order to discover bioenergy technology development trends, some methods should be used to study this framework. Similar to the gradual evolutionary process of life, the technological paradigm evolves under the driving forces of market demand and industrial competition. The technological paradigm is proposed to solve problems based on natural science principles, which became a classic concept in the innovation and technological change literature.

To focus on bioenergy technology evolution, an advanced data analysis system (DAS) was created based on bibliometrics and certain visual methods, which allows for a comprehensive literature analysis to determine that this focus trends. CiteSpace, as expressed by the keywords and clusters, is applied in this paper as the main analysis tool to detect and visualize emerging trends. The analysis results of foci trends were in accordance with the technological paradigm theory first defined by Dosi. Therefore, through the technological paradigm theory and a literature analysis, three distinct phases of bioenergy technologies were identified. Additionally, a bioenergy technological paradigm (BETP) was proposed to describe the evolution and provide a method for an investigation of past trends and a prediction of future possibilities.

BETP includes BFDP competition, BFDP diffusion, and BFDP shift. Different key technologies are in the above three stages. Direct combustion is in the BFDP competition stage, which contains stove combustion, boiler combustion, and biomass briquette combustion. These technologies seems immature and have low thermal efficiency and pollution problems. According to demand-pull and technology-push theories, technological innovation of bioenergy will go to next stage, which is BETP diffusion. Thermochemical conversion and biological conversion became the dominant designs in the BETP diffusion stage, which matured and developed a stable product structure. Gasification and pyrolysis are two thermochemical conversion technologies, and anaerobic fermentation of biogas, bioethanol, and biodiesel are biological conversion technologies. These technologies have the advantages of low energy consumption, high conversion rates, easy industrialization, and have significant environmental benefits. However, threats to forests and biodiversity, food price increases, and the competition for water resources are the key negative impacts of these technologies. Therefore, at the end of the BETP diffusion phase, there is a need to develop more paths, which can contribute to BFDP shift stages.

The emerging MSW technology in the BFDP shift stage has the potential to promote sustainable development. This is also because the problems of waste management arose with the start of urbanization, bringing people to live together in larger communities. Nowadays, the global quantities of waste, continuously increasing with the increasing world population, pose serious challenges to waste management, especially in urban areas. MSW technology includes landfill, incineration, composting and anaerobic digestion. However, in order to treat and handle MSW positively and realize the waste to energy as soon as possible, Waste-to-energy are designed for sustainable waste management. Among WTE, anaerobic digestion has the potential to produce energy from waste sustainably, safely, and cost-effectively. To minimize the amount of waste we generate and wring the most value out of the trash we create requires a mix of smart science, practical policy, and appropriate technology. To achieve the goal of sustainable waste management, we will have to work with our waste more than ever.

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Abbreviations

The following abbreviations are used in this manuscript:

BETP	Biomass energy technological paradigm
MSW	Municipal solid waste
WTE	Waste-to-energy
DAS	Data analysis system
WOS	Web of Science
ISI	Institute for Scientific Information
SCI-Expanded	Science Citation Index Expanded
SSCI	Social Sciences Citation Index
A&HCI	Arts & Humanities Citation Index
TF*IDF	Term frequency-inverse document frequency
AD	Anaerobic digestion
LFG	Landfill gas
BTU	British Thermal Unit
GT	Gas turbines
ICE	Internal combustion engine
CCP	Combined anaerobic/aerobic Composting Process
OFMSW	Organic part of municipal solid waste
IEA	International Energy Agency
GHG	Greenhouse gas
3E	Energy, economy and environmental

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