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Assessment of Air-Pollution Control Policy's Impact on China's PV Power: A System Dynamics Analysis

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Abstract: Recently, China has brought out several air-pollution control policies, which indicate the prominent position that PV power hold in improving atmosphere environment. Under this policy environment, the development of China's PV power will be greatly affected. Firstly, after analyzing the influencing path of air-pollution control policies on PV power, this paper built a system dynamics model, which can be used as a platform for predicting China's PV power development in every policy scenario during 2015–2025. Secondly, different model parameters are put into the SD model to simulate three scenarios of air-pollution control policies. Comparisons between the simulated results of different policy scenarios measure the air-pollution control policy's impact on China's PV power in the aspect of generation, installed capacity, power curtailment and so on. This paper points out the long-term development pattern of China's PV power under latest incentive policies, and provides reference for the policymakers to increase the effect and efficiency of air-pollution control policies.

Keywords: China's photovoltaic power; national incentive policy; system dynamics; full electricity price subsidy

1. Introduction

China's increasingly serious air-pollution problem is caused by its unreasonable energy developing pattern and the lack of pollution-controlling consciousness [1,2]. In September 2013, the Chinese government has introduced a severe policy named *The Action Plan for Air Pollution Control*, which shows the beginning of powerful air-pollution management. To drive the implementation of this action plan, China's energy industry introduced several supporting policies, which mention the necessity of adjusting energy structure. Among all the renewable energy generation technologies, photovoltaic (PV) power generation is regarded as the most perspective one because of its perfect match in time to the industry electrical load [3–7]. Then, China's solar power industry issued *Some Suggestions to Improving PV Industry Development* to match the requirement of air-pollution controlling for PV power industry.

These air-pollution control policies fully indicate the prominent position that PV power hold in improving atmosphere environment and promoting energy substitution. The macrolevel policies will increase the relative demand of PV power generation by limiting coal consumption. In addition, microlevel policies will complete the electricity price and subsidy mechanism of PV power, give priority to the generation scheduling of PV power, and implement the full acquisition of PV power generation. This favor policy environment will bring China's PV power an unprecedented developing opportunity [8,9]. However, on the other hand, the high targets for installed PV capacity set in these policies will bring PV power great challenges as well [10,11]. China's PV power is growing rapidly now, with installed-capacity growing by 60% and generation growing by 200% year on year. However, in 2014, China's installed PV capacity reached only 28,050 MW accounting for less than 1% of the total capacity. In addition, the newly-added capacity met only 76% of the national target. Thus, whether these air-pollution policies can give China's PV power an expected boost remains to be studied further.

These air-pollution control policies contain many policy measures, which can impact every factors involved in developing system of PV power from several perspectives. It will be of great significance for assessing the impact of China's air-pollution control polices to analyze the pathway and effect of each policy measure. Whether the modification of policy measures and targets are necessary can be determined by comparing the actual effects and expected effects. Further, analyzing the sensitivities of technical, economic and environmental indicators to specific policy measures is helpful to suggesting improvements for next policy making.

Many scholars have realized that air-pollution policies will have long-reaching effects on energy structure [12–16]. Other scholars have simulated the development of renewable energy resource including PV power under the influence of some energy-saving and renewable energy development policies in different countries [17–22]. However, none of these models considered China's latest air-pollution policies, so they could not be applied to China's current policy environment. The assessment of air-pollution control policy's impact on PV power is a complex dynamic evolution process, because the policy has many acting points, and the policy effects will keep transmitting along the intricate structure of PV power development system, which consists of many elements in many fields. System dynamics (SD) method can not only model system's real behavior but also explain the relationship between main variables within the system [17]. SD model has been used to assess the development of energy system [23–25] and national policies [26–29]. It enables us to stimulate generation increase, investment surge, capacity expansion, costs decline and composition change of China's PV power under the influence of air-pollution control policies.

This paper first systematically studied the effect path of air-pollution policies on China's PV power. On this base, a new platform for simulating the development of China's PV power are offered using a SD model, which can predict its developing trends under different policy environments by adjusting the parameter settings of variables according to relevant policies measures. The differences between simulated results of three policy scenarios indicate the effectiveness of air-pollution control policies and their effect on China's PV power. Additionally, this paper provides specific policy suggestions for guiding the development of PV power under the requirement of air-pollution control by analyzing the assessment results of these policies.

2. Air-Pollution Control Policy

2.1. Framework of Air-Pollution Control Policy

China's air-pollution control policy is set by central decision-making body, guided by fundamental national policy, and implemented throughout the whole country including energy industry. If these macro fundamental policies really want to make impacts, they need relevant supporting policies to implement their measures on micro level. Thus, the 'air-pollution control policy' mentioned in this paper is not a single policy but a framework containing policies on national level, energy industrial level and PV industrial level (see Figure 1), which can influence the development of China's PV industry. As essential supports for fundamental policy, *Energy Industry's Action Plan for Strengthening Air Pollution Control*, *Interim Regulations for Reducing and Replacing Coal Consumption* and *Several Recommendations to Promote Healthy Development of PV Industry* are put into the framework of air-pollution policy together with *The Action Plan for Air Pollution Control*. Although these policies are not made only for controlling air-pollution, they are three of the twenty-two supporting policies of *The Action Plan for Air Pollution Control*, and all mentioned the important role that PV power plays in controlling air-pollution.

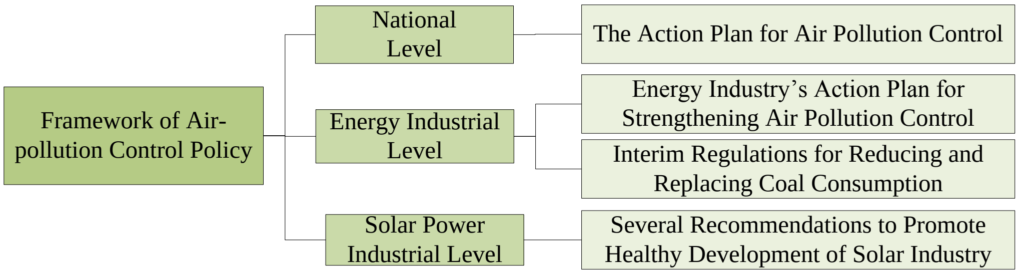

Figure 1. Policy Framework.

2.2. Analysis of Air-Pollution Policy Contents

In September 2013, China's state council issued *The Action Plan for the Control of Air Pollution*. It pointed out several measures which can influence PV industry: (1) encourage electric power replacement; (2) restrict new coal-fired power generation project; (3) set non-fossil fuel energy share target in 2017 as 13%; (4) stimulate renewable energy generation; (5) limit high energy consumption industry; (6) promote green building with distributed rooftop PV installation; (7) improve price mechanism of renewable energy generation. These policies measures will undoubtedly increase the share of non-fossil fuel energy, and bring about uncertainty to electricity consumption.

In March 2014, the National Energy Administration (NEA) issued *Energy Industry's Action Plan for Strengthening Air Pollution Control*, which formulated several measures to support *The Action Plan for the Control of Air Pollution* on energy industrial level: (1) set PV power as an important development direction for energy industry; (2) set targets for installed PV capacity and distributed PV installed capacity; (3) outline the 'feed PV power to grid after self-consumption' principle for the development of distributed PV power; (4) set the target of proportion of coal consumption in total energy consumption in 2017 as 65%; (5) set target for interregional power transmission; (6) improve subsidy mechanism of distributed renewable energy generation. These measures provided PV power with good opportunity and great challenge.

In December 2014, the National Development and Reform Commission (NDRC) issued other supporting policy *Interim Regulations for Reducing and Replacing Coal Consumption*. Its measures, which can influence PV power including: (1) set coal consumption reduction target; (2) close down backward production facilities; (3) accelerate power grids construction.

In July 2013, the state council issued *Some Suggestions to Improving PV Industry Development* to make sure PV power will make great contribution to air-pollution control. This policy is first proposed at the executive meeting of the state council on February 12 as a supporting policy of *The Action Plan for the Control of Air Pollution*, and formally announced a little earlier than *The Action Plan*. It (1) set benchmark prices for different PV resource areas; (2) set whole electricity subsidy (0.42 CNY/kWh before 2020) and purchase mechanism for distributed PV power; (3) free self-consumption electricity of distributed PV system from all taxes and fees levied along with electricity price; (4) accelerate technology advancement to increase utilization hours and reduce cost.

In general, air-pollution control policy on national level will indirectly affect PV industry by promoting electric power replacement and energy structure adjustment. In addition, air-pollution control policies on energy industrial level will indirectly stimulate PV industry by restricting coal consumption and setting it as an important development direction. These policies together with PV power stimulating policies constitute the framework of air-pollution control policy in this paper, to ensure PV power will give a boost to air-pollution control. The specific effects of policy measures on PV industry are shown in Figure 2.

Because of the uncertainties China's PV power will face, it is of great significant to figure out how China's PV power will be affected by these 'air-pollution' control policies. Considering its advantages on integrity and dynamics during the complex analysis, this paper plans to establish a SD model with different parameter settings, which can be determined by the policy analyses mentioned above, to simulate the development of China's PV industry in different policy scenarios. Further, comparing the differences between simulation results in different policy scenarios can help us assess the effect of air-pollution control policy on China's PV industry.

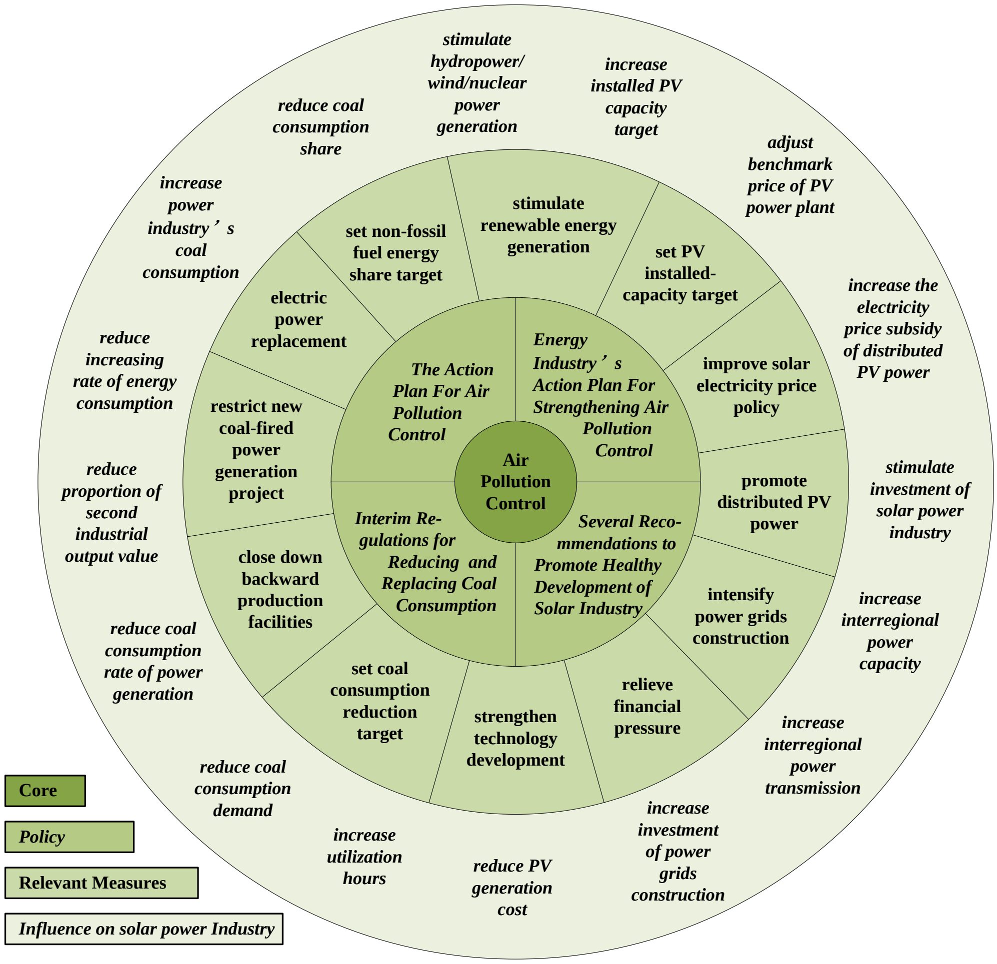

Figure 2. Air-pollution control measures and its effects on PV industry.

3. Methodology

China's PV power development with and without air-pollution control policy can be predicted by the same SD model with different parameter settings. As a systems modeling and dynamic simulation methodology, SD can analyze dynamic complexities in socio-economic and bio-physical systems [30,31]. SD model can better simulate China's PV power development than other types of quantitative modeling, because of its advantage of analyzing complex relationships among the variables involved in energy development system, and simulating the feedback effects of backward variables on forward variables. It also enables us to formulate relevant policies to control the dynamic behaviors of whole system, and understand the PV power system overall [32].

3.1. Causal Loop Diagram

Our SD model will involve main power generation and consumption sections, and the process of PV power investment, generation and transmission. As the first step of building SD model, a causal loop diagram of China's PV power development under the influence of air-pollution control policies is made to analyze the relationship of key variables and mechanism of air-pollution control policies, as shown in Figure 3. Positive links, which means the forward elements stimulate the backward elements, are marked with plus sign. In addition, negative links, which means the forward elements restrain the backward elements, are marked with minus sign. Positive loops, which have an even number of negative links, are marked with plus sign. Negative loops, which have an odd number of negative links, are marked with minus sign.

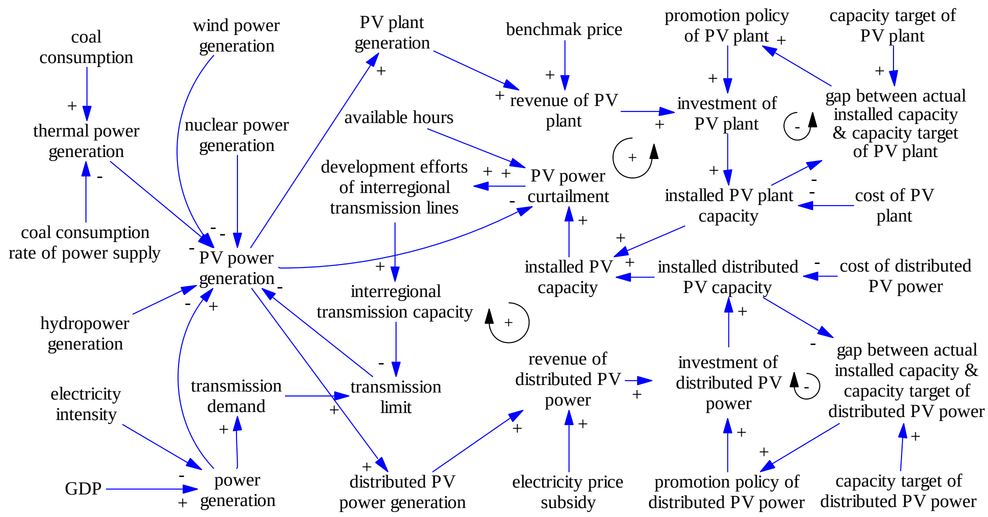

Figure 3. Causal loop diagram.

3.2. Flow Diagram

After drawing the causal loop diagram, we built the following flow diagram of China's PV power development under the influence of air-pollution control policies, as shown in Figure 4, using Vensim software. Flow diagram is a good tool for modeling the cause and effect relations between various variables of the SD model using directive arrows. This flow diagram contains three subsystems and over 70 variables including state variables (represent cumulative results, shown in boxes), rate variables (represent changing rate of state variables, shown with double triangles), and auxiliary variables (the rest relevant variables). Key variables and its initial values are provided in Table A1. There are over sixty controlling functions used to express the quantitative relationships among all the variables. Due to the limited length of the article, only the functional relationships with great significance and something unclear in the flow diagram are enumerated.

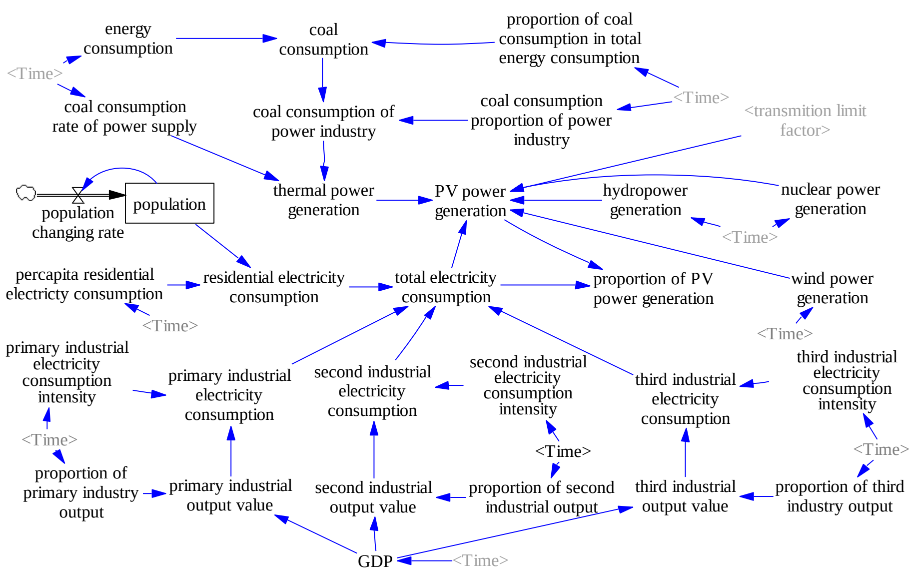

Figure 4. Flow diagram for power generation and consumption subsystem.

3.2.1. Power Generation and Consumption Subsystem

To stimulate the process of power generation and power consumption, we built the power generation and consumption subsystem, as shown in Figure 4. We assume that China's total power generation equals total power consumption. Total power consumption consists of the primary industrial electricity consumption, the second industrial electricity consumption, the third industrial electricity consumption, and residential electricity consumption. To simplify model, we assume total power generation only consists of PV power generation, thermal power generation, hydropower generation, wind power generation and nuclear power generation.

As the core of our SD model, PV power generation (GP) is determined by total electricity consumption (TC), thermal power generation (GT), hydropower generation (GH), wind power generation (GW), nuclear power generation (GN) and transmission limit factor (TF), as in Equation (1). TF, which is the major restricted factor for PV generation, is set to a piecewise function of the gap between interregional power transmit demand (ITD) and actual value of transmission capacity (IT) as in Equation (2).

$$\mathrm{GP} = (\mathrm{TC} \times 0.995 - \mathrm{GT} - \mathrm{GH} - \mathrm{GW} - \mathrm{GN}) \times \mathrm{TF} \tag{1}$$

$$\mathrm{TF} = \mathrm{IF\ \ THEN\,ELSE}\ \left((\mathrm{ITD} - \mathrm{IT}) < 0,\quad 1,\quad 1 - (\mathrm{ITD} - \mathrm{IT})\,/\,10000 \right) \tag{2}$$

Further with the assumption that distributed PV power has the same annual utilization hours as PV power plant, total PV generation is distributed according to the proportion of distributed PV installed capacity (CPD) and PV plant installed capacity (CPP) in installed PV capacity. Thus, distributed PV power generation (GPD) is as in Equation (3) and PV plant power generation (GPP) is as in Equation (4).

$$\mathrm{GPD} = \mathrm{GP} \times \mathrm{CPD}/(\mathrm{CPD} + \mathrm{CPP}) \tag{3}$$

$$\mathrm{CPP} = \mathrm{GP} \times \mathrm{CPP}/(\mathrm{CPD} + \mathrm{CPP}) \tag{4}$$

3.2.2. Power Transmit Subsystem

To stimulate the restriction of interregional power transmission capacity on PV power generation, we built the power transmit subsystem, as shown in Figure 5. The transmission limit factor is determined by actual interregional power transmission capacity and transmission demand. Increasing rate of interregional transmission capacity is stimulated by PV power curtailment, which depends on the actual value and theoretical value of PV power generation.

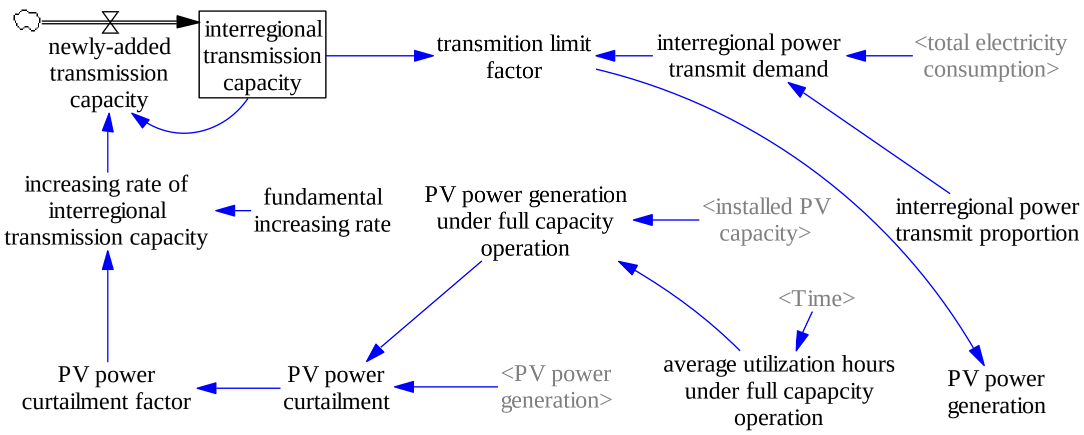

Figure 5. Flow diagram for power transmit subsystem.

As shown in Equation (5), the value of transmission capacity (IT) at time t depends on its value at time t-dt and newly-added interregional transmission capacity (ITN), which is the product of IT and its increasing rate (ITI). The increasing rate of interregional transmission capacity (ITI) is the product of fundamental increasing rate (ITIF) and stimulating factor of PV power curtailment (CPF), which is a piecewise function of PV power curtailment (PC). PC is set as an IF function of theoretical wind power generation (GPT) and actual generation (GP) as in Equation (6).

$$\mathrm{IT(t)} = \mathrm{IT(t-dt)} + \mathrm{(ITN)dt} = \mathrm{IT(t-dt)} + (\mathrm{IT} \times \mathrm{ITI})\mathrm{dt} = \mathrm{IT(t-dt)} + (\mathrm{IT} \times \mathrm{ITIF} \times \mathrm{CPF})\mathrm{dt} \quad (5)$$

$$\mathrm{CP} = \mathrm{IF(GPT - GP > 0, (GPT - GP)/GPT, 0)} \quad (6)$$

3.2.3. Installed PV Capacity Subsystem

To stimulate the development situation of China's PV power, we built the installed PV capacity subsystem, as shown in Figure 6. At present, China has price subsidy for full generation of distributed PV power, which can be feed back to grid after self-consumption at coal-fired benchmark price. PV power plants can sale all electricity to grid at PV benchmark price. These electricity price and price subsidies determine the revenue of PV power industry, which will be partly used to make investment in new installed capacity. The investment is also influenced by the gap between installed PV capacity target and actual value. Therefore, the government can control installed PV capacity by adjusting capacity target. Newly-added installed PV power capacity is determined by its investment and construction cost per capacity. We assume that the utilization hours of distributed PV power and PV plant are equal. Thus, the composition of installed PV capacity decided the composition of PV power generation.

$$\mathrm{RPD} = \mathrm{GPD} \times \mathrm{SPD} + (1 - \mathrm{PS}) \times \mathrm{GPD} \times \mathrm{PD} \quad (7)$$

$$\mathrm{RPP} = \mathrm{GPP} \times \mathrm{PB} \quad (8)$$

$$\mathrm{IPD} = \mathrm{RPD} \times \mathrm{IPDP} \times \mathrm{PFD/ISP} \quad (9)$$

$$\mathrm{IPP} = \mathrm{RPP} \times \mathrm{IPPP} \times \mathrm{PFP/ISP} \quad (10)$$

$$\mathrm{CPD(t)} = \mathrm{CPD(t-dt)} + \mathrm{(CPDN)dt} = \mathrm{CPD(t-dt)} + (\mathrm{IPD} \times 100/\mathrm{CPD})\mathrm{dt} \quad (11)$$

$$\mathrm{CPP(t)} = \mathrm{CPP(t-dt)} + \mathrm{(CPPN)dt} = \mathrm{CPP(t-dt)} + (\mathrm{IPP} \times 100/\mathrm{CPP})\mathrm{dt} \quad (12)$$

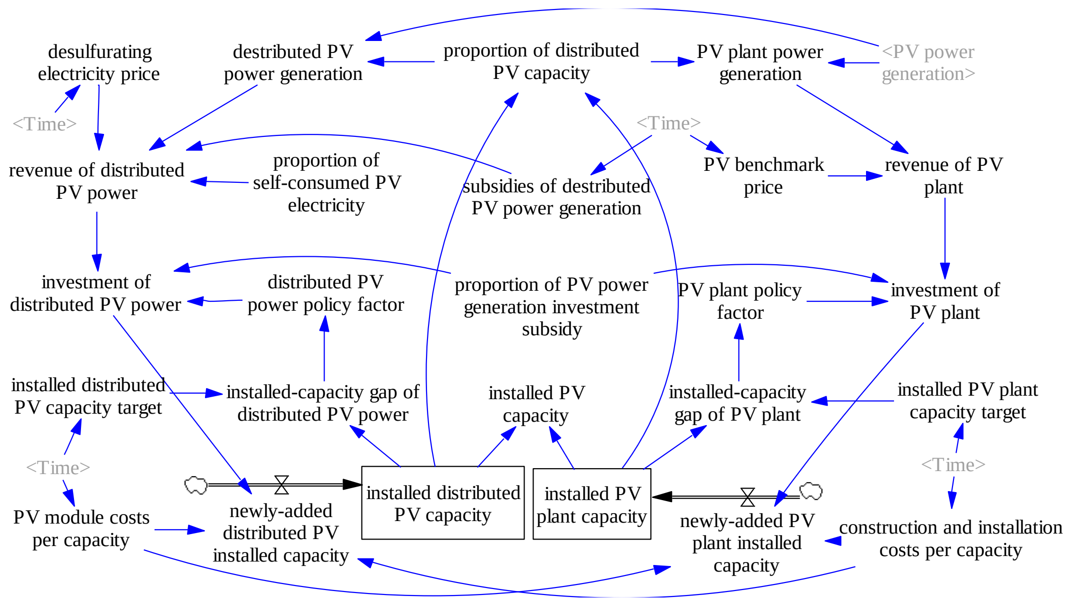

Figure 6. Flow diagram for installed PV capacity subsystem.

We can calculate the revenue of distributed PV power (RPD) as in Equation (7), and calculate the revenue of PV power plant (RPP) as Equation (8). Because distributed PV power has electricity price subsidy (PS) for the whole generation, and its excessive generation can be fed back to grid after self-consumption at desulfurating electricity price (PS). PV power plants can only get revenue (RPP) from selling all their generation (GPP) to grid at PV benchmark price (PB). Investment of distributed PV power (IPD) depends on RPD, discretionary investment proportion (IPDP), stimulating factor of policy (PFD) and proportion of investment subsidy (ISP) as in Equation (9). In addition, investment of PV power plant (IPP) is very similar as in Equation (10). Distributed PV installed capacity (CPD) at time t depends on CPD at time t-dt and newly-added capacity (CPDN), which determined by IPD and building costs per unit (CPD). The capacity of PV power plant (CPP) has very similar function as in Equation (12).

3.3. Model Validation

The validity of the model is tested using an authenticity test and a sensitivity test when the model design is finished. This paper used an authenticity test to justify the appropriateness of the proposed model by analyzing the error rate of eight variables between true value and simulation in 2012–2014. These variables cover all level variables and some key variables, which have overall situation and representativeness. Authenticity test results are provided in Table A2. It is worth mentioning that the true values of interregional transmission capacity are estimated by the development plan of China's State Grid Corporation, which may underestimate the actual development situation. It may lead to an error rate of 7.80% in 2014. However, the errors of other variables are almost all controlled within −5%~5%, which completely meet the requirement of authenticity test. In addition, the simulation period has significance on behalf of those typical periods of China's PV power development under the influence of 'air-pollution control policy'. Thus, our SD model is valid, and can be used to predict China's PV power development under different policy environments, if there are no structural changes in the future.

The sensitivity test is conducted to estimate the policy effects on PV power. PV power generation, installed PV capacity, PV power curtailment and the proportion of distributed PV installed capacity are chosen as studied variables, because they can basically reflect the development and utilization situation of PV power. In addition, ten parameters, which can simulate the effect of air-pollution control policies, are chosen as studied parameters. The sensitivities of four variables to ten parameters are shown in Table A3. The test results indicate that the proportion of coal consumption in total energy consumption, the increasing rate of interregional transmission capacity, interregional power transmit proportion and the proportion of the third industrial output value have a greater effect on PV power generation. The target of installed PV capacity, average benchmark price of PV power plant, and electricity price subsidy of distributed PV power have a greater effect on installed PV capacity. Average utilization hours, the target of distributed PV installed capacity, average benchmark price of PV power plant and increasing rate of interregional transmission capacity have a greater effect on PV power curtailment. The target of installed capacity, electricity price subsidy of distributed PV power and the increasing rate of interregional transmission capacity have a greater effect on the proportion of distributed PV installed capacity. Thus, these significant effect factors need to be further studied in policy scenario analysis.

3.4. Policy Scenarios

Air-pollution control policies can be divided into fundamental policies (*The Action Plan for the Control of Air Pollution*), which indirectly affect China's PV industry; and supporting policies (*Energy Industry's Action Plan for Strengthening Air Pollution Control*, *Interim Regulations for Reducing and Replacing Coal Consumption*, *Some Suggestions to Improving PV Industry Development*), which affect China's PV industry more directly. The policy scenario with no 'air-pollution control policy' is set as Scenario 1, the scenario with only fundamental policy is set as Scenario 2, and the scenario with both fundamental and supporting policies is set as Scenario 3. The specific policy measures and policy objectives in three policy scenarios are shown in Table 1.

Table 1. Policy measures and objectives in different scenarios.

Scenarios	Policy Measures	Policy Objectives
Scenario 1	No air-pollution control policies.	No policy objectives
Scenario 2	fundamental policy: (1) Restrict new coal-fired power generation project; (2) Stimulate renewable energy generation; (3) Improve price mechanism of renewable energy generation; (4) Control energy consumption; (5) Improve the efficiency of coal utilization; (6) Adjust industrial structure.	fundamental policy: (1) Non-fossil fuel energy share should reach 13% in 2017.
Scenario 3	fundamental policy: The same as above. supporting policy: (1) Restrict coal consumption; (2) Outline the 'feed PV power to grid after self-consumption' principle for the development of distributed PV power; (3) Set whole electricity subsidy and purchase mechanism for distributed PV power; (4) Accelerate power grids construction; (5) Increase benchmark prices for PV power generation; (6) Accelerate technology advancement to increase utilization hours and reduce cost.	fundamental policy: The same as above. supporting policy: (1) Installed PV capacity should reach 35,000 MW in 2017, and reach 100,000 MW in 2020; (2) Distributed PV installed capacity should reach 15,000 MW in 2017; and reach 40,000 MW in 2020; (3) Interregional power transmission to Jing-Jin-Ji region, Yangtse River Delta and Pearl River Delta should reach 68 million kWh.

These policy measures in different scenarios are used to set model parameters, which can simulate the control of air-pollution control policies on system behavior, as provided in Table A4. In addition, the policy objectives are set as important evaluating indexes of China's PV power development. Thus, the impact of air-pollution control policies can be assessed by comparing the predictions of evaluating indexes in different scenarios. To explain, most of the parameter settings vary every year. Our paper does not list the parameter settings of each year but the settings for time-invariant parameters and the settings for time-varying parameters in 2017 (some also in 2020) because of space cause. Year 2017 and 2020 are important years, because they are always highlighted in relevant policies. The parameter values of other years are evenly distributed on the trend-line determined by initial values and values in 2017 (some also in 2020).

4. Simulation Results and Analysis

First in this section, China's PV power development during 2015–2025 in different policy scenarios are simulated by the SD model we built above using Vensim software. Later, air-pollution control policy's effect on China's PV power is analyzed by comparing the differences between simulated results.

4.1. Simulation Results in Different Policy Scenarios

4.1.1. Scenario 1: With no Policy Influence

In Scenario 1, China's PV power industry will develop without any influence of air-pollution control policies. In this scenario, China will have excessive energy demand because of unreasonable industrial structure and high energy intensity. Clean power generation could not develop as expected due to the over-reliance on thermal power. In 2020, China's PV power generation will be only 153.22 billion kWh accounting for 2.09% of total power generation. PV power curtailment stays at a high level during the whole simulation period. It will peak in 2025 at 25.60% because of the lack of transmission channel. At that time, China's PV power generation will reach 220.19 billion kWh accounting for 2.59% of the total power generation. Installed PV capacity will have an accelerated growth during 2015–2020, and reach 109,855 MW in 2020. After that, the increasing rate will become steady, and installed PV capacity will reach 227,658 MW in 2025.

Without enough finance support, distributed PV power, which supposed to be the main developing trend of PV power internationally, will develop slowly in China due to high costs. In 2020 distributed PV installed capacity will reach 40,872 MW, which just meet the policy target, accounting for only 37.21% of total installed PV capacity. In addition, the generation of distributed PV power will be 96.21 billion kWh at that time. Although distributed PV power will develop steadily during the 13th five year plan period, its installed capacity will be only 88,836 MW, which lag behind the policy target (90,000 MW) in 2025. In addition, because of the relatively fast growth of PV power plant, the proportion of distributed PV power in PV power will generally remain at about 39% since 2020. The simulated results of all state variables and some important auxiliary variables in Scenario 1 are shown in Table A5.

In general, without air-pollution control policies, China can hardly get a reasonable energy structure, and PV power can hardly receive good development. Over-reliance on thermal power, high costs and outmoded transmission grid make China's PV power (especially distributed PV power) could not meet the development targets, which is quite low.

4.1.2. Scenario 2: With Influence of Fundamental Policy

In Scenario 2, China's PV power industry will develop with the influence of fundamental air-pollution control policy. Stimulated by this policy, China's industrial structure will be more reasonable, and energy intensity will be lower as well. Further, this policy will reduce the proportion of coal consumption in total energy consumption to 65%. In consequence, thermal power generation will be about 10% less than that in Scenario 1. Non-fossil energy including PV power will get steady growth. In 2020 China's PV power generation will be 260.89 billion kWh accounting for 3.72% of total power generation. After reaching its peak at 294.11 billion kWh in 2023, it will start to decline slowly because of the more rapid rise of nuclear and other clean power. In addition, without supporting policies, the proportion of PV power generation will start to drop from the peak in 2017 (4.06%), and will probably drop to the same level in Scenario 1.

Installed PV capacity will reach 131,229 MW in 2020, and reach 266,141 MW in 2025, which is not much higher than the simulations in Scenario 1. In order to relief the pressure of PV power curtailment, fundamental air-pollution control policy plans to enhance the construction of interregional transmission lines. However, without the supporting polices, which make plans for transmission lines to realize large-scale interregional electricity transmission, PV power curtailment will still stay at a high level in Scenario 2. At the end of our simulation, PV power curtailment will reach up to 29.28% with a rising trend.

In Scenario 2, the increase of generation will stimulate the investments of both distributed PV power and PV power plant. Although benchmark price and price subsidy are still not enough, the investment enthusiasm of PV power will be much higher than that in Scenario 1. In addition, the increasing rate of distributed PV installed capacity will be accelerated since 2015. In 2020, distributed PV installed capacity will be 67,262 MW, which exceeds the policy target (40,000 MW), accounting for 51.26% of total installed PV capacity. However, its increasing rate will slow down since 2021 as the end of electricity price subsidy of distributed PV power. Different from distributed PV power, the increasing rate of PV plant installed capacity will maintain at about 20%, because the benchmark price of PV power plant will remain stable. Thus, the proportion of distributed PV power will begin to drop since 2022. By 2025, distributed PV installed capacity will reach 121,293 MW, accounting for 45.57% of total installed PV capacity. At that time, distributed PV power generation will reach 128.31 billion kWh, and PV plant power generation will reach 147.85 billion kWh. The simulated results of all state variables and some important auxiliary variables in Scenario 2 are shown in Table A6.

In general, with fundamental air-pollution control policy, China can have a more reasonable energy structure. However, without relevant supporting policies, PV power will have lower competitiveness compared with other clean powers, which have obvious cost advantage. In this policy scenario, both distributed PV power and PV power plant will overly dependent on subsidies. Thus, the development of distributed PV power will slow down in 2021 as the end of electricity price subsidy. China's PV power still needs long-term subsidy unless technical and power transmission problem can be overcome. However, the subsidy will undoubtedly bring huge financial pressure to Chinese government.

4.1.3. Scenario 3: With Influence of Fundamental and Supporting Policies

In Scenario 3, China's PV power industry will develop with influence of both fundamental and supporting air-pollution control policies. In this scenario, China's industrial structure and energy intensity are all control in reasonable range, just as Scenario 2. Stimulated by supporting air-pollution control policies, energy consumption and the proportion of coal consumption will be further reduced. With this background, the increasing rate of thermal power will be controlled within 1%. PV power generation will keep increasing at an annual rate of over 10% during 2015–2020 in Scenario 3. In 2020, China's PV power generation will reach 301.00 billion kWh accounting for 4.30% of total power generation. After that, the increasing rate of PV generation will begin to decline, and the proportion of PV generation will maintain at about 4.5%. On the other hand, supporting air-pollution control policies will keep the increasing rate of interregional transmission capacity at about 10%. Thus, China's PV power generation can gradually break the limitation of power transmission. According to the simulations, the generation will keep increasing at a low speed during 2021–2025, and reach 347.91 billion kWh accounting for 4.41% of total power generation in 2025. PV power curtailment will continue increasing during 2015–2020, because of the lag of electricity grid construction behind the increasing demand of interregional transmission. China's PV power curtailment will reach its peak at 25.67% in 2020. As electricity grid becomes more mature, China's PV power curtailment will start to drop since 2021. The curtailment will be only 8.21% in 2025, and it will probably be eliminated before 2030.

In Scenario 3, supporting policies increase the benchmark price of PV power plant and electricity price subsidy of distributed PV power, which makes installed PV capacity higher than that in Scenario 1 and 2. China's Installed PV capacity will start to grow rapidly in 2015, and will reach 247,223 MW in 2020. However, along with the changes of policy environment, the increasing rate of installed PV capacity will fail suddenly and maintain at about 8% since 2021. At the end of our simulation, China's installed PV capacity will reach 414,925 MW.

China's distributed PV power will experience a revenue surge during 2016–2020, after that its revenue will return to pre-2015 levels and maintain at around 25 billion CNY as the stop of electricity price subsidy. Its investment has the same trend as revenue. Distributed PV installed capacity will experience accelerated growth during 2015–2020 because of investment surge. It will reach 143,343 MW accounting for 57.98% of total installed PV capacity in 2020. In this stage, distributed PV power will mostly benefit from subsidy not power generation, and become the mainstream of distributed PV. Compared with distributed PV power, PV power plant will develop more steadily. During 2015–2020, its generation will be restricted by insufficient transmission grids. In addition, its capacity will reach 103,880 MW just exceeding the policy target (90,000 MW) in 2020. Since 2021, as transmission grid become more mature, PV power plant will have greater development potential. Thus, the proportion of distributed PV installed capacity will begin to fall slightly. The simulated results of all state variables and some important auxiliary variables in Scenario 3 are shown in Table A7.

In general, with both fundamental and supporting air-pollution control policies, China's PV generation will keep increasing during the whole simulation. Its proportion in total power generation will rise to 4.5% in 2021, and maintain at that level. PV power curtailment will first increase, then decrease, and probably be eliminated before 2030. In this scenario, quite a high subsidy will bring investment and capacity surge to distributed PV power, which makes it the mainstream of China's PV power. In addition, developing distributed PV power is a good solution to deal with the problem of lagging transmission grids before 2021. In Scenario 3, the transmission problem will be significantly relieved since 2021. Therefore, that it is the proper time to end up the electricity price subsidy of distributed PV power and make the benchmark price of PV power plant on the same level as thermal power.

4.2. Analysis of Policy Effect

Based on the simulations, we analyze the impact of air-pollution control policy on China's PV power by drawing curves of the same variable in three scenarios in one graph (see Figures 7–16), and comparing the differences between them. We compared all variables presented in Tables A5–7 except for the investment of distributed PV power and PV plant, because they are not set as policy objectives, and can be reflected in installed capacity. The comparison results of PV power generation and its proportion, distributed PV power generation and PV plant power generation reflect the fulfillment of generation objectives mentioned in air-pollution control policy. The comparison results of PV power curtailment and interregional transmission capacity reflect the fulfillment of power transmission objectives. The comparison results of installed PV capacity, distributed PV installed capacity and PV plant installed capacity reflects the fulfillment of capacity objectives. In addition, the proportion of distributed PV capacity reflects the composition of PV power. In general, these ten variables cover almost all of the evaluate indexes of China's PV power development.

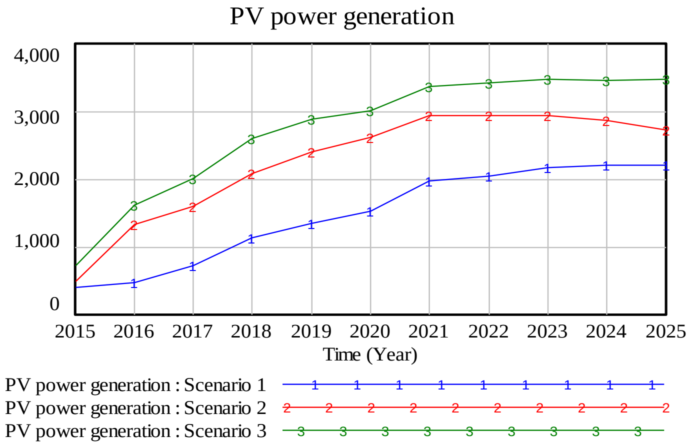

Figure 7. PV power generation (10^8 kWh).

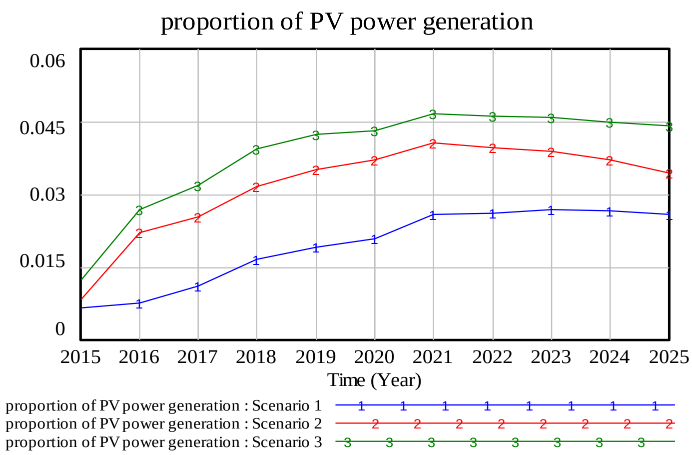

Figure 8. Proportion of PV power generation.

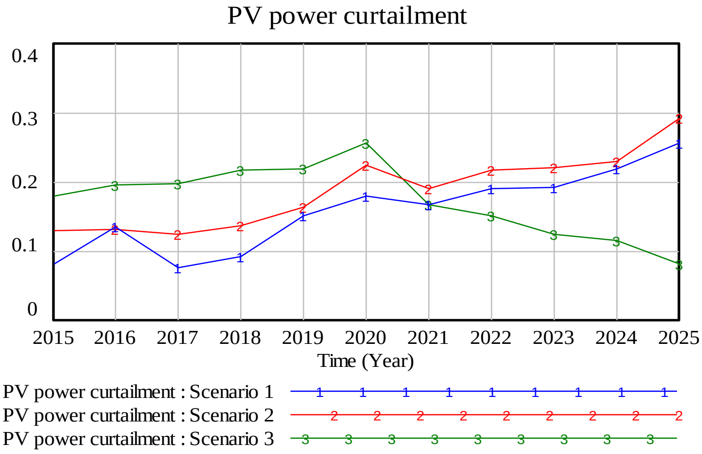

Figure 9. PV power curtailment

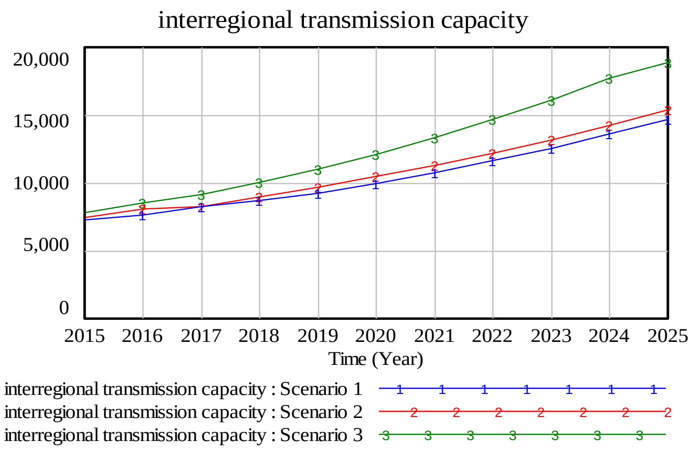

Figure 10. Interregional transmission capacity (10^8 kWh)

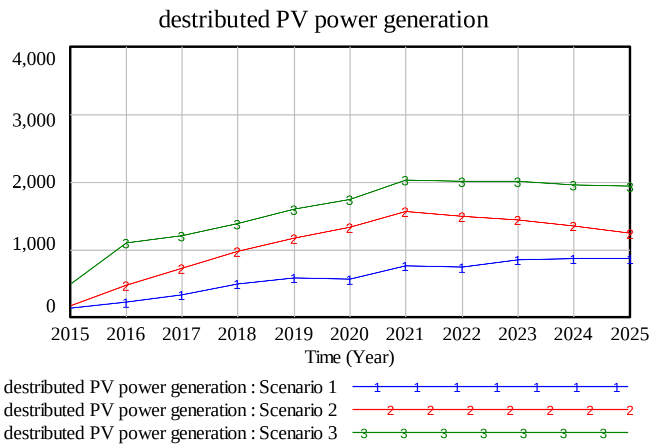

Figure 11. Distributed PV power generation (10^8 kWh).

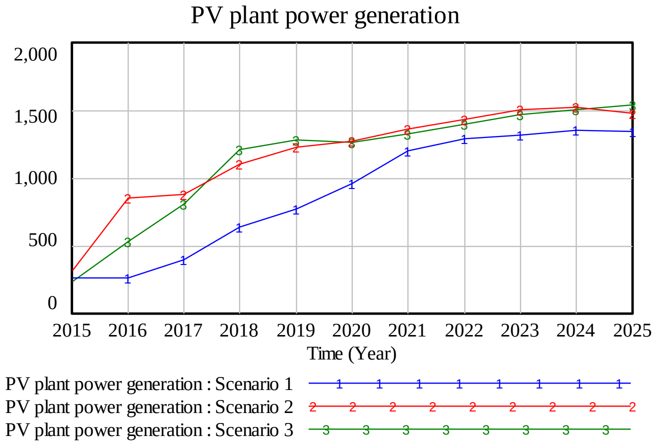

Figure 12. PV plant power generation (10^8 kWh).

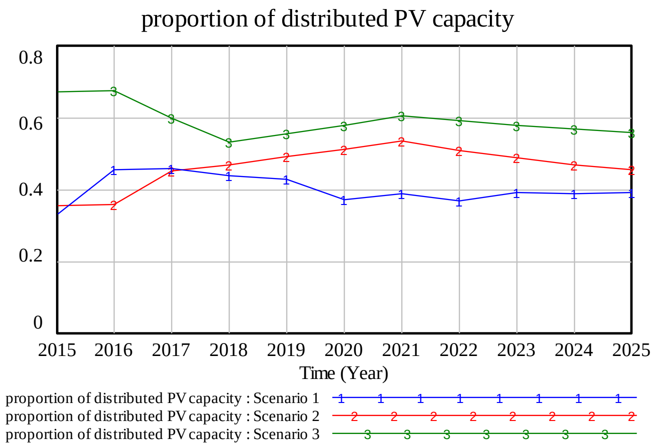

Figure 13. Proportion of distributed PV capacity.

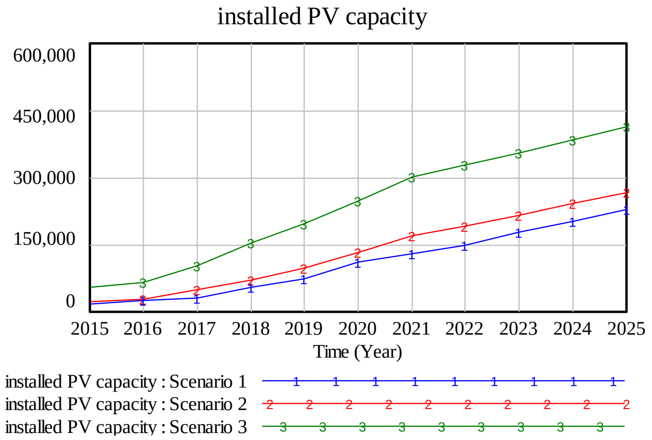

Figure 14. Installed PV capacity (MW).

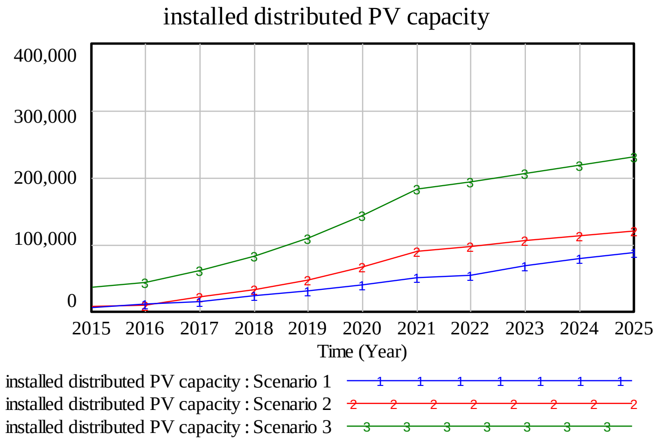

Figure 15. Distributed PV installed capacity (MW).

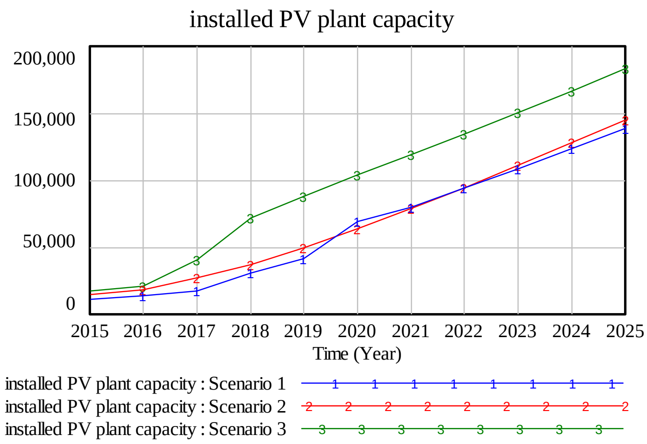

Figure 16. PV plant installed capacity (MW).

The differences between the curves of Scenario 1 and 2 indicate the impact of fundamental air-pollution control policy ('fundamental policy' for short) on China's PV industry. The differences between the curves of Scenario 1 and 3 indicate the impact of both fundamental and supporting air-pollution control policies ('supporting policies' for short). The differences between the curves of Scenario 2 and 3 indicate the impact of only supporting policies. We can tell from Figures 7–16 that:

(1) Fundamental policy will obviously increase the generation of all clean energies including PV power by limiting emissions. However, the proportion of PV generation in Scenario 2 will eventually drop to nearly the same level in Scenario 1, because of the lack of special supports for PV power. Supporting policies can make PV power generation and its proportion remain stable. However these policies cannot make generation continue increasing, because wind power will still have more mature technology and more competitiveness unless new technological revolutions occur in PV power.

(2) Fundamental policy will make PV power curtailment more severe because of the lack of control measures. Supporting policies will firstly aggravate PV power curtailment during 2015–2020 because of the surge of installed PV capacity. While after that supporting policies can reduce the curtailment sharply and eventually eliminate it by accelerating the construction of transmission grid.

(3) Fundamental policy can promote the development of China's PV power temporarily, but cannot maintain its growth trend. When China's transmission grid stays immature, the supporting policies will keep PV power generation increasing by promoting distributed PV power, which does not need to be transmitted over distance. However, since 2021, transmission problem will no longer be an important factor to limit power generation of PV plant, and the saturation of architecture resources

will become the restriction of distributed PV power. Thus, from that time PV power plant will be the new development priority, and the proportion of distributed PV power will start to drop slightly.

(4) Fundamental policy of China's PV power only involves subsidy mechanism and capacity target, but no suitable development planning. Therefore, the development of PV power will run out of steam since 2021. Under the influence of supporting policies, the installed capacity of both distributed PV power and PV power plant will be significantly raised by high subsidy and benchmark price. As the end of subsidy, the generation and capacity increasing rate of distributed PV power will begin to stabilize since 2021. If the subsidy won't end at this appropriate time, distributed PV power will face the problem of over-capacity. Since 2020, long-distance transmission and high costs won't be the limiting factors for PV power plant. At that time, protective benchmark price of PV power plant cannot lead to increase in generation but only over-capacity.

5. Conclusions

Under the stimulations of air-pollution control policies, China's PV power will develop better. It is of great significance to predict the developing trend of China's PV power, and identify whether these policies can work as expected. Hence, our paper offers a new platform for simulating China's PV power in different policy scenarios during 2015–2025. The simulations indicate that: (1) In the scenario of no air-pollution control policies, China's PV power could not develop satisfactorily due to the lack of essential incentives. PV power generation will only account for less than 3% of total power generation in 2025; (2) In the scenario of only fundamental air-pollution control policies, thermal power generation will be restricted. Although PV power will enjoy rapid grow during 2015–2020, its developing room will be gradually crowded out by other clean powers since 2021; (3) In the scenario of fundamental and supporting policies, PV power has a clear development plan, which ensures its continued growth. Distributed PV power will be energetically supported when transmission network are still immature. Since 2021, big PV plant will be given priority over distributed PV power when distributed architecture resources become saturated. The proportion of PV power generation will maintain at about 4.5%. The differences between simulations of three policy scenarios indicate air-pollution control policy's impact on China's PV power. Our paper provides a SD model, which can simulate the comprehensive relationships among various factors, for predicting the development of China's PV power. In addition, the results of sensitivity test and scenario analysis indicate the influence of single air-pollution control policy measure and a set of policies. Further, the assessments of policy efficiency provide reference for policy-making institutions.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix

Table A1. Variable setting.

Variable	Unit	Initial Value	Data Source
GDP	10^8 CNY	519,470	China Statistical Yearbook (2012)
proportion of coal consumption in total energy consumption	-	0.676	China Statistical Yearbook (2012)
energy consumption	10^4 tce	361,732	China Statistical Yearbook (2012)
coal consumption rate of power generation	g/kWh	321	China Statistical Yearbook (2012)
coal consumption proportion of power industry	-	0.49	China Statistical Yearbook (2012)
wind power generation	10^8 kWh	1164	survey data of Electricity Council
nuclear power generation	10^8 kWh	1055	survey data of Electricity Council
hydropower generation	10^8 kWh	8641	survey data of Electricity Council
interregional transmission capacity	10^8 kWh	7796	survey data of Electricity Council
proportion of primary industry output	-	0.05	China Statistical Yearbook (2012)
primary industrial electricity consumption intensity	kWh/CNY	0.02	China Statistical Yearbook (2012)
proportion of second industry output	-	0.50	China Statistical Yearbook (2012)
second industrial electricity consumption intensity	kWh/CNY	0.15	China Statistical Yearbook (2012)
proportion of third industry output	-	0.45	China Statistical Yearbook (2012)
third industrial electricity consumption intensity	kWh/CNY	0.02	China Statistical Yearbook (2012)
population increasing rate	-	0.005	China Statistical Yearbook (2012)
population	10^8 people	13.5	China Statistical Yearbook (2012)
per capita residential electricity consumption	kWh/person	443.83	survey data of Electricity Council
PV module costs per capacity	CNY/W	7.74	survey data of Electricity Council
construction and installation costs per capacity	CNY/W	2.12	survey data of Electricity Council
average benchmark price of PV power plant	CNY/kWh	1.05	survey data of Electricity Council
proportion of self-consumed PV electricity	-	0.80	survey data of Electricity Council
desulfurating electricity price	CNY/kWh	0.40	survey data of Electricity Council
target of distributed PV installed capacity	MW	1950	survey data of NEA
target of PV plant installed capacity	MW	4850	survey data of NEA
subsidies of distributed PV power generation	CNY/kWh	0.35	survey data of Electricity Council
proportion of self consumption	-	0.80	survey data of Electricity Council

Table A2. Authenticity test results.

Year	GDP (10^8 Yuan)			Population (10^8)		
	True Value	Simulation	Error (%)	True Value	Simulation	Error (%)
2012	519,470	533,484	2.70%	13.5	13.5404	0.30%
2013	568,845	585,834	2.99%	13.5675	13.6072	0.29%
2014	636,463	638,184	0.27%	13.6353	13.5678	−0.49%
Year	**Total Electricity Generation (10^8 KWh)**			**Interregional Transmission Capacity (10^8 KWh)**		
	True Value	Simulation	Error (%)	True Value	Simulation	Error (%)
2012	49,865	49,497.3	−0.74%	6000	6055	0.92%
2013	53,720	53,294.7	−0.79%	6200	6381.97	2.94%
2014	54,638	56,947.2	4.23%	6400	6898.91	7.80%
Year	**PV Power Generation (10^8 KWh)**			**Installed PV Capacity (MWe)**		
	True Value	Simulation	Error (%)	True Value	Simulation	Error (%)
2012	38.2	40.2176	5.28%	6800	6800	0.00%
2013	87	90.3832	3.89%	19,420	19,788	1.89%
2014	250	251.04	0.42%	28,050	26,721.4	−4.74%
Year	**Distributed PV Installed Capacity (MWe)**			**PV Plant Installed Capacity (MWe)**		
	True Value	Simulation	Error (%)	True Value	Simulation	Error (%)
2012	1950	1950	0.00%	4850	4850	0.00%
2013	3100	3026	−2.39%	16,320	16,762	2.71%
2014	4670	4469	−4.30%	23,380	22,252.4	−4.82%

Table A3. Sensitivity test results.

Parameter	PV Power Generation					
	10%	**5%**	**3%**	**−3%**	**−5%**	**−10%**
proportion of coal consumption in total energy consumption	−56.5070%	−31.5665%	−16.9525%	16.9516%	19.9899%	31.9621%
proportion of third industrial output value	−3.9165%	−5.4323%	−6.7665%	1.0978%	10.5632%	5.4613%
average utilization hours	2.4975%	4.2976%	2.4204%	0.1556%	−1.3657%	−4.0428%
increasing rate of interregional transmission capacity	23.4556%	20.1111%	12.3479%	−8.5482%	−7.6413%	−12.5345%
interregional power transmit proportion	−15.6783%	−5.3212%	−4.7694%	1.6759%	7.1943%	10.2224%
average benchmark price of PV power plant	0.6320%	0.3752%	3.5119%	−0.7400%	−2.3142%	−1.3181%
electricity price subsidy of distributed PV power	0.3146%	0.8239%	3.3545%	−1.8965%	−0.4369%	−0.4473%
target of distributed PV installed capacity	1.0723%	1.2645%	0.3403%	−0.7965%	−0.8542%	−0.9452%
target of PV plant installed capacity	0.4924%	1.0748%	2.6349%	0.9027%	−1.7131%	−2.0572%
PV module costs per capacity	−0.0789%	−0.5059%	−0.8924%	0.2377%	1.3953%	0.5583%
Parameter	**Installed PV Capacity**					
	10%	**5%**	**3%**	**−3%**	**−5%**	**−10%**
proportion of coal consumption in total energy consumption	−1.9429%	−2.6110%	−1.7509%	0.7332%	1.4256%	1.1489%
proportion of third industrial output value	−0.2456%	−0.0562%	−0.1439%	0.4321%	0.8554%	0.6894%
average utilization hours	1.2415%	1.8771%	0.3822%	0.3812%	−1.3812%	−1.2749%
increasing rate of interregional transmission capacity	3.6561%	3.2007%	3.9120%	−0.9009%	−1.7032%	−0.6599%
interregional power transmit proportion	1.9370%	−0.1919%	0.0942%	2.5612%	−1.5467%	1.3276%
average benchmark price of PV power plant	7.4613%	4.6534%	2.0081%	1.2281%	−3.1400%	−2.0183%
electricity price subsidy of distributed PV power	5.0719%	3.7042%	1.8215%	−1.2913%	−2.5717%	−2.2938%
target of distributed PV installed capacity	8.3553%	5.7996%	0.3745%	−1.3208%	−3.1112%	−3.6953%
target of PV plant installed capacity	5.7188%	4.8869%	2.9772%	−1.0331%	−5.2039%	−5.6862%
PV module costs per capacity	8.2651%	7.1461%	5.7966%	3.5674%	−0.8700%	−7.6631%
Parameter	**PV Power Curtailment**					
	10%	**5%**	**3%**	**−3%**	**−5%**	**−10%**
proportion of coal consumption in total energy consumption	22.5761%	5.0570%	13.7528%	−18.2839%	−12.4578%	−33.2535%
proportion of third industrial output value	2.5761%	5.0570%	3.7528%	−4.2839%	−4.7823%	−3.2535%
average utilization hours	40.2447%	24.5764%	17.9931%	−4.9890%	−11.3156%	−28.7008%
increasing rate of interregional transmission capacity	−10.4238%	−0.5929%	−11.1262%	11.0953%	2.0923%	1.9621%
interregional power transmit proportion	5.6155%	3.5680%	1.6237%	0.3803%	−5.1220%	−4.9480%
average benchmark price of PV power plant	20.5192%	4.8071%	11.3880%	−3.6743%	−8.9963%	−11.4157%
electricity price subsidy of distributed PV power	10.2132%	10.5555%	10.8774%	−9.4164%	−1.6983%	−3.8737%
target of distributed PV installed capacity	34.8166%	16.1998%	1.1035%	−3.9547%	−3.3207%	−8.1859%
target of PV plant installed capacity	15.9866%	13.7694%	8.5443%	−4.4823%	−6.6597%	−17.8167%
PV module costs per capacity	−2.5605%	−6.4809%	2.8937%	1.1801%	5.4245%	4.8348%

Table A3. *Cont.*

Parameter	Proportion of Distributed PV Installed Capacity					
	10%	**5%**	**3%**	**−3%**	**−5%**	**−10%**
proportion of coal consumption in total energy consumption	−2.8318%	−1.2204%	−0.2072%	−0.8877%	1.0179%	1.4538%
proportion of third industrial output value	−0.8297%	−1.2204%	−1.2072%	−0.8877%	1.5485%	1.4538%
average utilization hours	0.8431%	0.9931%	0.2594%	−0.5673%	−0.1673%	1.0807%
increasing rate of interregional transmission capacity	5.6123%	4.2340%	4.9233%	3.7384%	2.2144%	2.0417%
interregional power transmit proportion	−0.4465%	−0.9039%	0.6207%	0.0038%	0.7912%	0.4301%
average benchmark price of PV power plant	−2.6509%	−1.7261%	0.1748%	1.8040%	2.2761%	3.8606%
electricity price subsidy of distributed PV power	6.9170%	4.6754%	2.7330%	0.2575%	−0.9905%	−2.1951%
target of distributed PV installed capacity	11.7028%	9.9917%	3.3423%	−1.1340%	−6.0873%	−4.9864%
target of PV plant installed capacity	−6.6163%	−3.7157%	−4.2703%	3.5942%	5.7294%	6.6591%
PV module costs per capacity	−2.3328%	−0.6270%	−0.1783%	0.1187%	−0.8746%	0.3348%

Table A4. Parameter settings for different policy scenarios.

Parameter	**Scenario 1**	**Scenario 2**	**Scenario 3**
	Without Policy Influence	**Only Fundamental Policy**	**Fundamental and Supporting Policies**
proportion of coal consumption in total energy consumption in 2017	0.6668	0.6500	0.6323
energy consumption in 2017 (10^4 tce)	450,280	425,707	418,697
coal consumption rate of power generation in 2017 (g/kWh)	306	301	300
proportion of second industrial output value	0.4248	0.4142	0.4142
proportion of third industrial output value	0.5252	0.5358	0.5358
nuclear power generation in 2017 (10^8 kWh)	1606.34	1750.53	2800.00
wind power generation in 2017 (10^8 kWh)	2440.33	2440.33	2614.97
hydropower generation in 2017 (10^8 kWh)	11,688.92	11,688.92	12,175.86
average utilization hours in 2017 (h)	1294	1294	1400
increasing rate of interregional transmission capacity	0.09	0.09	0.11
interregional power transmit proportion	0.14	0.15	0.15
average benchmark price of PV power plant in 2017/2020 (CNY/kWh)	0.81/0.70	0.81/0.70	0.85/0.65
electricity price subsidy of distributed PV power before/after 2020 (CNY/kWh)	0.35/0.00	0.35/0.00	0.42/0.00
target of distributed PV installed capacity in 2017/2020 (MW)	15,000/40,000	15,000/40,000	35,000/60,000
target of PV plant installed capacity in 2017/2020 (MW)	20,000/60,000	20,000/60,000	35,000/90,000
PV module costs per capacity in 2017 (CNY/W)	5	5	4.5

Table A5. Simulated results of key variables in Scenario 1.

Year	PV Power Generation (10^8 kWh)	Proportion of PV Power Generation	Distributed PV Power Generation (10^8 kWh)	PV Plant Power Generation (10^8 kWh)	Installed PV Capacity (MW)	Distributed PV Installed Capacity (MW)	PV Plant Installed Capacity (MW)	Proportion of Distributed PV Capacity	Investment of Distributed PV Power (10^8 CNY)	Investment of PV Plant (10^8 CNY)	PV Power Curtailment	Interregional Transmission Capacity (10^8 kWh)
2015	395.12	0.0066	130.72	264.40	16,535	5471	11,065	0.3308	536.83	360.91	0.0809	7271
2016	480.63	0.0077	218.74	261.89	25,246	11,490	13,756	0.4551	226.61	394.14	0.1346	7664
2017	723.97	0.0111	330.69	393.28	31,311	14,302	17,009	0.4568	691.37	1486.58	0.0751	8285
2018	1128.90	0.0166	494.18	634.72	54,030	23,652	30,378	0.4378	521.20	1140.38	0.0916	8732
2019	1356.43	0.0191	583.20	773.23	72,659	31,240	41,419	0.4300	620.53	2670.21	0.1514	9204
2020	1532.18	0.0209	570.06	962.12	109,855	40,872	68,982	0.3721	611.86	1021.45	0.1796	9949
2021	1966.66	0.0259	764.11	1202.55	131,054	50,919	80,135	0.3885	203.25	1203.75	0.1663	10,755
2022	2041.56	0.0260	748.88	1292.68	148,372	54,425	93,946	0.3668	838.74	1235.16	0.1906	11,626
2023	2161.27	0.0268	843.01	1318.26	178,302	69,547	108,755	0.3901	487.82	1199.62	0.1919	12,568
2024	2213.42	0.0267	860.56	1352.87	202,408	78,694	123,714	0.3888	522.07	1169.55	0.2189	13,586
2025	2201.86	0.0259	859.20	1342.66	227,658	88,836	138,822	0.3902	537.29	1099.64	0.2560	14,687

Table A6. Simulated results of key variables in Scenario 2.

Year	PV Power Generation (10^8 kWh)	Proportion of PV Power Generation	Distributed PV Power Generation (10^8 kWh)	PV Plant Power Generation (10^8 kWh)	Installed PV Capacity (MW)	Distributed PV Installed Capacity (MW)	PV Plant Installed Capacity (MW)	Proportion of Distributed PV Capacity	Investment of Distributed PV Power (10^8 CNY)	Investment of PV Plant (10^8 CNY)	PV Power Curtailment	Interregional Transmission Capacity (10^8 kWh)
2015	490.85	0.0083	173.97	316.88	23,466	8317	15,149	0.3544	178.61	432.54	0.1295	7458
2016	1333.36	0.0220	479.54	853.82	28,694	10,320	18,374	0.3596	993.61	1113.67	0.1307	8062
2017	1601.60	0.0253	722.43	879.17	50,217	22,651	27,565	0.4511	755.18	1080.06	0.1245	8280
2018	2082.06	0.0317	975.51	1106.55	70,143	32,864	37,279	0.4685	1028.84	1292.27	0.1361	8950
2019	2399.43	0.0352	1175.79	1223.64	97,633	47,843	49,790	0.4900	1251.04	1373.33	0.1628	9675
2020	2608.87	0.0372	1337.20	1271.67	131,229	67,262	63,966	0.5126	1435.26	1350.09	0.2241	10,459
2021	2929.57	0.0406	1569.50	1360.06	169,536	90,828	78,708	0.5357	417.49	1361.42	0.1910	11,306
2022	2928.89	0.0396	1492.64	1436.25	192,359	98,031	94,328	0.5096	417.94	1372.34	0.2167	12,222
2023	2941.05	0.0388	1435.08	1505.97	216,347	105,566	110,781	0.4879	415.22	1370.43	0.2214	13,212
2024	2867.98	0.0370	1347.69	1520.30	241,222	113,352	127,870	0.4699	408.80	1314.30	0.2301	14,282
2025	2716.62	0.0344	1238.09	1478.53	266,141	121,293	144,848	0.4557	387.11	1210.91	0.2928	15,439

Table A7. Simulated results of key variables in Scenario 3.

YEAR	PV Power Generation (10^8 kWh)	Proportion of PV Power Generation	Distributed PV Power Generation (10^8 kWh)	PV Plant Power Generation (10^8 kWh)	Installed PV Capacity (MW)	Distributed PV Installed Capacity (MW)	PV Plant Installed Capacity (MW)	Proportion of Distributed PV Capacity	Investment of Distributed PV Power (10^8 CNY)	Investment of PV Plant (10^8 CNY)	PV Power Curtailment	Interregional Transmission Capacity (10^8 kWh)
2015	727.79	0.0123	489.24	238.55	54,383	36,558	17,825	0.6722	582.20	400.76	0.1799	7796
2016	1622.55	0.0268	1094.22	528.33	64,462	43,472	20,990	0.6744	1312.33	2243.64	0.1962	8568
2017	2012.89	0.0318	1204.85	808.05	101,884	60,984	40,900	0.5986	1456.26	3205.25	0.1966	9133
2018	2591.26	0.0394	1380.52	1210.74	154,734	82,436	72,298	0.5328	1681.47	1450.67	0.2165	10,037
2019	2882.78	0.0424	1599.55	1283.23	197,186	109,412	87,774	0.5549	1963.18	1401.28	0.2179	11,031
2020	3010.04	0.0430	1745.25	1264.78	247,223	143,343	103,880	0.5798	2158.30	1246.87	0.2567	12,123
2021	3357.20	0.0466	2033.86	1323.34	302,356	183,174	119,182	0.6058	541.01	1184.17	0.1664	13,323
2022	3413.12	0.0462	2014.10	1399.02	328,340	193,755	134,585	0.5901	563.95	1145.80	0.1504	14,642
2023	3478.60	0.0460	2008.73	1469.88	355,652	205,372	150,280	0.5775	581.19	1136.95	0.1244	16,092
2024	3462.39	0.0448	1962.25	1500.14	384,508	217,913	166,595	0.5667	595.21	1137.61	0.1154	17,685
2025	3479.05	0.0441	1939.46	1539.60	414,925	231,307	183,618	0.5575	606.40	1167.53	0.0821	18,852

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