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What China's Environmental Policy Means for PV Solar, Electric Vehicles, and Carbon Capture and Storage Technologies

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Abstract: This perspective paper elaborates on how the burden of environmental issues on public health and the economy led China's government to declare its revised environmental policies or "war on pollution". It explains the importance of photovoltaic solar (PV), electric vehicles (EV), and carbon capture and storage (CCS) in helping China to mitigate its environmental concerns while maintaining economic growth. China already leads PV solar and EV manufacturing; however, it has not made a tangible contribution to CCS technology yet. On the other hand, CCS is far behind its envisaged role in contributing to the reduction of greenhouse gas emissions and supporting countries to meet their net carbon zero targets. China's existing coal power plants are good candidates to be retrofitted with CCS. Similar to PV and EV technologies, China could influence this technology globally, by reducing the uncertainties, demonstrating the viability, and driving the costs lower. China's revised policies have been effective and shown global impacts, but their implementations remain as strong as the political will behind them.

Keywords: environmental technologies; China environmental policy; PV solar; electric vehicles; carbon capture and storage (CCS); innovation

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1. Introduction

The other side of becoming the second most robust economy in the world for China is the thousands of people that die every day because of the adverse environmental health impacts across the country. Air pollution in China, which claims close to 2 million lives every year, or the emergence of cancer villages, where the cancer rates are high due to the presence of polluting industries, are prime examples [1–5]. The explosive economic growth has taken its toll on China—the capital's air is so polluted that even rooftop solar panels fail to work efficiently [6]. In a survey by the Pew Research Center, Chinese participants showed willingness to undergo slower economic growth for cleaner air. In other words, half of those participating in this study stated that China should reduce its air pollution even if it leads to slower economic growth [7,8].

In 2013, for the first time, China acknowledged the existence of the cancer villages and elaborated on the links between the dangerous levels of pollutant concentrations and health issues in areas close to intensive industrial activities [2,9,10]. In shaping China's new environmental policies, the role of economic loss due to pollution is also important. The economic costs are not explicit and existing data are not always consistent; nevertheless, they are notably high [11–14]. New reports indicate that the economic loss of exposure to $PM_{2.5}$ alone was over 101 billion USD in 2016, and even for short-term exposure to ambient air pollutants, the overall health burden reached around 2.5% of the national GDP in 2017 [15,16]. A study, using 2015 data, suggests that China could reduce its healthcare costs by up to 42 billion USD if it brings the annual $PM_{2.5}$ levels to the World Health Organization (WHO) standard of 10 mg/m^3 [17]. While the number of lives saved and the reduction in economic loss vary based on different scenarios, e.g., exposure to indoor and outdoor pollutants and the source of particulate matter, nevertheless, all studies indicate the significant health and financial benefits of improving air pollution in China [18]. With such a burden on society and the economy, it was not surprising that, in 2014, China announced its war on pollution [1]. It is worth noting that China's environmental policies and climate change policies are not identical, but they overlap to a great extent. For example, while $PM_{2.5}$ is major concern for environmental health but not climate change, nevertheless, one of the main sources of this pollutant is the inefficient combustion of fossil fuels. China's climate change policies are intertwined with its international commitments, e.g., COP21, while its environmental policies are broader, more comprehensive, and aim to address the country's ambitions. In this work, we consider China's environmental policies, although they have clear, direct international impacts on climate action efforts too.

In a recent study, Zhang. G. et al. have evaluated China's environmental policies from 1978 to 2019. In their work, they have explained how different variables and intrinsic uncertainty in reporting, e.g., emissions data, could affect the provision of a reliable picture of China's environmental policy [19]. For this reason, they have used a machine learning algorithm to analyze the texts of the environmental policies issued by China's government, introducing a concept called "policy intensity". However, even such in-depth analysis of the texts of the policies has its own limitations, as it is challenging to verify the implementation of environmental policies and regulations. The aim of this article is not to provide a detailed quantitative analysis or cross-compare published studies and data gaps as a research paper. This manuscript elaborates on China's environmental policies as a perspective study.

This perspective article aims to reflect on China's new environmental policies through adopting a clean energy mix, investing in environmental technologies, and their global impacts. The focus of this paper is on photovoltaic (PV) solar, electric vehicles (EV), and carbon capture and storage (CCS) technologies. In this forward-looking piece, after introducing the concept of adopting a clean energy mix for reducing environmental pollution in China, we discuss China's new environmental policies with an emphasis on photovoltaic solar, sustainable transport and electric vehicle (EVs), and carbon capture and storage (CCS). The last section of the paper is the Conclusions, which aims to reflect on the topics mentioned earlier. This article aims to offer a new perspective and provide a broader picture of China's environmental policies' impacts on three key technologies that have a significant role in addressing today's global environmental concerns. We hope that this paper stimulates environmental policy impact-related discussions and initiates new studies.

2. Adopting a Clean Energy Mix to Address Environmental Pollution

Coal is the backbone of China's energy mix. Half of the world's annual coal consumption is by this country [1]. Burning available, low-cost, and highly polluting coal has supported China's economic growth for decades and, in turn, has imposed its negative impacts on public and environmental health. The release of particulate matter, toxic trace elements, and organic chemicals is a side effect of inefficient coal combustion, which causes severe health issues, including lung cancer [20,21]. It seems that the first step for China towards a "war on pollution" and addressing its COP21 commitments is reducing coal consumption and adding more renewables to its energy mix [22].

In China, economic growth has been closely associated with a growth in coal consumption [23]. As we have tried to illustrate in Figure 1, the 2000–2010 period showed the highest number of coal power plants commissioned within the past 40 years (Figure 1a) [24]; coal power is also expected to have reached its peak during 2020 [25] and only coal-dependent developing regions have not yet reached their peak in the use of coal [26]. It is worth adding that implementing coal or other fossil fuel capacity cuts may not always progress as planned, especially as unforeseen technical or economic challenges cannot be avoided. For example, China's economic growth and its energy consumption in 2020 faced a high level of uncertainty due to COVID-19 [27,28]. As Figure 2, produced by the NASA Earth Observatory [29], shows, there was a significant decline in nitrogen dioxide (which is an indicator of industrial activities and the burning of fossil fuels [30]) presence in the atmosphere in Wuhan in January and February 2020 compared to the same period in 2019 [29]. However, as the impacts of the virus fully subside, China's economy needs to compensate for its contraction during this period, which affects this country's emission reduction policies in the short term.

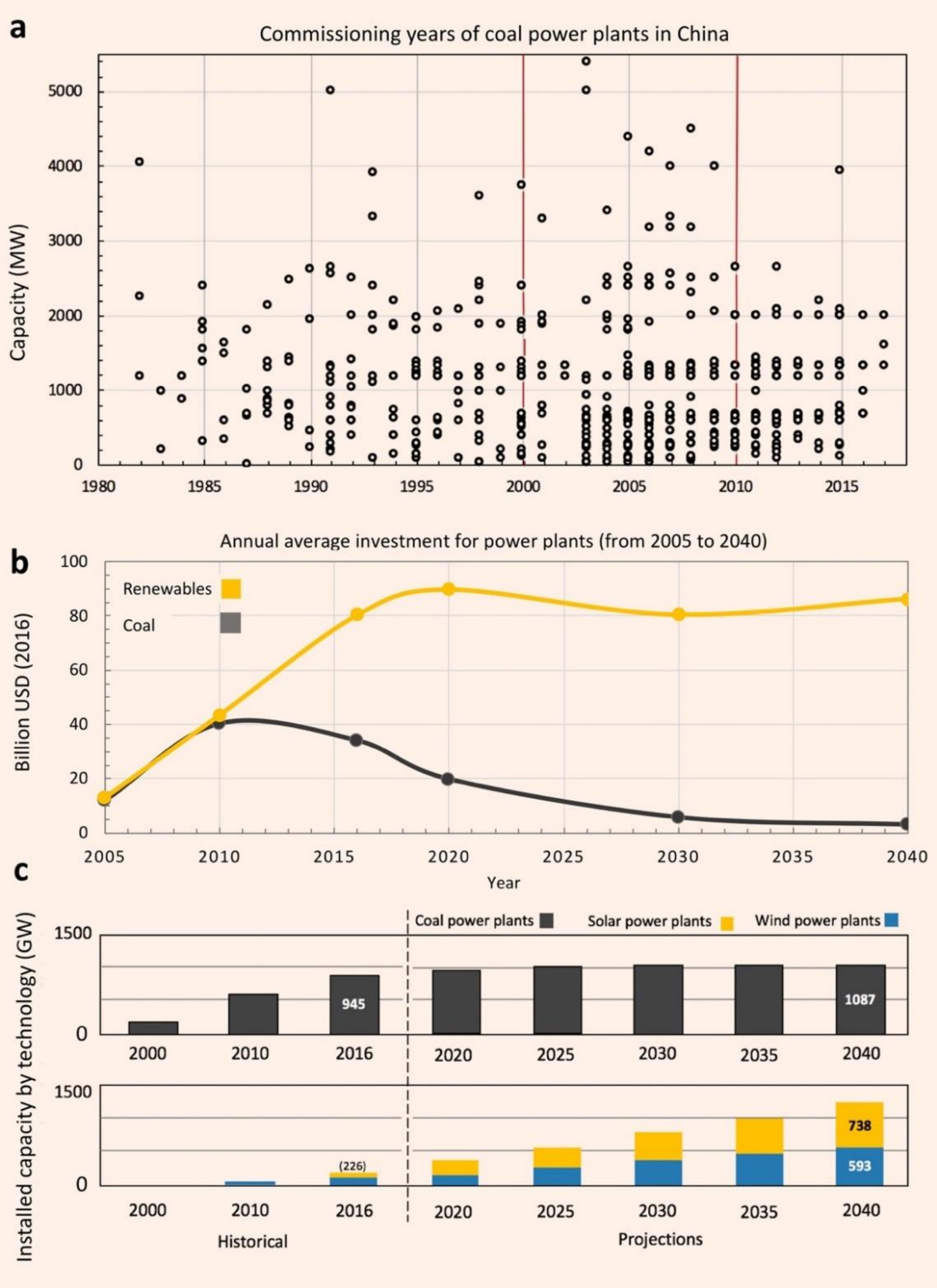

Figure 1. In this figure, the commissioning years and the capacities of coal power plants. (**a**) as well as the average annual investment in renewable energies and coal (**b**) are shown. The historical and projected installed capacities of coal compared to wind and solar power plants are also demonstrated (**c**). As seen 2000–2010 period, between the two redlines in (**a**), shows the highest number of coal power plants commissioned within the past 40 years.

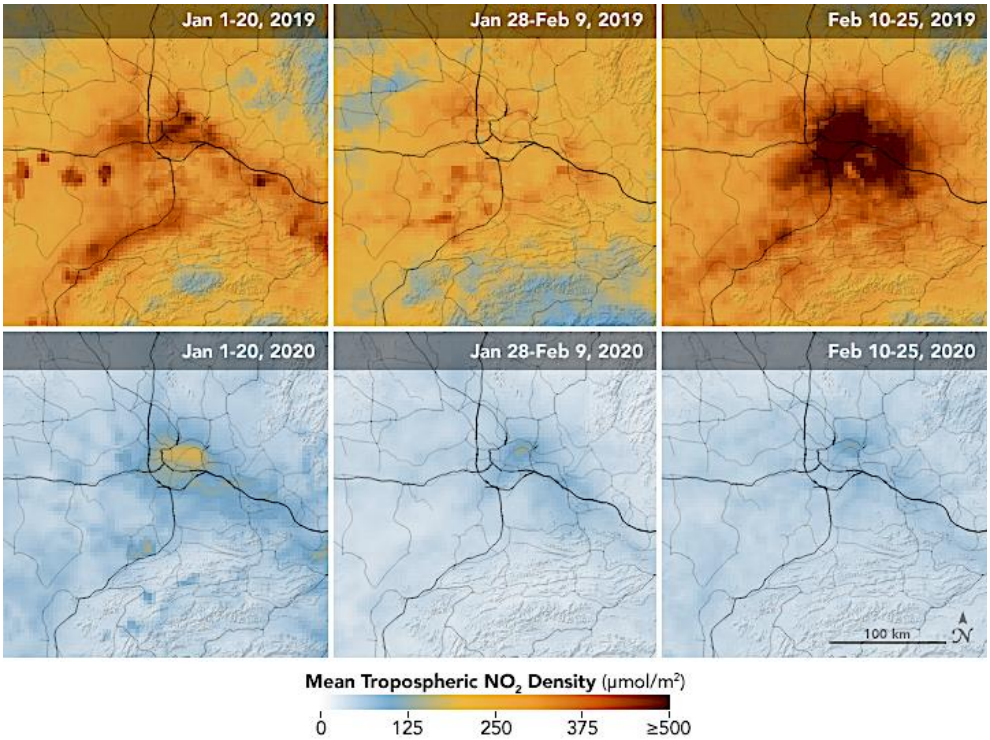

Figure 2. The satellite images show a drop in nitrogen dioxide concentration over Wuhan in China, which is a clear indication of reduced industrial activities and fossil fuel consumption due to the economic impacts of COVID-19.

International Energy Agency (IEA) reports also suggest a sharp decline in investment in coal power plants from 2010 to 2040 [31,32]. However, renewables are expected to receive additional funds, reaching over 86 billion USD of annual average investment between 2031 and 2040 (Figure 1b). As seen, the ratio of energy generated by wind and solar to coal power plants would be increased from less than 25 percent in 2016 to 122 percent in 2040 (Figure 1c). A recent study shows that China's carbon peak will be achieved by 2021–2026 with >80% probability [33].

3. China's New Environmental Policies Influence PV Solar, Electric Vehicles, and CCS Technologies

Photovoltaic (PV) solar, electric vehicles (EV), and carbon capture and storage (CCS) are three game-changing tools as their deployment in China has positive global implications for supporting sustainable development and reducing environmental pollution.

3.1. Photovoltaic (PV) Solar Energy

Despite the US's unique inventions and discoveries in the course of utilizing solar energy, this technology remained peripheral until China decided to enter the market [1,34]. In a matter of years, China has developed the most extensive PV solar infrastructure in the world [35,36].

In 2010, China and the US generated approximately 700 GWh and 3000 GWh from PV solar, respectively. Nonetheless, in 2013, China passed the US and in 2017 it produced approximately 95 percent more PV solar energy, as we have illustrated in Figure 3 [37,38]. By the end of 2017, from the total of 415 GW global PV installations, 130 GW belonged to China [39], which is rooted in this country's investment, as seen in Figure 3. Available information suggests that despite the significantly higher investment in PV solar in 2018–2019 compared to 2011–2012, in 2017, annual investment in solar energy was the highest both in China and globally, when China's investment in PV solar reached over 85 billion USD or more than 50 percent of the global amount in that year (Figure 3) [40].

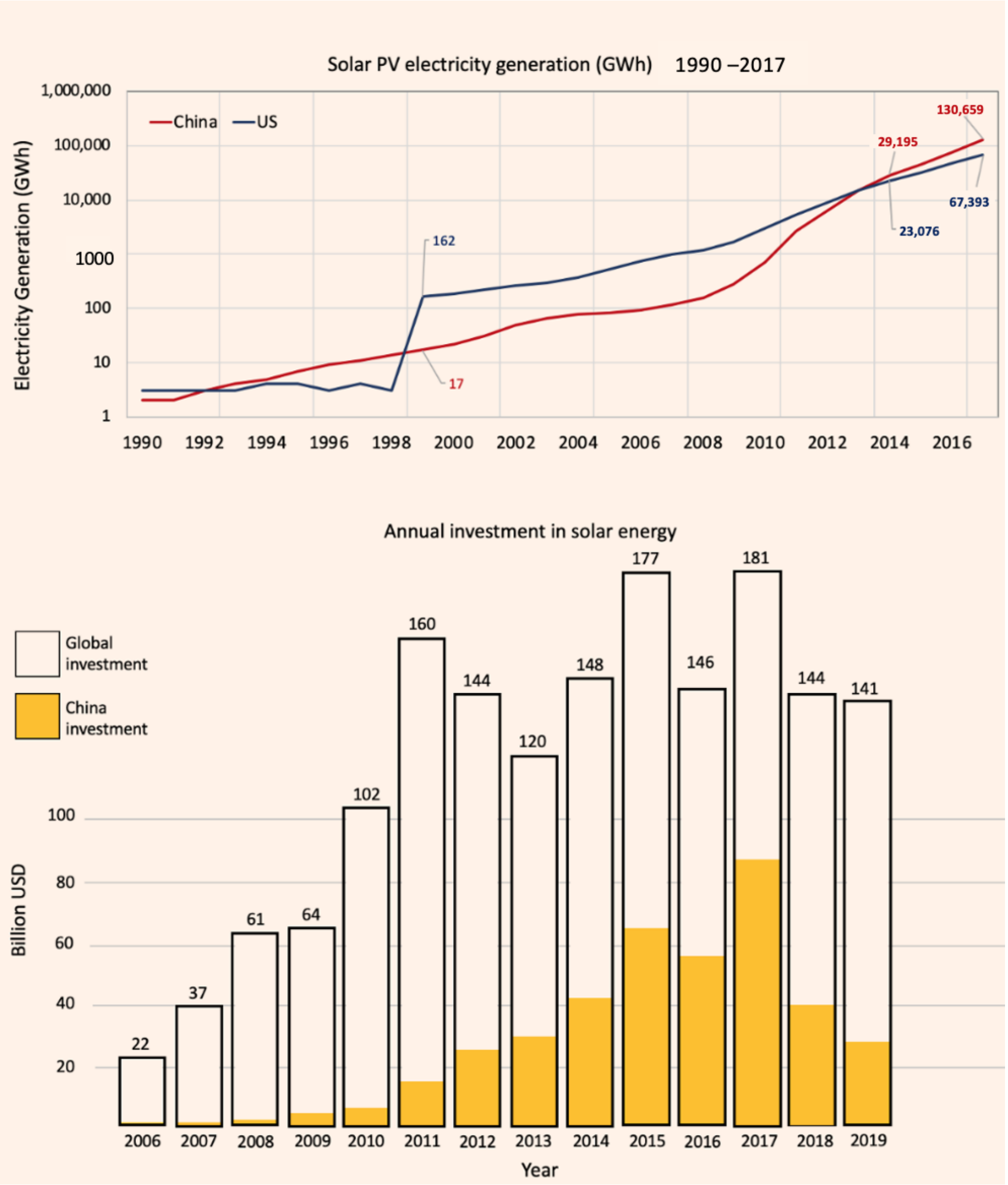

Figure 3. Solar energy electricity generation (GWh) for China and the US between 1990 and 2017. In this graph, the electricity generation axis has a logarithmic scale. A comparison between the global and China's annual investment in solar energy between 2006 and 2019 based on Bloomberg New Energy Finance (BNEF) data. In 2017, China invested over 85 billion USD in the sector.

While China's investment in solar energy in 2019 was around 26 billion USD, or less than a third of the figure reached in 2017, this country still was the largest investor in renewables in total, with over USD 83 billion in 2019. This decrease could be attributed to the nation reducing its aggressive solar subsidies to get costs under control as, in 2018, the subsidy standard for distributed PV projects was lowered for the first time in four years [41]. It is worth noting that the manufacturing scales seem to be more important than the cheap labor for China's competitive edge in manufacturing PV modules [34,42,43]. In addition to manufacturing, more than 60 percent of the world's solar panels invest in and build mega solar projects overseas, reinforcing China's influence on this market [44]. The global expansion of PV solar is the result of international efforts and, so far, China's role has been crucial in shaping this clean energy market. The latest example of this influence is floating PV power plants, also known as FPVs [45].

The inauguration of the world's largest floating solar power plant in China in 2017, on a flooded coal mine, was not the first deployment of such technology in the world but it received the most attention. This 70 MW power plant covers more than 63 ha of the flooded area and is part of a 1 GW project that involves building floating solar farms on abandoned coal mines. In 2013, the first megawatt-scale, 1.1 MW floating power plant in the world was built on a rainwater retention pond in Okegawa City in Japan, and in 2016, Europe's largest floating solar farm, 6.3 MW, was deployed near London on a drinking water reservoir. Nevertheless, it was the scale of China's FPV projects that encouraged other countries to invest in this technology [1]. Figure 4 is a schematic representation of the 70 MW installed floating solar power plant in Anhui Province.

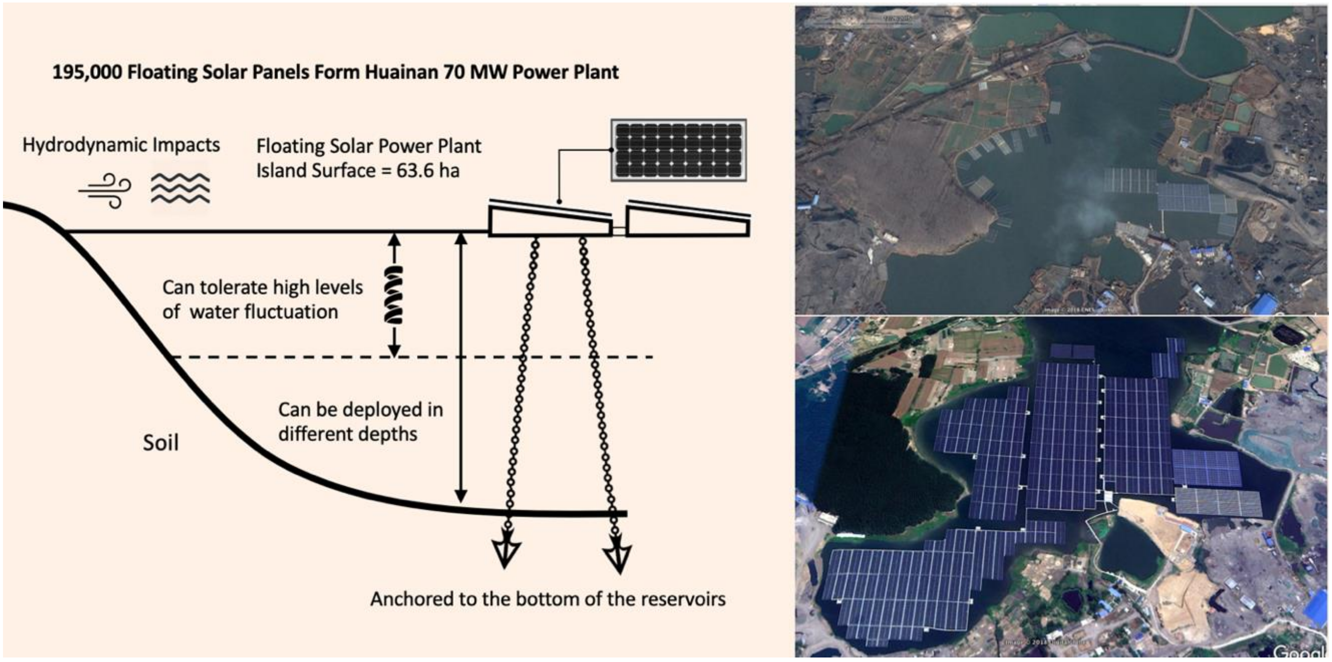

Figure 4. Schematic representation of the installed FPV plant (**left**) and satellite images of the FPV on the flooded coal mine in Anhui Province that show the beginning and the current state of the project, taken from Google Earth Pro (**right**).

As seen in Figure 4, the floating parts need to be flexible yet stable enough to resist water level variations and environmental hydrodynamic impacts to the flooded coal mine subsidence area.

This innovative example, which was followed by a sharp increase in global expressions of interest in using the same FPV technology [1], highlights the extent of China's environmental policy influences.

3.2. Sustainable Transport and Electric Vehicles

Smog and high levels of air pollution are a feature of China's urban and industrial environment. In these regions, concentrations of particulate matter are even high enough to scatter the sunlight and prevent the PV panels from functioning as they should. For such areas in China, an average irradiance reduction of close to 20 percent in a year has been reported (compared to clean days) [6,46]. Urban expansion intrinsically adds more vehicles, greenhouse gas emissions, and air pollution to the environment. China expects to see the emergence of a 1800 km coastal urban corridor between the northeast and the eastern part of the country with 100 billion USD annual investment in urban infrastructure by 2030 [47–49].

China's urban population increased from 26.4 percent in 1990 to 59.15 percent in 2018 [50] and is expected to reach one billion by 2030. Such an expansion, and consequently the required transportation, would place the air quality of the cities in even greater jeopardy than it currently is [51–53]. Driving restrictions and the banning of highly polluting vehicles during air quality alerts is a policy that China has deployed in cities such as Beijing in recent years. These measures help to reduce smog levels, especially during the wintertime, but also disrupt daily life and cause economic losses.

China has the largest auto market in the world, and achieving a sustained improvement in air quality without using electric vehicles (EV), while facing tremendous urbanization, is unrealistic [54]. EVs potentially can address various concerns about sustainable transport through electrification [55], and developing a strong EV industry can help China to address three key priorities: environmental pollution, energy security (heavy dependence on oil import), and responding to the demands of the domestic auto market [56]. It is worth noting that while using EVs has tangible environmental benefits for society, the implications of the sources of energy used for charging EVs, e.g., coal versus renewables, or other socio-technical concerns related to electric cars should not be underestimated [57,58].

In 2018, a total of 2.3 million electric cars, around 45 percent of the total EVs on the road (battery electric and plug-in hybrid vehicles), belonged to China. To put this into perspective, the number of EVs in the US was 0.18 million in 2013 and reached 1.12 million in 2018, while, for China, it has changed from 0.03 to 2.31 million during these 5 years [54]. This brought the total number of electric cars on the world's roads to approximately 16.5 million, triple the amount in 2018 [59]. According to the IEA's Global EV Outlook 2022 report, nearly 10% of global car sales were electric in 2021, four times the market share in 2019. It is the scale of China's market that has already started influencing the EV industry, making this country the number one market for EV cars in the world, followed by Europe and the United States. The International Energy Agency projects that, by 2030, the number of EVs will reach 250 million (including two/three wheelers) and China maintains its world lead, with 57 percent of this market [54]. Nevertheless, such an increase is not feasible without overcoming existing hurdles, including advancing battery technologies, which is a crucial component of the progress of this industry. China is currently the world's leading EV producer and could de-risk new EV technologies, deploy them on large scales, reduce production costs, and make them readily available to other countries.

Batteries are a critical part of electric cars, which, in addition to a long life and fast charging, are expected to remain safe and functional under different climatic conditions [60–62]. Lithium-ion batteries are the current backbone of energy storage in EVs and are expected to remain the dominant technology in the near future [63,64]. However, in addition to the high costs, the existing uncertainties about the ingredients' supply, especially cobalt, have encouraged manufacturers to improve this technology [65]. For example, China holds most of the global capacity for refining raw cobalt, which is mainly supplied by the Democratic Republic of Congo (DRC). DRC is a politically unstable country and over 50 percent of the global production of cobalt takes place there. Any disruption in the cobalt supply, e.g., due to political tensions, is a legitimate concern for China and could affect the manufacturing of lithium-ion batteries on large scale and consequently EV industries [66–69]. Such concerns have encouraged China to think beyond manufacturing lithium-ion batteries and aim to push this technology both in scale and through cutting-edge innovations [70,71].

The technology of electric vehicles and their life cycle are far more complex than those of PV modules. Nevertheless, we can still see a pattern in China's role in the global expansion of the PV industry. This could happen through increasing the manufacturing scales, de-risking new technologies to make them commercially viable, producing new types of EVs for different market sectors, e.g., private, public, and industry, and investment in the production of EVs in other countries. Such events demonstrate how adopting new environmental policies in China and incentivizing electric cars has placed it in a position to influence this technology on a global scale.

3.3. Carbon Capture and Storage (CCS)

Carbon capture and storage (CCS) consists of a series of technologies that allow the capturing, transporting, and storing of captured carbon [72]. This method can retain up to 90 percent of the emitted carbon dioxide and store it in geological media. Recently, because of technological advancements and CCS' potential in mitigating greenhouse gas emissions, it has received more attention. CCS is considered a viable option in supporting countries to reach their CO21 goals [73,74].

A recent report by the Global CCS Institute suggests that the combined estimated capture capacity reached 96 million tons of CO_2 by the end of 2019, which includes 19 in operation, four under construction, and 28 in different stages of development. Currently, China has the highest number of CCS pilot and demonstration plants in operation and construction, as well as the largest number of large-scale CCS facilities in planning [75,76]. Even if all the proposed projects progress as planned in the next few years, we will only reach a CCS capacity of 96 million tons of CO_2, which is far less than the envisaged role of this technology in reducing greenhouse gas emissions. The Energy Technology Perspective 2017 report of the IEA argues that in order to achieve the 2DS scenario—limiting the average global temperature increase to 2 °C—6800 million tons of CCS are required to be deployed across different industries, including power generation and fuel processing, in the next 40 years, and for the medium term, this capacity needs to be increased to 4000 million tons in the next 20 years [77]. The significance of CCS technology was reiterated in the Energy Technology Perspective 2020, including its contribution in producing hydrogen. The report indicates that coal power plants with no CCS will be nearly phased out by 2045 if sustainable development scenarios are implemented. Nevertheless, retrofitting coal power plants with CCS technology allows electricity generation of around 1000 TWh of electricity beyond this point [78].

The status of CCS deployment indicates that such an increase in global CCS facilities will be challenging, to say the least. However, China's expression of interest and efforts in utilizing this technology can pave the road for CCS to achieve the role that many hope it will play in greenhouse gas mitigation [79]. These state-sponsored efforts include the provision of comprehensive research and development funding and the China National Petroleum Company's role in operating large-scale CCS facilities [63].

One of the reasons behind CCS' slow growth is the uncertainties surrounding this technology. Experts have expressed concerns about the ambiguity associated with this technology, which has different aspects, including environmental risks that could even affect microbial communities if they are exposed to the long-term leakage of carbon dioxide [80–83]. Unlike fossil fuels and nuclear and solar energy, there are no strong opponents or advocates for CCS in the private and public sectors that can shape governments and energy firms' approach to CCS [74,84]. Moreover, CCS still carries some perceived concerns that stem from our knowledge gaps; a key example is the fate of the deposited carbon dioxide in geologic media over the long term, which involves monitoring, leakage, and plume migration. In addition to further technological development, financing instruments are another important requirement for the expansion of CCS deployment [74].

CCS covers a series of technologies, from the methods used for capturing carbon to the transport and storing of carbon dioxide [85]. This creates a costly system. Such complexity makes the estimated costs highly uncertain, variable, and case-specific [86–88]. Some studies argue that the lack of political commitment to CCS is a greater barrier than the deployment cost, as some technologies, including offshore wind, receive generous support from governments [74].

China is in a strong position to draw the world's attention to this technology and demonstrates a portfolio of large-scale CCS facilities [89,90]. This demonstration will help the development of further projects by learning through replication, de-risking related technologies, and developing viable business cases [79]. The reason for this is China's current energy mix. As seen in Figure 1, this country has a young fleet of coal power plants, which form the backbone of its electricity generation. Over the next 20 years, these coal power plants will have a lower share than renewables; nevertheless, their role and performance will remain crucial. China has also asserted its aim to meet the Paris Agreement commitments [1]. The task of reducing greenhouse gas emissions and simultaneously supporting the electricity required by the expanding economy makes the early retirement of coal plants a challenging path and the extensive deployment of CCS a viable option [91,92].

Interestingly, an IEA report shows that around 385 GW of China's coal power plants can find suitable carbon dioxide storage within a 250 km radius and around 310 GW of the existing ones are, to a good extent, suitable to be retrofitted with CCS [77,92]. Moreover, China needs 175 GW of its coal-fired plants retrofitted with CCS with a requirement of less than 2 °C in order to meet its reduction targets [93]. The successful deployment of CCS on an extensive scale by China will help this country to meet its sustainability commitments and energy demands but also would encourage other countries to replicate this process and accelerate global efforts in implementing this technology [79].

As discussed earlier, China has a successful track record in shaping PV solar energy globally and, so far, has proven to have an instrumental role in the electric vehicle industry. CCS technology is far behind the role that was envisioned for it. The nature of this technology is fundamentally different from that of PV and EV; nevertheless, China still could exert a tangible global impact on CCS development. This impact includes addressing the existing knowledge gaps related to the long-term implications of storing captured carbon, e.g., its fate and impacts on the environment. Providing know-how, expertise, and investment in retrofitting existing coal power plants with CCS in other countries, improving the current CCS technologies to make them more efficient, and creating viable business models for this technology that other nations could replicate are examples of how China could influence CCS technology progress.

4. Conclusions

There are compelling reasons behind China's bold steps in committing to new environmental policies, but they are often overshadowed by this country's progress in clean technologies and its contribution to PV solar. We could conclude the following.

The damage to public health, economic loss, and a consensus on prioritizing public health over the economy are the main reasons behind China's revised environmental policies.

Official acceptance of the existence of the cancer villages in 2013 and the declaration of war on pollution in 2014 were the turning points in China's environmental policies.

To reduce environmental pollution while maintaining economic growth, China has redefined its energy mix by investing in renewables. This approach would make the share of solar and wind energy more than that of coal in China's energy portfolio by 2040.

Investment in renewables have made China the leading PV module manufacturer in the world and reduced the costs significantly (compared to 2010, we see a 82% reduction in the cost of utility-scale PV systems [94]).

China's interest in renewables has strategic reasons far beyond environmental pollution, as the country seeks energy independence.

China has incentivized the manufacturing and use of electric vehicles (EVs). This policy supports the mitigation of urban air pollution as the country's urban population is expected to reach one billion by 2030.

China is the number one EV manufacturer and has created capacities that expand to different sectors, including refining and processing cobalt and lithium-ion batteries.

China has started influencing the EV industry globally through de-risking new technologies and reducing the production costs.

China could also influence carbon capture and storage (CCS) as a key environmental technology for reducing emissions. CCS is a complex and expensive technology with significant knowledge gaps.

China is already running a large portfolio of in-progress CCS projects, but it is unclear what is required in mitigating emissions and meeting the COP21 targets.

Most of China’s coal-burning power plants were built after 2000. The country has the third most coal resources in the world. It is not economically viable for it to immediately retire coal power plants, among which 310 GW are, to a good extent, suitable to be retrofitted with CCS.

High coal consumption and new coal power plants with compatibility with CCS place China in a unique position to develop this technology further, demonstrate the feasibility, and build viable business models.

China’s revised environmental policies are the result of an amalgam of socioeconomic and political reasons. Some of them have led to tangible progress in environmental technologies on global scales, namely in the PV and EV sectors; CCS also could be potentially influenced in a similar way. During COP26 in Glasgow, participants agreed to phase out the use of coal; in COP27, some countries aimed to expand this to all fossil fuels, but such an attempt failed. Instead, the final text of the resolution included supporting “low emission energy”, which, in addition to solar and wind, could include coal-fired power plants when fitted with CCS technology. Such an important role for carbon capture and storage technology, particularly in countries with significant reliance on coal power stations, highlights the importance of CCS and the further development of this technology in the coming years.

The above-mentioned impacts on advancing environmental technologies, which can be seen thousands of miles beyond China’s borders, have been achieved through implementing new regulations. However, China’s environmental policies, and the improvement of existing regulations by this country, do not necessary mean that they will be implemented. These policies always remain only as strong as the political will behind them.

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