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The Transformation of China's Chemical Industry: Analysis of the Causes and Countermeasures from the Perspective of Circular Economy

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Abstract: This article concerns analyzing China's chemical industry from the circular economy perspective, which will elaborate on the reasons for applying circular economy policies in this industry and the countermeasures (solutions) for the chemical industry or firms achieving a circular economy. The reasons include the economic, energy, and environmental aspects. From an economic aspect, the trend of the total revenue of the chemical industry in China from 2005 to 2021 is constantly increasing. Moreover, in 2021, its total revenue was top in the world. Thus, China's chemical industry benefits China's economy and has predominance globally, which is an essential industry. Furthermore, in energy and environmental aspects, the chemical industry in China has the characteristics such as high emissions, and high-pollutions, and being energy-intensive. These features damage the environment and sustainable development. Fortunately, this article will state the solutions for reaching CE in this industry when adopting circular economy policies. The countermeasures contain decarbonization and a circular chemistry framework, which are the reliable solutions presently.

Keywords: circular economy, China's chemical industry, sustainability, literary research

1. Introduction

1.1. Research Background

The focused fields, including climate change, energy use, environmental pollution, renewable energy, and sustainability, are mutually relevant. Many national and international departments and leaders are concerned about the issues and developments in these fields. Wherein climate change, the use of energy, and environmental pollution have an adverse influence on nature and humans. The United Nations Framework Convention on Climate Change (UNFCCC) secretariat (United Nations Climate Change), The Intergovernmental Panel on Climate Change (IPCC), and World Health Organization (WHO) attach great importance to the cause and impacts of climate change, the politics on climate change, addressing climate change, etc. [1-3]. Climate change is the changes in climate patterns, which is because by greenhouse gases from humans' activities and natural systems [4]. In 2018, the natural disasters associated with climate change, including wildfires, storms, droughts, and floods, were 315 cases [4]. 68.5 million people were impacted, and economic losses were about

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$131.7 billion, a deplored occurrence [4]. Unfortunately, the experts predict it may global warm above 1.5 °C from 2030 to 2052 compared to the pre-industrial level [4]. Thus, the UNFCCC, as the parent treaty 1997 Kyoto Protocol and 2015 Paris Agreement devote to encouraging and supervising parties contributing to addressing climate change and global warming [1]. The United Nations refers to the use of energy that mainly causes climate change, which has 60% responsibility for global greenhouse gases emission [5]. In addition, the use of energy will likewise lead the environmental pollution. For example, fossil fuels will pollute the toxic greenhouse gases: nitrogen oxide (NO2) and Sulphur dioxide (SO2), which leads to acid rain [6]. Because of wind, acid rains fall into the soil, changing the soil's characteristics [6]. Except for acid rains, other pollutions from fossil sources, including particulate matter, smog, and aerosols, damage the environment, human health, and social welfare [6]. Simultaneously, energy is limited, particularly non-renewable natural resources (fossil fuels, etc.). Cause the rapid development of the international economy, the rising consumption of natural energy is conspicuous. Significantly, the quantity of non-renewable resources will not increase, which brings a sense of crisis to humans on limited energy and economic development. Furthermore, energy-causing global warming and pollution are practical issues. Thus, improving and creating renewable energy is the cornerstone of human development, which comprises biological funds and energy flows such as fisheries funds, forests, hydropower, solar energy, etc. [7]. Indeed, when renewable energy is considered, sustainability will be introduced because it can stimulate sustainability in developed and developing countries. The World Commission on Environment and Development defined sustainable development as satisfying current generations' demands and protecting future generations [8]. This definition is equally the central principle of the sustainable development goals (SDGs) from the United Nations (UN), which has 17 SDGs and was influential [8]. The SDGs aim to assist global development and provide information for public policy-decision [8]. Therefore, climate change, energy use, environmental pollution, renewable energy, and sustainability are interrelated, leading to some theories or terms that may spin-off, such as the circular economy (CE).

1.2. The Circular Economy

Moraga et al. proposed that CE as an umbrella concept emphasize using energy or resources responsibly and cyclically [9]. Fan and Fang referred to that CE is opposite to the traditional linear economy [10]. The linear economy supports the model with 'take, use, and dispose of' [11]. From 1970, resource extraction was 92 billion tons every year, which will increase by 70% in 2050 [11]. The enormous quantity of resource extraction and uses threaten the environment and natural resource reserves or energy. The UN indicated that in 2021, there would be only 8.6% circular for the global economy [11]. The role of CE is maximizing reduce environmental pollution and use of energy and improving economics at the same time [9]. Thus, CE becomes a policy to regulate firms, including disconnecting the relationship between energy uses and economic development, decreasing material inputs and wastes, and the rising capability of cyclic utilization [9]. In addition, Schroeder et al. illustrated that CE is primarily associated with SDGs 6, 7, 8, 12, and 15, which are Clean Water and Sanitation, Affordable and Clean Energy, Decent Work and Economic Growth, Responsible Consumption and Production, and Life on Land, respectively [12]. Therefore, how much the UN values CE and the functions of CE in sustainability are prominent and effective. In the last few decades, scholars, policymakers, and leaders likewise start to understand and attach importance to CE [13]. Pesce et al. mentioned that in recent years, CE theory has become more meaningful in China's scientific, economic, and political debates [13]. For CE in China, Zhu et al. illustrated since 2000, CE-relevant policy has been complete as time changes [14]. The policy actors contributed to the cumulative progress of CE policy because of their positive attitudes and learned knowledge or experiences from the international society [14]. Therefore, CE is a major theory and model for achieving sustainability and reducing pollution.

1.3. CE in China's Chemical Industry

Many scholars studied the level or overview of CE in China and the generalized strategies for achieving CE. However, only some articles analyze CE in China's one specific industry. Evidently, the chemical industry is an appropriate objective because it drives China's economy, has mass energy consumption, and produces pollution damaging the environment. All over the world, the chemical industry, as the basis of modern society, can earn $4 trillion (American dollars) in total revenue per year [15]. Up to 2020, the revenue of the chemical industry in China accounted for 45 percent of total global revenue, which created the highest revenue in the chemical industry in the world [15]. Nevertheless, the energy uses in China's chemical industry are not optimistic. In 2011, energy consumption in China's chemical industry corresponded to the sum of energy uses in the Czech Republic and Uzbekistan [16]. The results are polluting water, air, and soil, which harms the environment and human health [17]. Thus, this article plans to analyze the transformation of the chemical industry in China from the CE perspective.

1.4. Structure

In this article, there are five main parts. Firstly, the introduction inducing background, the circular economy, and CE in China's chemical industry. The 'background' is associated with CE, which introduces the causes of the existence of CE. Moreover, it illustrates the consequences of high emissions and pollution and the heavy emphasis of the world on renewable energy and sustainability. 'The circular economy' illustrated the concepts or principles of CE. 'CE in China's chemical industry' states the author's motive to analyze CE in China's chemical industry. Secondly, the method that literary research will be demonstrated. Thirdly, the results show the causes of adopting CE policies in China's chemical industry covering economic reasons and energy consumption, and environmental issues. Fourthly, in the discussion, the author will propose two steps for reaching CE in the chemical industry comprising decarbonization and using the framework of circular chemistry (CC). Finally, the conclusion will show the summary of the article, the expected audiences, and the drawback of this article.

2. Methods

In this article, literature research will be utilized to analyze the causes of applying the CE policy in China's chemical industry and solutions for achieving CE in this industry. Literature research explores and surveys the relevant literature to the authors' field. Based on the literature, the authors will describe the causes and countermeasures, summarize the core thoughts, and think critically. According to the literature research, this article demonstrates the causes, including economic reasons and the issues of energy and the environment. The literature may be academic articles, official and industrial reports, databases, and news. Subsequently, the literature research is expected to find the solutions for applying CE in this industry. Therefore, literary research is an ideal approach to analyze this topic.

3. Results

CE in China has been considered a national policy. In 2008, adopting the Circular Economy Promotion Law of the People’s Republic of China was a milestone for applying CE in China [13]. Moreover, from 2006 to 2010, the Eleventh Five-Year Plan and the Thirteenth Five-Year Plan had one

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part illustrating CE and its further strategies specifically and respectively [13]. In 2021, the 14th Five-Year Plan (2021–2025) Circular Economy Development Plan indicated that CE is the path to achieving emission peak and carbon neutrality [18]. In these mentioned policies, China has encouraged and enhanced the advancement of CE in the chemical industry. Due to the existing policy highlighting CE, CE is the essential fundamental and politic of developing economy and sustainability in China. Therefore, two causes resulted in China adopting these CE policies in the chemical industry: economic reasons, energy consumption, and environmental issues.

3.1. Economic Reason

Since 2011, the revenue of China's chemical industry has been the largest in the world, which stimulates 50 percent of the global chemical industry's growth at least [19]. Although the start of China's chemical industry was later than Europe, the evolution of the chemical industry in China was rapid [19]. As figure 1 shows, there was an increasing trend in the revenue of the chemical industry in China from 2005 to 2021. In 2005, the revenue of the chemical industry in China was the lowest, which was $2,035.9 billion. From 2011, there was a dramatic rise, which increased from $3,181 billion to $3,848.5 billion. The revenue grew steadily until 2015, which had a decrease from $4,140 billion to $3,783.1 billion. Fortunately, the revenues in 2015, 2016, and 2017 were still higher than before 2010. From 2014 to 2020, although the revenues were not excessively low, there was an apparent fluctuation. Due to COVID-19, human welfare and the international economy were shocked, and the revenues of the chemical industry in China in 2019 and 2020 were impacted identically. However, in 2021, the revenue peaked, which created a mass gap between 2020 and 2021 ($4,732.1 billion).

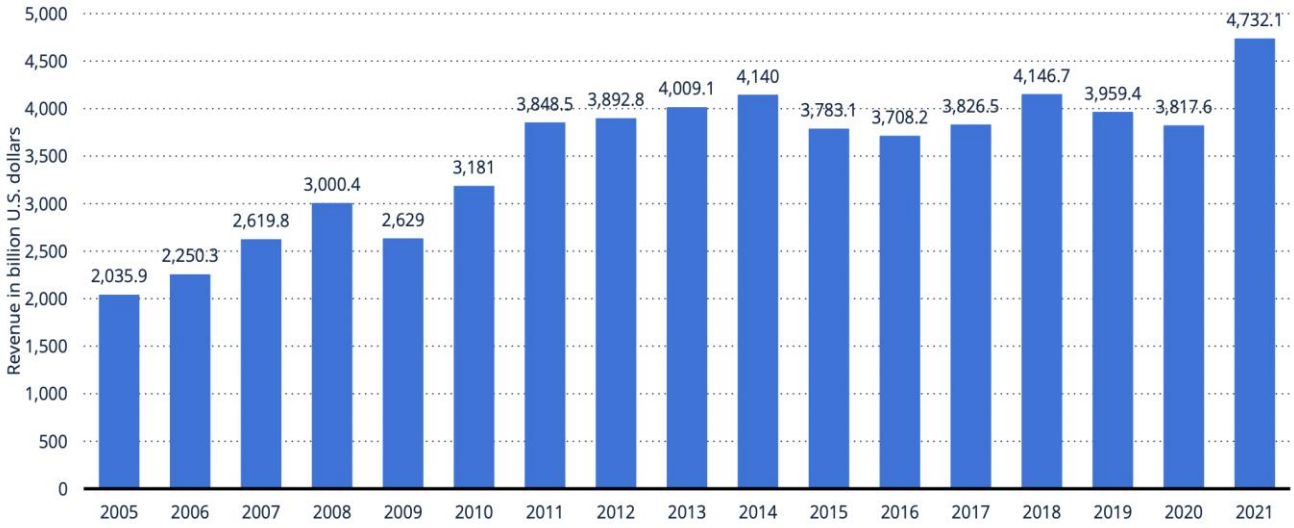

Figure 1: The revenue of the chemical industry in China from 2005 to 2021 (unit: U.S dollars). Data source: https://www.statista.com/study/101026/china-s-chemical-industry/ [20]

For comparing to other counties' chemical industry, figure 2 illustrate the comparison between the twelve states' revenues in chemical markets in 2021, which have the major chemical markets in the world, including China, the United States, Germany, Japan, South Korea, India, France, Ireland, Switzerland, Belgium, Brazil, and Italy. Indubitably, in 2021, the revenue of China's chemical industry was the highest in the world, which was 1,685.15 billion euros larger than the United States in second place. Therefore, the status of China's chemical industry worldwide is distinct and conspicuous.

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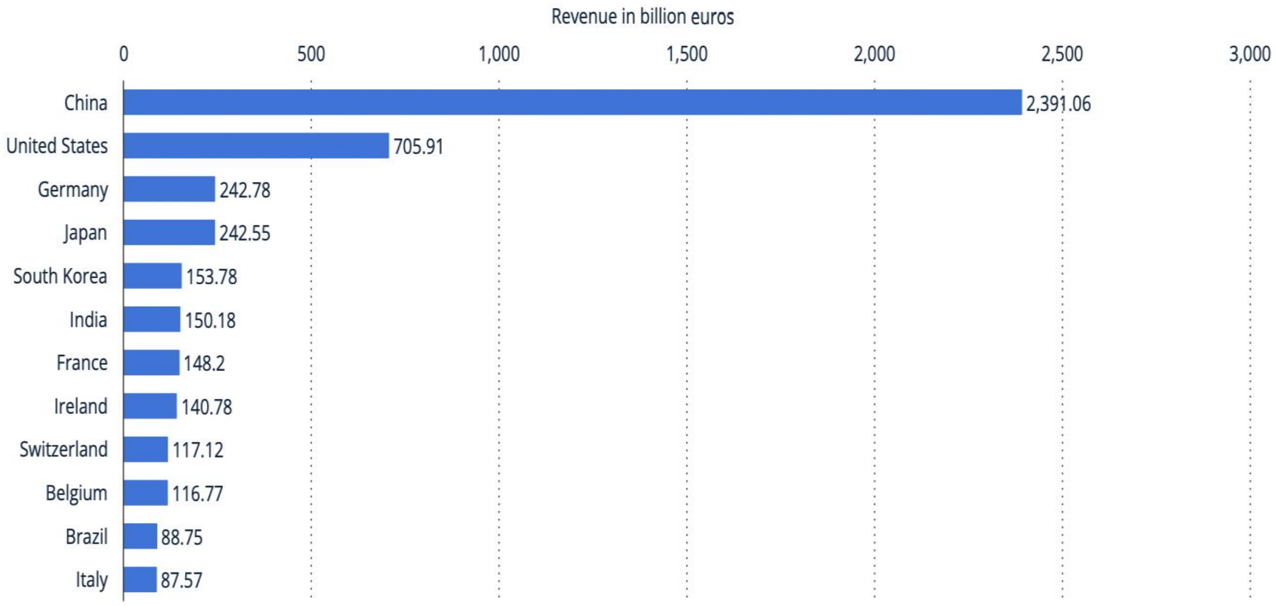

Figure 2. The revenue of guiding chemical industry by the national wild in 2021 (unite: billion euros).

Data source: https://www.statista.com/study/101026/china-s-chemical-industry/ [20]

Assuredly, the primary chemical enterprises have contributed to China's economy and gross domestic product (GDP). State-owned chemical enterprises are the major categories in China's chemical industry [21]. They have the capability and resources to lead the national chemical industry. According to the national economic index, from 2011 to 2015, the average annual growth rate of the chemical industry in China was 7%, which was higher than developed countries [16]. Indeed, for China's economy, the chemical industry is the main driving force. As figure 3 shows, in 2021, the Fortune China 500 ranking indicated the revenues of leading chemical enterprises in China, comprised of Hengli Petrochemical Co., Ltd, Xinjiang Zhongtai Chemical, Wanhua Chemical Group Co.,ltd, Yunnan Yuntianhua Co., Ltd, etc. Hengli Petrochemical Co., Ltd had the most significant revenue in 2021, which was 152.37 billion yuan. Moreover, the value of chemical sales in China proves the importance of this industry and these leading enterprises for the economy because it is commonly the largest GDP component. As figure 4 demonstrates, there was a stable and increasing trend. As mentioned, China's chemical industry's total revenue fell in 2019 and 2020 because of the shock from COVID-19. However, the value of chemical sales did not decrease. Thus, the price of chemical products per unit may decline in 2019 and 2020; the demand and supply of chemicals were not impacted negatively. In 2020, the value of chemicals peaked in figure 4, which was 1,546.6 billion euros. Therefore, the leading chemical enterprises in China play a highly efficient role in improving the economy.

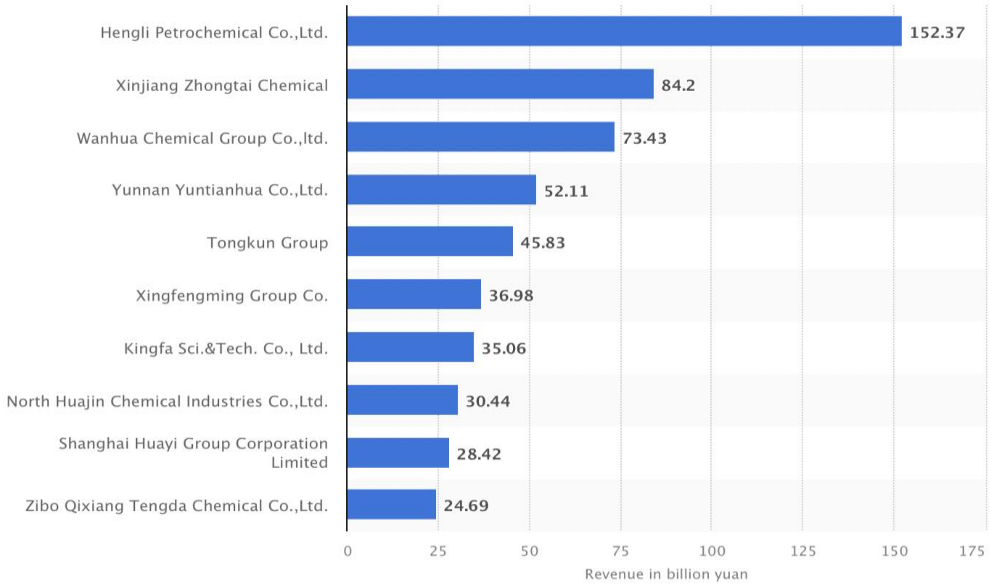

Figure 3: The revenues of leading chemical enterprises in China (the Fortune China 500 ranking). Data source: https://www.statista.com/statistics/454585/china-fortune-500-leading-chinese-chemical-companies/ [22]

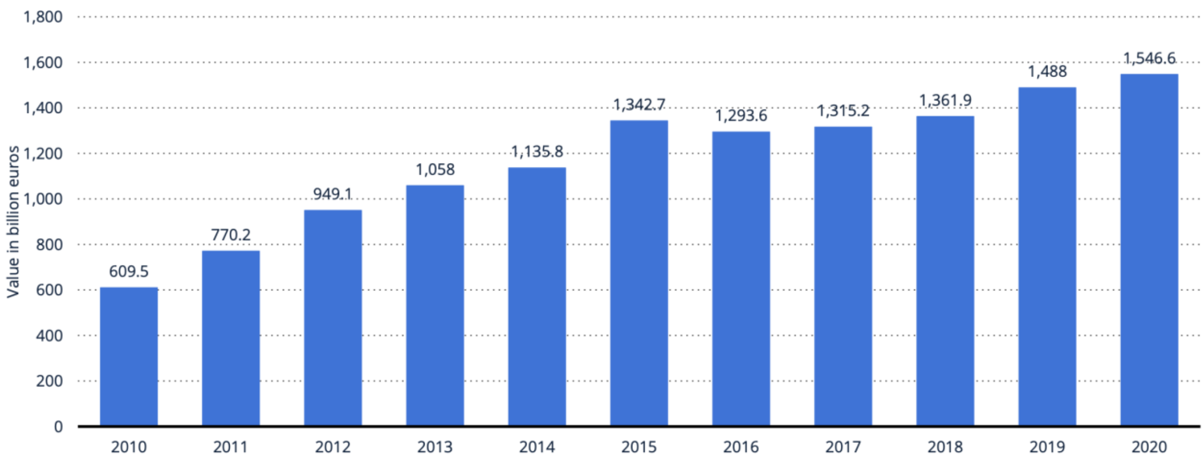

Figure 4: From 2010 to 2020, the value of chemical sales in China (unit: billion euros). Data source: https://www.statista.com/study/101026/china-s-chemical-industry/ [20]

4. Energy Consumption and Environmental Issues

The chemical industry is a project with energy-intensive, has high emissions, and high-pollutions. China's chemical industry is no exception, which is the primary carbon dioxide emissions industry. As mentioned, China's chemical industry is prominent in China and worldwide. It launched the advance of the economy in China. According to the experiences of developed states such as America and Japan, the economy's advance will lead to high energy consumption. The rise of the chemical industry in China costs energy overconsumption and environmental issues, which cramps sustainable development. In addition, the non-renewable characteristics of energy cause people anxiety because they must consider the welfare of current and future generations. Generally, the chemical industry will utilize energy as fuel and inputs such as liquefied petroleum gases (LPG), natural gas, and natural gas liquids (NGL) [23]. Thus, as figure 5 illustrates, the energy consumption in China's chemical industry persistently rises from 2000 to 2016. Between these sixteen years, the energy consumption in China's chemical industry increased from 143-million-ton coal equivalent (Mtce) to 480 Mtce [24]. From 2001 to 2007, it annually increased by 15%. The energy consumption in 2008 and 2009 was almost equal, approximately 310 Mtce. Additionally, from 2009 to 2015, the yearly growth rate was 6.5%. Although the growth rates fell about twice as low, the trend of energy consumption went upward.

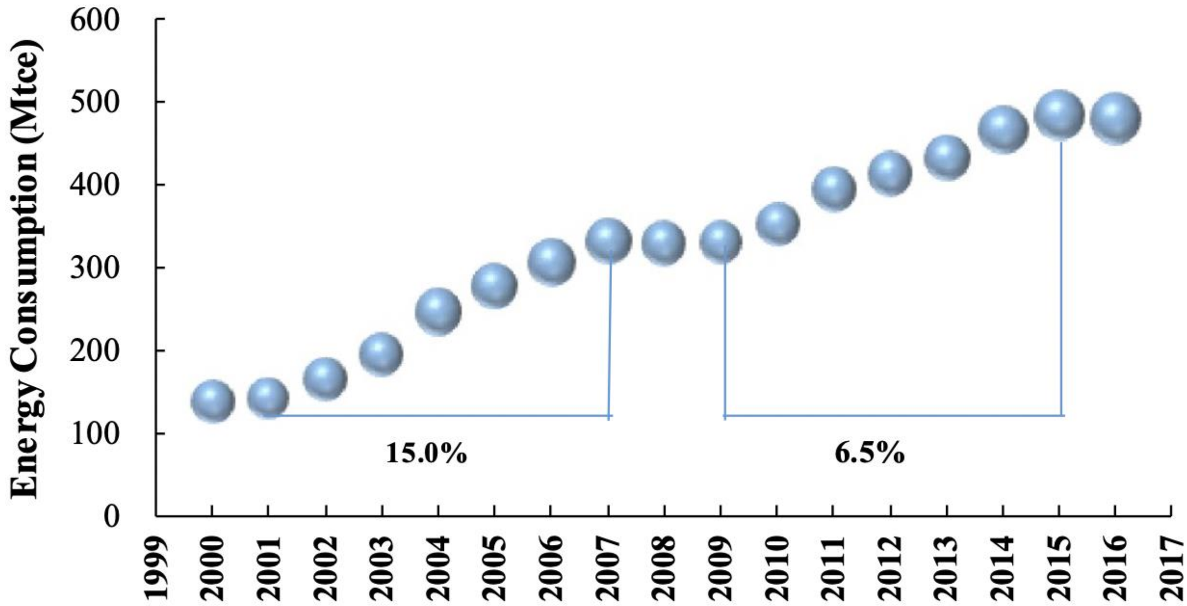

Figure 5: The energy consumption of the chemical industry in China from 2000 to 2016.
Data source: https://kd.nsfc.gov.cn/paperDownload/1100002744044.pdf [24]

In China, coal is a prominent actor in the energy structure. Between 1990 and 2009, China's coal consumption increased from 1.06 billion metric tons to 4.02 billion, almost quadrupled. As of 2020, 56.8% of the coal was used in producing energy [21]. It is difficult to change this mode in the short term. For the chemical industry in China, coal is not only the source of primary energy but also input [21]. Indeed, the chemical industry has a high demand for coal and energy, leading to increased emissions. The carbon dioxide emissions (or greenhouse gases) of the chemical industry in China account for 20% of the national industrial emissions in total; it likewise accounts for 13% of the country's carbon dioxide emissions in China [21]. Although China's chemical industry has significant emissions, the different chemicals may have a separate carbon dioxide emission level. As figure 6 shows, there is ten essential chemicals' carbon dioxide emission level. The greenhouse gases from producing ammonia, oil refining, and methanol are most outstanding in 2020 in China, which are 220 million metric tons, 218 million metric tons, and 204 million metric tons, respectively. The gaps between them were not distinct. However, the carbon dioxide emissions from calcium carbide, CtG & CtL, ethylene, Caustic soda, P-xylene, sodium carbonate, and coal to ethylene glycol are apparently lower than the first three chemicals. Coal to ethylene glycol's carbon dioxide emissions was inferior in figure 5, which is 19 million metric tons. Moreover, the carbon emission of sodium carbonate was broadly the same, which only differed by 1 million metric tons. Although their carbon emissions are relatively lower than the first three chemicals, their contribution to emissions is massive. Therefore, China's chemical industry is energy-intensive, with high carbon dioxide emissions.

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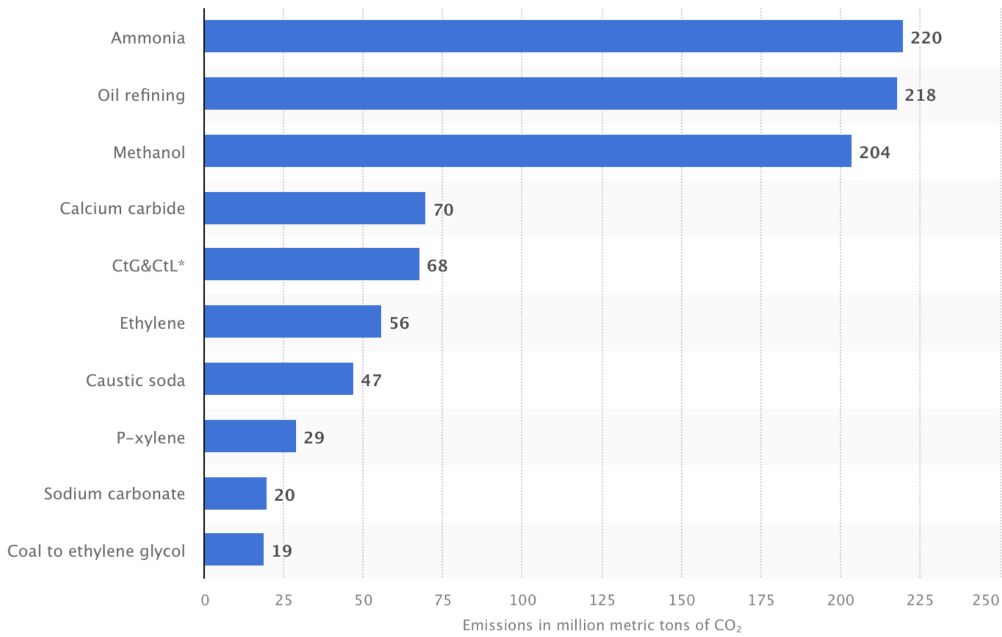

Figure 6: The carbon dioxide emissions of China's main chemicals in 2020 (unit: million metric tons).
Data source: https://www.statista.com/statistics/1329892/china-chemical-industry-carbon-dioxide-emissions-by-segment/ [25]

Furthermore, the chemical industry pollutes the environment caused of energy-intensive production processes and waste disposal. Firstly, the most considered environmental problems are the pollution of air, water, and soil. Due to the chemical industry's high emissions in China, air and water pollution is obvious around the chemical enterprises, especially in chemical industry parks (CIPs) [26]. As of 2020, the numbers of CIPs in China are large worldwide, which are 2100 CIPs [27]. The environmental problems of the chemical industry reflect clearly in CIPs. Some actions in chemical companies will lead to the pollute air and water, such as using specific chemical processes (e.g., chlorophenols), utilizing some chemical groups (e.g., sulphurous compounds and volatile organic compounds (VOCs)), treating wastes and wastewater, reaction, and operating distillation facilities [28]. The air pollution from CIPs will affect people's health, including sulphur dioxide (SO2), volatile organic compounds (VOCs), and particulate matter (PM2.5) [26]. If people live in an environment with mentioned air pollution in the long term, they may suffer diseases such as asthma, lung cancer, acute respiratory infections, and respiratory diseases [26]. Secondly, relying on the evidence, 80% of chemical firms located the densely populated area and areas near lakes and rivers in 2006 [27]. Thus, since 2006, the water pollution of chemical firms has usually occurred every two days, which was the most common environmental issue in China's chemical industry, accounting for 70% of environmental issues [27]. When water pollution is happed, the drinking water, agricultural water, and fishery may be harmed. Thirdly, the organic pollutants, Polycyclic aromatic hydrocarbons (PAHs), possibly exist in the chemical firms' areas to negatively impact soil [29]. PAHs are mutagenic, teratogenic, and carcinogenic, with a higher pathogenicity rate in children than in adults [29]. Through combusting coal and petroleum, PAHs may be produced to pollute soil and agriculture [29]. For example, scholars researched the soil in the Yangtze River Delta because there were many chemical firms. The result was that the soil in the Yangtze River Delta was monitored existence of PAHs; moreover, soil near the chemical firms has higher PAHs [29]. Apparently, the effect of

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PAHs is broad, and which not just damage the soil near the chemical firms. Therefore, the pollutions of water, air, and soil are the environmental issue of the chemical industry in China.

5. Discussion

When one industry has higher economic value, increased emissions, high-pollutions, and the energy-intensive, circular economy may be the effective economic model to improve these situations. Thus, the transformation of the chemical industry in China is valuable for China to achieve sustainability and the chemical value chain's low-carbon transformation in the world. Although the CE policies in China for the chemical industry has been adopted, researchers and industry insider are still exploring the specific approaches to achieve CE in this industry. Due to the complex technological process in the chemical industry and the advances in science and technology, people may constantly innovate the movement of CE in the chemical industry in the future. At present, decarbonization and the framework of CC are admirable measures [21, 30].

5.1. The Decarbonization

The decarbonization of the chemical industry can be summarized in three features, energy-saving, low-carbon inputs, and low-carbon fuels. The concrete steps are consumption reduction, enhancing efficiency, substituting fuel and inputs, and back-end treatment. Firstly, as mentioned, ammonia was the largest emitter in China's chemical industry in 2020. Moreover, it usually produces major carbon dioxide emissions in the chemical industry. However, ammonia is mainly used to produce fertilizer [21]. Thus, consumption reduction represents decreasing fertilizer consumption by increasing fertilizer efficiency. Likewise, consumption reduction encourages firms to recycle rubber, synthetic fiber, and waste plastics rather than use an amount of plastic. Secondly, enhancing efficiency can be managing thermal energy more actively and developing the catalyst's efficiency because most chemical reactions are processed under a catalyst, high temperature, high pressure, and the use of large fuel [21]. If enhancing efficiency can be achieved, energy efficiency can be realized by reducing fuel and carbon dioxide emissions. Thirdly, substituting fuel and inputs means using clean energy and zero-carbon resources rather than fossil fuels and traditional feedstock. For example, using clean energy, including electric heating, biomass, and hydrogen. Electric heating can alternate fossil fuel; biomass such as livestock manure, forestry waste, and straw can be utilized as bunkers; hydrogen can satisfy the required higher temperatures of chemical reactions, which will only leave the water after burn [21]. Additionally, zero-carbon resources like ethane and green hydrogen will fall the carbon dioxide emission from the production processes [21]. Finally, back-end treatment is through negative carbon technology to manage the rest of the carbon dioxide emissions after using carbon reduction solutions [21]. Carbon capture and storage (CCS) is one category of negative carbon technology that aims to reduce carbon dioxide emissions from the atmosphere directly. For example, after CCS catches carbon dioxide emissions, it can be kept underground by compressing or injecting into saline aquifers and oil and gas fields [21]. Therefore, the decarbonization of the chemical industry is a series of solutions that assist chemical firms in achieving CE.

5.2. The Framework of Circular Chemistry

After the basic step for the chemical industry achieving CE (decarbonization), applying the framework of CC can reach CE more completely. Although transforming the chemical industry to CE is difficult because of its heterogeneous nature, the framework of CC provides a proper plan. It suggests the transformation of three main parts: the development of the process, the modification of the process or products, and the scenario for the end of use [30]. Firstly, as figure 7 shows (development of process), the first and second processing show a closed loop, which means chemical firms

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can reuse the inputs circularly and use renewable energy such as chemicals, water, recovered solvent, etc. The use of renewable energy and cycled materials at the first and second processing can reference the practices of decarbonization. The circular level at the first processing decides a chemical firm's sustainability level [30]. Secondly, process intensification (PI) can realize the modification of processes or products, which assists chemical insiders in consuming or designing a new process or equipment to avoid the drawbacks of using resources and energy (producing waste and costs). The development of PI may follow the principle of CE to motivate recycling, low emission, and sustainability. Finally, innovative technology (new chemistry) can be adopted in three parts mentioned, especially the third. As figure 7 demonstrates, at the scenario for the end of use, the chemical industry is encouraged to recycle their waste or reuse the products or byproducts such as polymers, fine chemicals, active pharmaceutical ingredients (API) or pharma, petrochemicals, agrochemicals, and electronics. They can be recycled, recovered, refurbished, and repurposed. If they become waste totally, the new chemistry may rationally manage them to avoid high pollution or emissions. Therefore, decarbonization and CC are effective methods for the chemical industry to reach CE in China.

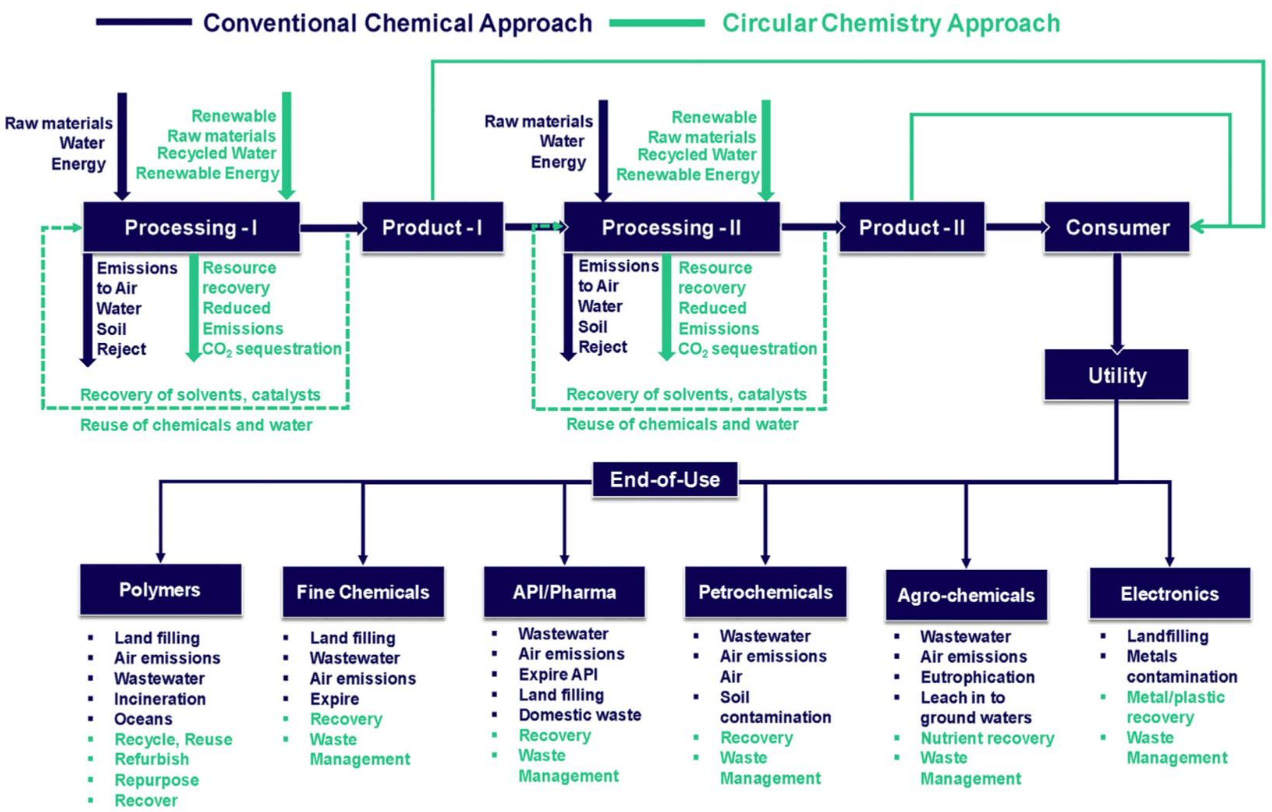

Figure 7: The framework of CC: the difference between the conventional chemical approach and CC.

Data source: https://www.sciencedirect.com/science/article/abs/pii/S2452223620301310 [30]

6. Conclusion

In conclusion, this article illustrates why China has adopted CE policies in the chemical industry. They are economic reasons and energy consumption, and environmental issues. China's chemical industry can create tremendous value in China's economy and occupy a central status in the international chemical industry. Moreover, the energy-intensive, high-emissions, and high-pollutions of the chemical industry in China cannot be ignored. China's chemical industry uses energy as feedstocks and fuel, resulting in high energy consumption and higher carbon dioxide emission and pollution. These issues harmfully impact the environment, sustainability, and climate change. Thus, although China's chemical industry is planned to transform, China will protect its maximum economic value. In other words, CE is an ideal and impelling economic model that can positively modify the unsustainable situation and benefit China's chemical industry's long-term economy. After that, the author states two solutions to assist chemical firms in reaching CE through the practical steps: decarbonization and the using framework of CC. Decarbonization principally aims to decrease energy and non-recycled resource consumption, increase the efficiency of products, choose low-carbon inputs and fuels, and use CCS for back-end treatment. In addition, the framework of CC supports the improvements in the development of processes, the modification of processes or products, and scenarios for end-of-use. This framework not only concerns decarbonization but also emphasize the critical roles of innovative process, equipment, and new technique in the chemical industry in achieving CE. Therefore, this article plan to assist the insiders of the chemical industry in China because it explains the reasons for adopting CE policies and provides the solutions for transformation. However, because of the lack of original data, this article did not use other methods to analyze the current developed level of CE in China's chemical firms as examples. Therefore, the author analyzes China's chemical industry macroscopically from CE's perspective.

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