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Sustainable Development of Lithium-Based New Energy in China from an Industry Chain Perspective: Risk Analysis and Policy Implications

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Abstract: Lithium-based new energy is identified as a strategic emerging industry in many countries like China. The development of lithium-based new energy industries will play a crucial role in global clean energy transitions towards carbon neutrality. This paper establishes a multi-dimensional, multi-perspective, and achievable analysis framework to conduct a system analysis for determining the potential risks involved in the sustainable development of lithium-based new energy industries in China and other countries towards a carbon-neutral future. The results show that critical risk points including resource supply risks, overcapacity risks, environmental impact risks, and regulation absence risks have emerged with the large-scale development of the lithium-based new energy industry in China. These will not be helpful for the sustainable development of the lithium-based new energy industry, which will play a vital role in attaining the goal of carbon neutrality. Based on our risk identification, a policy implication analysis was performed to investigate potential policy countermeasures including promoting the exploration and development of domestic lithium resources, improving the coordination degree of the lithium-based new energy industry, adopting green and low-carbon development paths, and improving the quality of industry regulation. Based on our findings, recommendations are proposed to optimize policy formulation and implementation for stimulating the sustainable development of the lithium-based new energy industry towards a carbon-neutral future.

Keywords: carbon neutrality; lithium-based new energy; industry chain; risk; policy implication

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1. Introduction

Attaining carbon neutrality is the world's most urgent mission to combat climate change. To meet their carbon neutrality goals, many countries like China will have to increase their efforts to drive the necessary energy transition [1,2]. In the transition to a cleaner energy system, a wide range of clean energy technologies, including new energy technologies, will be deployed. Building new energy power stations (for example, solar PV) and new energy vehicles (for example, EVs) generally requires more critical minerals than building their traditional energy-based counterparts [3,4]. A huge increase in the requirements for these minerals will bring new challenges to resource security, energy security, and industry security in a decarbonising world.

The rapid deployment of new energy technologies as part of clean energy transitions implies a fast-growing demand for critical minerals. The types of mineral resources used vary across new energy technologies [3,5,6]. From solar PV panels, wind turbines, and energy storage systems to electricity networks and EVs, critical metal resources including lithium and copper have been widely used. In a scenario aiming at achieving the Paris Agreement goals, the share of total demand for lithium with clean energy technologies will

increase distinctly over the next twenty years to almost 90% [3,7]. Given its importance in the clean energy transition aimed at meeting carbon neutrality goals for combating climate change, the development of lithium-based new energy is important for many countries, like China, which are committed to playing leading roles in global climate governance. The industry of lithium-based new energy is defined as a strategic emerging industry in China. In 2022, China's lithium battery exports amounted to nearly CNY 342.7 billion. China's lithium-ion battery shipments reached a total of 660.8 GWh in 2022, accounting for over 60% of the global market share. Although other metal-ion batteries [8,9] may become important options in the future, lithium-ion batteries will dominate the technological route of batteries for a long period of time due to their technology and cost advantages. Therefore, government departments in countries like China will step up their efforts to promote the development of lithium-ion battery industries and lithium-based new energy industries [10–12]. As global competition intensifies, the stable and sustainable development of these lithium-based new energy industries will face many challenges. Determining the risk points will be helpful to identify effective policy measures to promote the high-quality and sustainable development of lithium-based new energy industries. In this situation, risk identification and policy implications aiming at pursuing the sustainable development of lithium-based new energy industries will encapsulate particular concerns and receive a lot of research attention in the world.

Given the short development history of lithium-based new energy in China, very few studies have focused on the sustainable development of lithium-based new energy in China from an industry chain perspective towards carbon neutrality. Many published studies focus on the supply security of critical minerals in the clean energy transition. Some studies focus on critical metals but exclude lithium [13,14]. Meanwhile, some studies focus on critical minerals highlighting the role of lithium or taking lithium as a case [15–17]. As the rapid diffusion of new energy technologies such as EVs in the growing contingent of countries with carbon neutrality goals been occurring, many researchers have been paying close attention to the supply risks of lithium resources [18,19]. For instance, Yan et al. (2020) [18] adopted the system dynamic methods to assess the resilience of the lithium supply chain in China considering the impact of new energy vehicles and supply interruption risks. Notably, the studies by these recent researchers have usually conducted the analysis of lithium resources from the perspective of supply chains rather than industry chains [20–22]. Due to sustainability becoming an emerging and rapidly growing interdisciplinary field of research, some studies have focused on the sustainable management of lithium resource development [23,24], though most of these studies have highlighted their analyses from review perspectives [25,26]. In addition, some studies have highlighted the various sustainability practices and circular carbon economy approach for other industries [27,28] rather than for the lithium-based new energy industry.

In this article, we aim at filling the research gaps in existing studies by (1) establishing an analytical framework for providing policy recommendations to promote the sustainable development of lithium-based new energy in China from an industry chain perspective, considering the impact of a carbon-neutral vision, (2) determining critical risk points from a system perspective, rather than only focusing on one section of the industry chain, to systematically investigate the potential risks involved in the sustainable development of China's lithium-based new energy industry towards a carbon-neutral future, and (3) providing policy implications for identifying which policy measures may have significant effects in promoting the sustainable development of the lithium-based new energy industry based on an investigation of practical problems in China. The proposed policy recommendations may help policymakers in many countries like China, which aim to achieve carbon neutrality, to address the practical obstacles to promoting the sustainable development of their lithium-based new energy industries.

The rest of this article is structured as follows. Section 2 describes a framework for a system analysis of lithium-based new energy in China from an industry chain perspective. In Section 3, critical risk points of the sustainable development of the lithium-based new

energy industry for this study are presented. Section 4 provides policy implications for promoting the sustainable development of the lithium-based new energy industry in China towards a carbon-neutral future. Finally, Section 5 concludes the article and presents policy recommendations.

2. A System Analysis Framework to the Development of the Lithium-Based New Energy Industry

2.1. Constructing a Comprehensive Analysis Framework

With an increase in the demand for cleaner energy, ensuring the stabilization development of lithium new energy industries is at the heart of securing a sustainable supply of new energy and related products. This study attempts to explore the possible critical risk points of the high-quality development of the lithium-based new energy industry in China towards carbon neutrality. Then, this paper intends to determine suitable policy countermeasures aiming at promoting the sustainable development of the lithium-based new energy industries in China and other countries towards a carbon-neutral future. Based on an investigation of the characteristics of the development of the lithium-based new energy industries in China and other countries, this study presents a multi-dimensional, multi-perspective, and achievable analysis framework to perform a system analysis aiming to ensure the sustainable development of the lithium-based new energy industries in China and other countries towards a carbon-neutral future, as displayed in Figure 1.

From the perspective of systems thinking and industry chains thinking, the lithium-based new energy industry in China in this study was divided into five components including the lithium mining industry, the lithium-ion battery material industry, the lithium-ion battery industry, the new energy vehicle (EV) industry, and the lithium recycling industry. These industries can also be divided into several sub-industries. Consider the lithium-ion battery material industry, for instance: it includes four sub-industries, including the anode material industry, the cathode material industry, the battery diaphragm industry, and the electrolyte industry. Accordingly, this paper will investigate the current situation of the lithium-based new energy industry in China by using industrial chains decomposition. This analysis will be a key basis of the subsequent analysis for identifying risk points which may pose a threat to the high-quality and sustainable development of the lithium-based new energy industry in China. Our findings will help investigate the policy implications for ensuring the sustainable development of the lithium-based new energy industry and provides guidance on improving policy formulation and management practice. After a risk identification combined with subsequent policy implication analysis, possible useful ideas and suggestions aimed at securing the sustainable development of the lithium-based new energy industry in China towards carbon neutrality are proposed.

The purpose of the established analysis framework is to help academics and policy-makers explore the critical risk points of the sustainable development of the lithium-based new energy industry and investigate possible policy countermeasures for promoting the sustainable development of the lithium-based new energy industry in China. The proposed framework can effectively help China identify suitable policy measures from a new perspective using systems thinking and industry chains thinking. The proposed framework in this paper is also beneficial for countries similar to China in their efforts to stimulate the sustainable development of lithium-based new energy industries towards a carbon-neutral future.

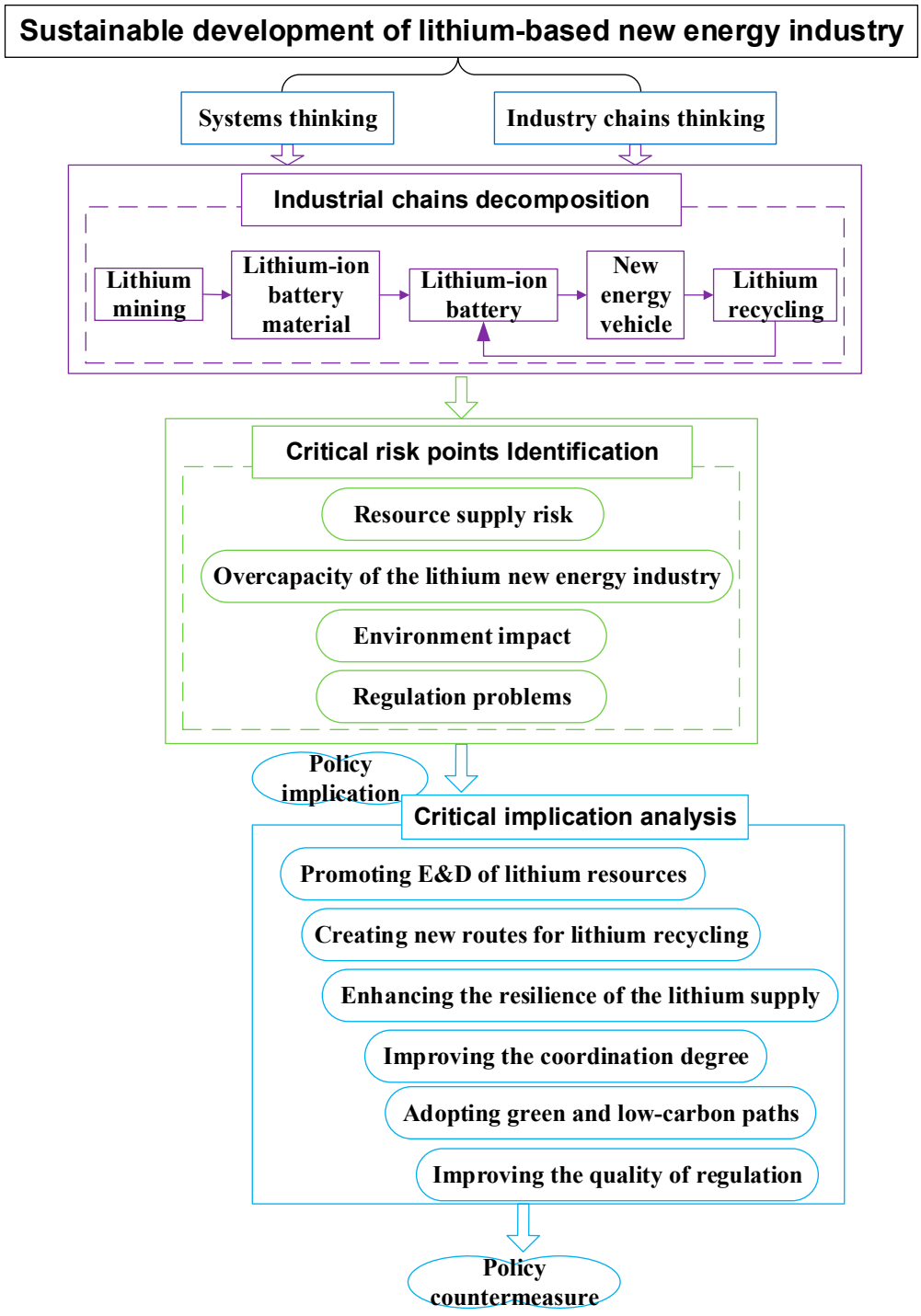


Figure 1. The framework for the sustainable development of the lithium-based new energy industry.

2.2. System Thinking for Sustainability Considerations

In the context of global climate change threats, lithium-based new energy fulfils a lot of expectations in order to achieve a clean energy transition and a more sustainable solution for carbon neutrality. In light of this new situation, promoting the development of lithium-based new energy for the growth of energy-sustainable countries is crucial. Given that lithium-based new energy is an entire system of its own, characterized as complex and dynamic, sustainability considerations should be undertaken for the purpose of high-quality development [29,30]. This will provide a unique and critical opportunity to support policies, practices, and behaviors that align the development of the lithium-based new

energy in line with the global sustainable development goals (SDGs) adopted by the United Nations in 2015 [31,32].

With the continuous development and dynamic evolution of systems thinking, there are an increasing number of academics and policymakers taking the systems approach to addressing sustainability challenges [33,34]. In view of the complex and dynamic nature of the lithium-based new energy industry, systems thinking is beginning to be adopted in the fields of policy formulation and management practice. This study adopts the systems approach to identify the critical risk points of the high-quality development of the lithium-based new energy industry in China, which is a typical country committed to the development of its lithium-based new energy industry aiming at sustainability considerations towards carbon neutrality. The advantages of China's lithium-based new energy industry compared to those of other countries include obvious competitive advantages: complete industrial chains, huge industry scale, and significant cost competitiveness. China's lithium-based new energy industry also has some disadvantages, and one of the most prominent of these is its lithium resource bottleneck.

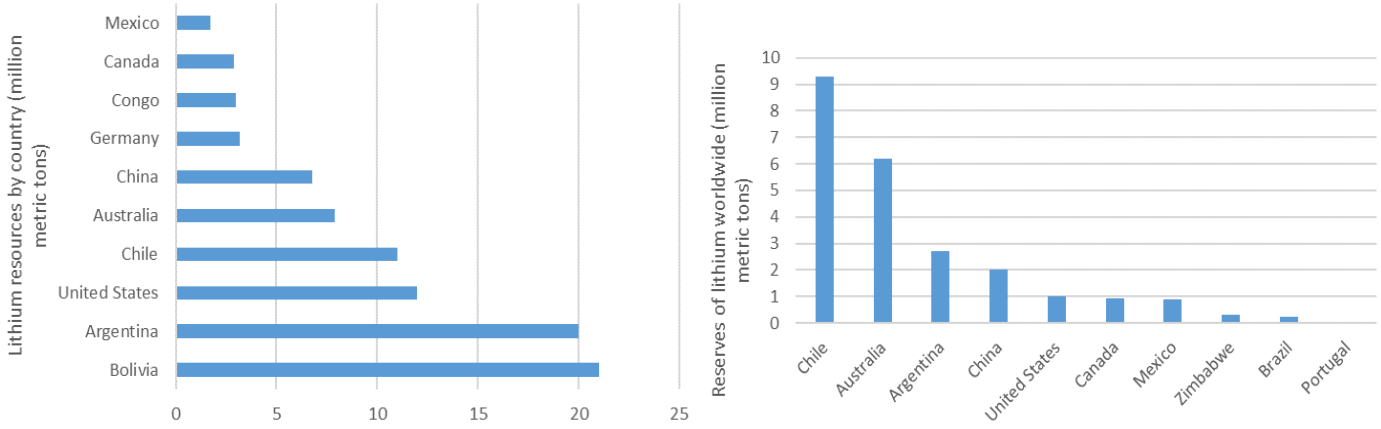
The lithium-based new energy industry is a system of major components, such as lithium mining, linked together in an intimate and interdependent relationship. That is, the lithium-based new energy is not simply an industry but rather an entire system and an entire industry chain [35,36]. Given that the lithium-based new energy industry is a dynamically complex industry, it is also necessary to adopt industry chain thinking in the fields of policy formulation and management practice. This study adopts the industry chain approach for determining critical risk points involved in the high-quality development of the lithium-based new energy industry in China, which is committed to sustainability considerations towards a carbon-neutral future.

3. Critical Risk Points of the Sustainable Development of the Lithium-Based New Energy Industry

Lithium is one of the crucial raw materials for the deployment of strategic emerging industries in many countries. With the continuous development and dynamic evolution of lithium utilization, lithium-based new energy has received considerable attention due to its crucial role in green energy transition and economy transition in recent years. However, there are increasing challenges involved in the high-quality and sustainable development of the lithium-based new energy industry considering new situations [37–39]. To better meet the challenge of creating a sustainable lithium-based new energy industry, this paper attempts to investigate possible critical risk points which may pose a threat to the stable and sustainable development of the lithium-based new energy industry in China after a current status analysis.

3.1. Resource Supply Risks

The sustainable supply of lithium resources is at the base of the development of lithium-based new energy industries. However, lithium resources are unevenly distributed around the world [40,41]. The top ten countries with the largest lithium resources in the world in 2022 are illustrated in Figure 2a. Of the top ten countries with the largest concentrations of lithium resources, Bolivia tops the list, containing 21 million metric tons of lithium in 2022 [42,43]. The top ten countries with the largest lithium reserves in the world in 2022 are displayed in Figure 2b [44]. The country with the largest lithium reserves in the world is actually the South American nation of Chile. Chile had 9.3 million metric tons of lithium in total in 2022. In the list shown in Figure 2a, the top three countries' lithium resources account for more than 70% of global lithium resources. Due to the uneven distribution of lithium resources, many countries like China which are pursuing the large-scale deployment of lithium new energy will face severe supply challenges.



(**a**) (**b**)

Figure 2. (**a**) Top ten countries with the largest lithium resources in the world in 2022. (**b**) Top ten countries with the largest lithium reserves in the world in 2022. (Source: [42–44]).

China is relatively rich in lithium resources in terms of salt-lake lithium, spodumene, and lepidolite. But its resource endowment is usually lower [45]. This will not be conducive to increasing lithium extraction and expanding domestic supply. China is a major consumer of lithium resources, accounting for 55% of the global lithium resource consumption. Therefore, its lithium consumption is dependent by more than 70% on imported resources [46,47]. These foreign lithium resources are mainly imported from Australia and the South American nations of Chile and Argentina, as displayed in Figure 3. These nations have higher grade spodumene and salt-lake lithium. However, they need long distance transportation and are susceptible to political circumstances. This will pose a threat to the stable and sustainable supply of lithium resources and subsequent related products for the lithium-based new energy industry in China.

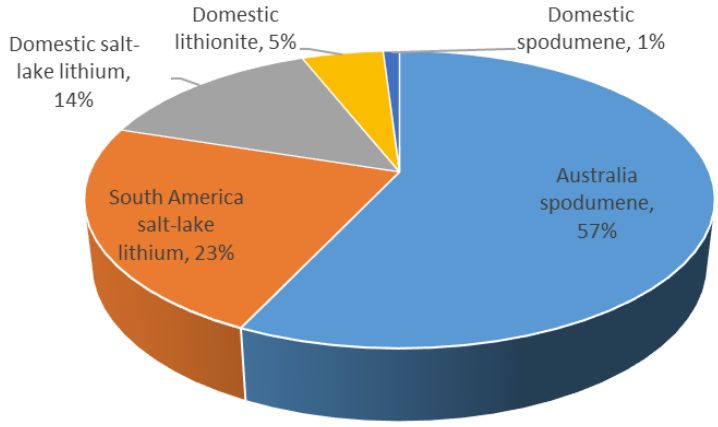


Figure 3. Sources of lithium resources supply for China. (Source: [45–47]).

3.2. Overcapacity of Lithium-Based New Energy Industries

Lithium salt is a dominant raw material for the production of lithium-ion batteries. Taking, lithium carbonate for instance: it is one of the most crucial lithium salts, having a high demand in the lithium-ion battery industry including in the preparation of cathode materials, lithium metal, and electrolyte additives [48]. Due to the growing demand expectations and signs of weak supply, prices for battery-grade lithium carbonate in China hit an all-time high of CNY 587,000 per ton in November 2022 (as shown in Figure 4). On average, the price for battery-grade lithium carbonate in China has increased by 108% in 2022. Lithium carbonate prices in China tumbled to a new low of CNY 351,000 per ton in March 2023, losing 45% of their value in the last four months, pressured by a pullback

in demand expectations and signs of strong supply. Both insufficient production capacity and overcapacity may cause distinct price fluctuations [49,50]. The capacity problem of battery-grade lithium carbonate in China will have a negative impact on the development of the lithium carbonate industry and the development of the lithium-ion battery industry.

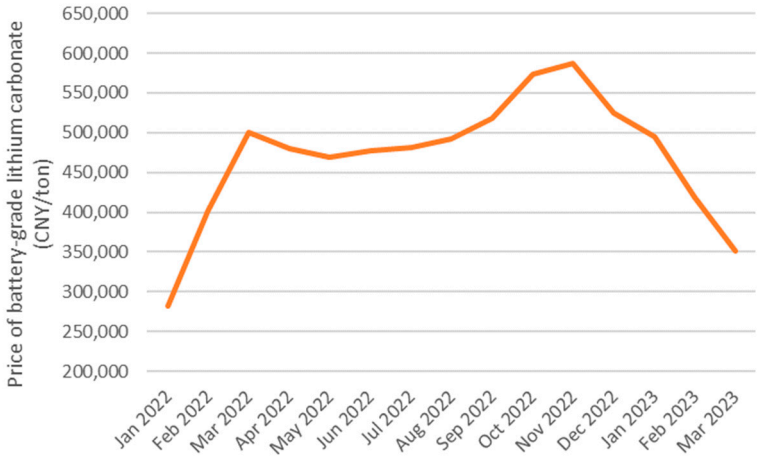


Figure 4. Price volatility of battery-grade lithium carbonate in China in recent years. (Source: [49,50]).

Global demand for lithium-ion batteries is increasing, driven largely by the imperative to reduce climate change impacts through the electrification of vehicles and the broader energy transition. For example, lithium-ion batteries have become one of the main energy storage solutions in modern society. The application fields and market share of lithium-ion batteries have increased rapidly and continued to show steady rising trends. From 2016 to 2022, the production capacity and output of lithium-ion batteries in China increased significantly (as presented in Figure 5), increasing by more than 800% [50,51]. According to predictions [50,52], the production capacity of lithium-ion batteries in China will continuously increase in the future under current conditions. However, the use efficiency of the production capacity of lithium-ion batteries in China will distinctly decrease in future. The reason may be that the production capacity is growing faster than the practical demand due to blindly expanding production without effective planning, based on text analysis conducted by extracting data from open sources. The overcapacity of lithium-ion batteries may be a critical factor hindering the high-quality development of the lithium-ion battery industry and the high-quality development of the new energy vehicle industry.

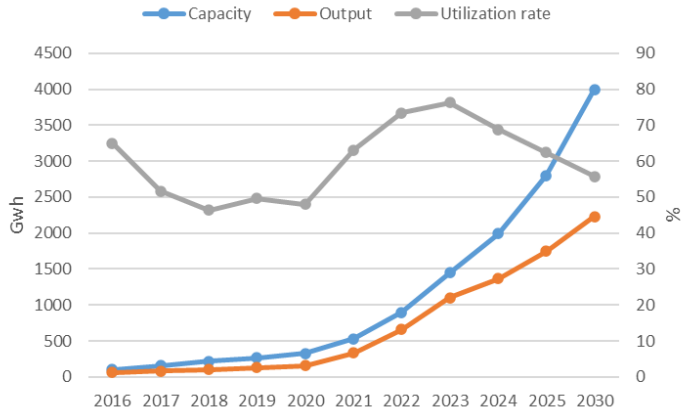


Figure 5. Utilization rate of the capacity for lithium-ion batteries production in China in 2016–2022 with forecast for 2023 through 2030. (Source: [50–52]).

3.3. Environmental Impacts

The development of the lithium-based new energy industry has played a crucial role in clean energy transitions and the deployment of strategic emerging industries in recent years. Meanwhile, with the large-scale development of the lithium-based new energy industry, the public remains concerned about the potential negative impact of the lithium-based new energy industry on the environment [53]. Based on field investigations, we found that there are significantly negative environmental impacts that occur throughout the entire industry chain of the lithium-based new energy industry. Consider the development of lithium mining based on lepidolite resources in China, for instance: the production process of lithium minerals and lithium concentrates based on current technology pathways may cause significantly negative environmental impacts including water pollution, vegetation deterioration, soil contamination, and hazardous waste. In particular, the large-scale exploitation of lithium concentrates is producing more and more mine tailings which are urgently necessary to be handled;, this may cause serious environmental problems in China (Figure 6).



Figure 6. A new storage facility for lithium mine tailings in China. (Source: [54]).

In addition to the possible environmental impact of lithium mining and lithium-salt production, the production of lithium-ion batteries also has potential environmental impacts. In 2022, shipments of global lithium-ion batteries grew by 70.3% to 957.7 GWh [50,52], after growing 3.5-fold over the period 2016–2021. In 2022, China's lithium-ion battery shipments increased by 97.7% to 660.8 GWh, accounting for about 70% of global shares. It is estimated that China's lithium-ion battery market shipments will maintain a continuous growth in future. Due to the large-scale deployment of the lithium-ion battery industry, potential environmental impacts will gradually emerge. Take the lithium-ion battery industry in Yichun city of China, for instance. Due to the operation of lithium-ion battery projects such as Ningde Contemporary Amperex Technology (CATL) and Gotion High-tech, the electricity consumption of Yichun city in Jiangxi province has been pushed from 24.5 billion kWh in 2021 to 40 billion kWh in 2022, showing a growth of 63.3% [54]. According to predictions [54], the electricity consumption of Yichun city will reach 60 billion kWh in 2025 considering the continuous deployment of the lithium-ion battery industry. This increased energy consumption will contribute to a significant increase in GHG emissions in Yichun city, which will pose a threat to the realization of the "Double Carbon" goal for Yichun city and will thereby affect the development of the lithium-ion battery industry in Yichun city.

3.4. Regulation Problems

The lithium-based new energy industry is a complex system, including several industries and more sub-industries. Due to the impact of demand changes, COVID-19 repeats, and economic downturn, the coordinated stability of the lithium-based new energy industry chain has been becoming lower. This will pose a threat to the regulation of the industry. We take Yichun city for the purpose of providing an example. Yichun is famously

known as the "Lithium Capital of Asia" due to it containing the world's largest mine for the lithium-bearing mineral lepidolite. It not only accounts for as much as 40% of China's domestic reserves of the lithium-rich mineral lepidolite, but also accounts for 25% of China's lithium carbonate production, making up about 10% of the global lithium supply. Based on its resource superiority, Yichun has a complete industry chain for lithium new energy. However, without effective regulation, problems have emerged in the development of the lithium-based new energy industry in recent years. For example, there are mining irregularities by producers, including mining without qualifications, continuing to mine after qualifications have expired, and the "chaotic" extraction in surrounding natural areas by locals (see Figure 7a,b)) [55–57].



(**a**) (**b**)

Figure 7. (**a**) The "chaotic" extraction in surrounding natural areas by locals. (**b**) Lepidolite ore from the "chaotic" extraction. (Source: [55–57]).

Meanwhile, unregulated extraction has caused other chaos problems, including environmental damage and welfare loss, as illustrated in Figure 8a,b [55–57]. Due to this unregulated extraction, many mountains in the lithium ore-producing area that are close to residential areas have been destroyed by digging in recent years. Several truck accidents have happened in certain mining areas of Yichun in the recent past, as the large-scale operation of transport vehicles by lithium companies has affected local transportation. In addition to the chaos in the lithium mining industry without effective regulation, there is also other chaos in other industries such as the lithium salt industry in Yichun. For example, a local river in the Shanggao county in Yichun has been polluted by a thallium-metal leak from a lithium-salt production company which omitted the disposal of lithium slag [58].



(**a**) (**b**)

Figure 8. (**a**) Environmental damage from unregulated extraction. (**b**) Local transportation has been affected by the large-scale operation of transport vehicles by lithium companies. (Source: [55–57]).

4. Policy Implications

4.1. Promoting the Exploration and Development of Domestic Lithium Resources

Although the gross of lithium resources in China is relatively high, the endowment of lithium resources is lower. Moreover, current lithium resource consumption in China is highly dependent on foreign sources. In the context of carbon neutrality, global lithium competition intensity will increase gradually in the future. With the large-scale application of new energy vehicles (such as electric vehicles) and smart grids, the limited lithium resources and their uneven geographical distribution in China have become the main bottlenecks in the development of lithium-based new energy industries in the country. Promoting the exploration and development of domestic lithium resources will be a vital pathway to solving these bottlenecks in China. This will increase the domestic lithium resource supply and will reduce the external dependence on imported lithium resources, both of which will help ensure national security in China. On the one hand, in view of the low proved reserves of lithium resources in China, more efforts should be directed towards increasing resource exploration to increase the lithium resource base, which will help guarantee industrial development. On the other hand, technology research and development urgently need to be accelerated for enhancing the domestic supply of lithium resources. Consider the technology pathway for lithium production based on lepidolite resources in Yichun, for instance. Not only is the production efficiency in this pathway low, but also, its environmental impact is significant. More advanced and eco-friendly technologies need to be developed for increasing the lithium resource supply while protecting the environment. Future policy countermeasures should focus on stimulating the development of more advanced and eco-friendly technologies aiming to promote the exploration and development of domestic lithium resources in China [36,46]. Considering the differences between the lithium resources in different areas of China, differentiated policies should be formulated to stimulate the exploration and development of domestic lithium resources.

4.2. Creating New Routes for the Recycling of Lithium Resource

Apart from promoting the exploration and development of lithium mining, strengthening the recycling of spent lithium-ion batteries is also a vital pathway to solving the bottlenecks in the development of lithium-based new energy industries in China. This important option will also help increase the domestic lithium resource supply. With the large-scale deployment of the lithium-ion batteries, such as in power batteries for EVs and energy-storage batteries for new energies, there is a growing demand for the recycling of large numbers of spent lithium-ion batteries. In 2021, the amount of retired lithium batteries in China reached a total of 600,000 tons [59]. The weight of recycled retired lithium batteries in China in 2021 was about 299,000 tons, only accounting for 49.5% of the total amount. Most of these retired lithium batteries are used for recycling, accounting for 86.3% of their usage. The rest of the retired lithium batteries are used for echelon utilization. In future, policy measures focusing on new routes for the recycling of spent lithium-ion batteries based on circular economy should be created which can not only help increase lithium resource supply and battery supply, but can also help reduce resource waste and environmental impact. The current recovery rate of lithium metal in spent lithium batteries is about 90% [60,61]. Promoting the research and development of more advanced technologies and processes aiming at improving the recovery rate will further increase the lithium resource supply and reduce resource waste in future. Future policy formulation should highlight the research and development of more advanced technologies and processes for improving the recovery rate of lithium metal in spent lithium batteries in China [10,59].

4.3. Enhancing the Resilience of Lithium Supply Chain

The lithium resource supply chain is rife with political interference and trade tensions compared to the traditionally stable resource demand. Changes in the external environment have increased the risk of lithium supply interruption in China. Enhancing the resilience of

lithium supply chain from the perspective of the balance of supply and demand will be a crucial option to ensure lithium supply and industry security in China [15,18]. From the perspective of the lithium supply chain, establishing a supply risk assessment and early warning system for the lithium supply chain in China will help assess the supply security of lithium resources and provide early warning for supply security situations. Based on these findings, dynamic adjusting strategies and related policy measures will be determined for enhancing the resilience of lithium supply chain and improving the supply security of lithium resources in China. Learning from the experience of resilience improvement of resource supply of other strategic critical minerals such as petroleum, establishing strategic lithium reserve may be a viable option to furtherly improve the resilience of lithium supply chain in China. Future policy design should put many efforts on how to help establish strategic lithium reserve for China.

4.4. Improving the Coordination Degree of the Lithium-Based New Energy Industry

Due to the dynamic changes of internal and external factors, the stability and coordination degree of lithium new energy industry are usually facing severe challenges. For example, the connections of upstream and downstream industries of lithium new energy were not smooth in China in 2022 [62]. Hoarding and unfair competition even appeared in some areas of lithium new energy industry. How to improve the coordination degree of lithium new energy industry in China is a crucial challenge for the governments and companies. Enhancing the coordination degree of lithium new energy industry from the perspective of the balance of supply and demand will be a crucial option to ensure industry security of lithium new energy in China [12,41]. From the perspective of systems thinking and industries chain, developing matching degree of supply and demand and early warning system for the lithium-based new energy industry in China will help assess the matching degree of supply and demand of lithium new energy industry and provide early warning for matching degree situations. Based on these findings, dynamic adjusting strategies and corresponding policy countermeasures can be formulated for improving the coordination degree of lithium new energy industry and promoting the sustainable development of lithium new energy industry in China.

4.5. Adopting Green and Low-Carbon Development Paths

The lithium-based new energy industry is positioned as a strategic emerging industry in many countries like China in the context of carbon neutrality. All of these nations put their efforts to promote the development of the lithium-based new energy industry. However, the development of the lithium-based new energy industry is accompanied by potential negative environmental impacts. Green and low-carbon development paths is urgent to be adopted for reducing the negative environmental impacts which may become barriers to the high-quality and sustainable development of the lithium-based new energy industry in China. Green and low-carbon technology pathways and corresponding processes should be developed by lithium companies. For instance, the GHG emissions of the production of lithium carbonate based on mineral lepidolite in China is relatively high considering the technology and process and energy consumption mix. Therefore, incentive policies should be implemented to stimulate the research and development of green and low-carbon technology pathways and corresponding processes. Moreover, lithium companies can use more green and low-carbon energy such as deploying distributed PV generation to reduce the carbon footprint of their lithium products. For government departments, policy incentives should be issued to motivate the deployment and use of more green and low-carbon energy. In addition, green and low-carbon development patterns based on circular economy should be developed to improve the whole industry chain of the lithium-based new energy [30,63]. It will reduce the negative environmental impacts originating from low efficiency and resource waste as a whole.

4.6. Improving the Quality of Industry Regulation

Due to the complex nature of the development of the lithium-based new energy industry, industry regulation faces many challenges. For example, the prices of some intermediate products and materials fluctuate sharply and even go beyond the normal range in China in 2022 [62]. Some enterprises are blindly expanding their production capacity. Moreover, competition with low quality and low price often occurs. In addition, there are illegal mining practices in lithium resource bases such as Yichun. How to improve the quality of industry regulation for the lithium-based new energy industry in China is a critical challenge for the Chinese government. To address the practical problems in the existing lithium-based industries, the Jiangxi and Yichun governments have expended many efforts to undertake some policies to change the current dilemma [64–66]. However, these polices have focused on the lithium resource industry only, and more policies should be issued to improve the quality of industry regulation while further highlighting the whole industry chain. Given that the development of the lithium new energy industry is at an initial stage, government sectors should attempt to formulate industry development planning for guiding the industry development of the lithium-based new energy industry in China [23,46]. Regarding rules and regulations: the government sectors should attempt to issue laws and regulations for regulating the industry development of the lithium-based new energy industry in China. Moreover, more regulation actions should be implemented to exert the effects of these laws and regulations. In addition, strengthening public supervision may be a viable option to further improve the quality of industry regulation for the development of the lithium-based new energy industry in China. Government sectors should implement policy incentives for encouraging the public to take active initiatives in industry supervision, helping regulators commit to issuing high-quality regulation.

5. Conclusions

Aiming to achieve global carbon neutrality goals, many countries like China are focusing their efforts on the development of lithium-based new energy industries, which are positioned as strategic emerging industries. With the large-scale development of the lithium-based new energy industry in China, some potential risk points, which may hinder the high-quality and sustainable development of the lithium-based new energy industry, begin to emerge. In addition to the dynamic changes in internal and external factors, the stability and coordination of the lithium-based new energy industry in China are facing severe challenges. These will be not helpful for the sustainable development of the lithium-based new energy industry in China, which will play a crucial part in attaining the goal of carbon neutrality.

Based on systems thinking and industries chain decomposing, this paper proposes a multi-dimensional, multi-perspective, and achievable analysis framework to conduct a system analysis aiming to ensure the sustainable development of lithium new energy industries in China and other countries towards a carbon-neutral future. The results show that critical risk points, including resource supply risks, overcapacity risks, environmental impact risks, and regulation absence risks, have emerged with the large-scale development of the lithium-based new energy industry in China. Based on our risk evaluation, a policy implication analysis was conducted to investigate potential policy countermeasures including promoting the exploration and development of domestic lithium resources, creating new routes for the recycling of lithium resources, enhancing the resilience of the lithium supply chain, improving the coordination degree of the lithium new energy industry, adopting green and low-carbon development paths, and improving the quality of industry regulation.

Based on these findings, some policy recommendations are proposed for promoting the high-quality and sustainable development of the lithium-based new energy industry in China. Specific policy measures proposed are as follows: (a) stimulating the development of more advanced and eco-friendly technologies aiming to promote the exploration and development of domestic lithium resources in China, bearing in mind that differentiated

policies should be considered; (b) motivating the creation of new routes for the recycling of spent lithium-ion batteries based on the circular economy, highlighting the research and development of more advanced technologies and processes for improving the recovery rate of lithium metal in spent lithium batteries in China; (c) establishing a supply risk assessment and early warning system for formulating dynamic adjusting strategies and related policy measures for enhancing the resilience of the lithium supply chain and improving the supply security of lithium resources in China, expending many efforts on finding how to help establish a strategic lithium reserve for China; (d) developing a matching degree of supply and demand and an early warning system for formulating dynamic adjusting strategies and corresponding policy countermeasures aiming at improving the coordination degree of the lithium-based new energy industry in China; (e) stimulating the research and development of green and low-carbon technology pathways and corresponding processes, motivating the deployment and use of more green and low-carbon energy; and (f) formulating industry development planning for guiding the industry development of the lithium-based new energy industry in China, issuing laws and regulations for regulating the industry development of the lithium-based new energy industry in China, and encouraging the public to take active initiatives in the industry supervision.

The systematic analysis in the study will be helpful for decision-makers seeking to determine critical risk points which affect the sustainable development of the lithium-based new energy industry in China and investigate suitable policy countermeasures to stimulate the sustainable development of the lithium-based new energy industry in China towards a carbon-neutral future. It is anticipated that the findings of this article are valuable resources for decision-makers in many countries like China that are moving towards carbon neutrality. The policy recommendations proposed in this article will also help decision-makers implement suitable approaches aiming at optimizing the development of the lithium-based new energy industries in their nations. Lastly, we anticipated that the findings of the paper will provide a useful reference for researchers aiming to determine critical risk points affecting the sustainable development of their lithium-based new energy industries and to investigate suitable policy countermeasures for stimulating the sustainable development of their lithium-based new energy industries towards a global carbon-neutral future.

Considering the impact of carbon neutrality, this study attempts to establish a qualitative analysis framework to perform a system analysis aiming to determine possible critical risk points involved in the sustainable development of lithium-based new energy industries in China and other countries. This paper intends to present policy implications for identifying which policy measures may have stronger effects when it comes to reducing the potential risks and promoting the sustainable development of the lithium-based new energy industry based on the investigation of the practical problems in China. The proposed policy recommendations may help policymakers in many countries like China address the practical obstacles to promoting the sustainable development of their lithium-based new energy industries for achieving carbon neutrality goals. Our future work will highlight a quantitative analysis framework for evaluating the potential risks more precisely. It will conduct an in-depth analysis by developing a risk evaluation model based on the original data. Based on the in-depth analysis, more suitable policy recommendations will be proposed to promote the sustainable development of the lithium-based new energies in the world from an industry chain perspective considering the impact of a carbon-neutral vision.

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