Subsidy Policy Design for Increasing Solar Photovoltaic Installed Capacity in China

-A System Dynamics Based Study

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Abstract

China's photovoltaic (PV) based electricity generating capacity is obviously lagging behind the world level, although its manufacturing capacity of PV cells and modules has remained ahead worldwide since 2006. The Chinese government is the major investor contributing to PV-based installed generating capacity in China. A trial subsidy policy has been implemented by the Chinese government since 2007 to encourage the participation of enterprise investment. In terms of Chinese government's goals on installed PV-based generating capacity in 2010 and 2020, the historical data shows a sluggish development trend, which raises doubts about the viability of the government's goals. A system dynamics model was built to study the problem and used to design and test policy options for increasing installed PV-based generating capacity in China. It was found that lack of funds and inactive enterprise investment are the major reasons for the sluggish unfolding of China's installed PV-based generating capacity. Several policy suggestions are developed correspondingly, one of which is to increase PV fraction so as to solve the funds constraints, another of which is to raise up the subsidy granted to the enterprises to catalyze enterprise investment to accelerate the development of PV-based generating capacity in China.

Key words: *photovoltaic (PV) electricity generating capacity, Photovoltaic (PV) manufacturing industry, subsidy policy, generating cost, system dynamics*

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1 Introduction

Exploration of renewable energy has been put on the agenda in China from the perspective of both economic development and environmental protection (Zheng & Liu, 2005). The unprecedented economic growth in China has claimed huge energy consumption. However, conventional energy resources will finally be exhausted in the long run, which would then hold back economic development. On the other hand, with the coal-dominance energy structure in China, pollutant emission and discharge exert much pressure to the ecological environment.

To achieve the sustainable development for energy and environment, Solar photovoltaic (PV) has attracted increasing attention in recent years as a technology capable of delivering sustainable electricity supplies and releasing the burden of fossil fuels on the environment (Tim Jackson and Mark Oliver, 2000). Compared with conventional power generation technology, PV solar electricity is a method to produce electricity without moving parts, emissions or noise-and all this by converting abundant sunlight without practical limitations (Winfried Hoffmann, 2006).

There has been an explosion in global PV market, and that has boosted China's PV manufacturing industry in recent years, but not the domestic installation of PV-generated electricity (PVG). China possesses of sizable manufacturing capacity of PV cells and modules (PVM)[1], which has remained ahead worldwide since 2006. It ranked the biggest solar cells manufacture in the world with 1.78GWp output in 2008, accounting for 26% of the world's total (Zhang, 2009). However, the drastic development of PVM in China is mainly driven by the oversea demand instead of domestic market demand. Among all the PV cells and modules output in China, more than 90% are exported abroad. In other words, the domestic application of PV products is obviously lagging behind its manufacturing. In 2008, the PVG in China was 40MWp, accounting for only 2.43% in the world total and 2.25% of its output.

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[1] To be simplified, the abbreviation of PVG will be used to stand for installed PV generated electricity capacity and PVM is for manufacturing capacity of PV cells and modules in the paper.

China’s PVG has been suffering a sluggish development since its initial application in 1970s. Last decade witnessed a relatively high progress, but the growth rate is still slow.

China has favorable conditions in utilizing solar photovoltaic technology. More than 2/3 of China's territory is covered by abundant solar energy; with annual quantity radiation reaches 60 hundred million joule/sq.m. The solar energy absorbed by the earth's surface amounts to 1.7 trillion tons of standard coal, especially in the area like the northwest part, Tibet and Yunnan etc. (China's Renewable Energy Report, 2006)

Photovoltaic cells in China were successfully applied to the launch of DF2 satellite in 1971. The first land application was the navigation light at Tianjin harbor in 1973. In the 1980s, the rudiments of the PV industry appeared in China with quite low annual output at expensive price.

Table 1-1 Annual output of PV cells and annual PVG in Chin from 1976-2008（KWp）

Year	1976	1980	1985	1990	1995	2000	2002	2004	2005	2006	2007	2008
Annual Output	0.5	8	70	500	1550	3300	10000	50000	200000	369500	1086957	1780000
Annual PVG	0.5	8	70	500	1550	3300	20300	10000	5000	10000	20000	40000

Source: China's PV industry Report 2006-2007. Data of 2007 and 2008 is from Energy Industry Research Center

Table 1-1 illustrates the annual manufacturing output of PV cells and PVG in China from 1976 to 2008. Although both of the annual output and PVG have been growing steadily after 1995, annual PVG is obviously lagging behind the output. Compared with the development rate of global PVG, the disparity is still wider. We can see in Figure 1-1 that the global PVG has been developing with the average annual growth rate 42% in the last 12 yeas. In 2008, the global annual output of PV cells has reached 6.85 Gwp and cumulative PVG is 5.5 Gwp (Energy Industry Research Center, 2009).

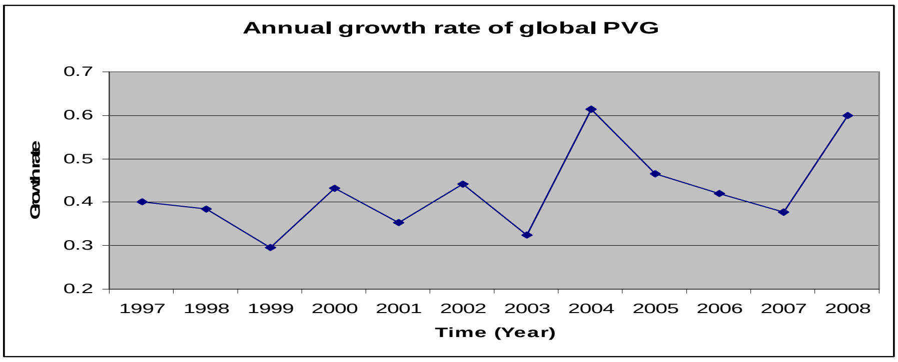

Figure 1-1. Annual growth rate of global PVG

Source: China's PV industry Development Report 2007. Data of 2007 and 2008 is from Energy Industry Research Center

In September 2007, the State plans for medium and long-term development of renewable energy announced that the ratio of renewable energy consumption to the whole energy consumption should be increased from currently 8% to 15% in 2020. High priorities have been given to hydropower, bio-power, wind power and solar PV power. The estimated total investment reaches 2 trillion CNY. It also set the targets for each system. With respect to the solar PV, the target cumulative installed capacity is 300MW in 2010 and 1800MW in 2020, which only occupy 0.68% and 1% of the world respectively, even when implemented successfully (PV Industry, 2007).

The focus for this paper is to model the sluggish unfolding of China's PVG over time and test subsidy incentive policy options for accelerating the development of domestic PV-based electricity generating capacity, particularly in light with the government’s energy goals.

The rest of the paper is organized as follows. Major problems regarding PVG development are elaborated in the following section. Then relevant research on similar problems are reviewed at section 3. Section 4 illustrates the dynamic hypothesis including Causal Loop Diagram (CLD) and Stock & Flow Diagram (SFD). Model validation is then exhibited in section 5, followed by policy test and discussion in section 6. The paper concludes with a summary and future work. System dynamics concepts and terminology can be found in the appendix in the end of the paper.

2. Defining the Problem dynamically

The dynamic problem to be addressed in this paper is the sluggish development of PVG in China from 1995 to 2008 and it's possible trend compared with the relatively high government's goals in the year 2010 and 2020.

We can see from Table 1-1 that both annual PV cells output and PVG in China were suffering slow development before 1995. From the late 1990s, China's annual PVG started the gradual development with the annual growth rate around 20%[1]. Although so, the PV systems used in China's domestic market is far below the world average growth level in the corresponding period (Figure 1-1).

Because of the discrete data we got so far in China before 1995, plus the insignificant development of PV systems in use then, we take the time horizon from the year 1995 to 2008 as the focus in this research. Table 2-1 shows the annual and cumulative PVG in China from 1995 to 2008.

Table 2-1 Annual and cumulative PVG in China from 1995-2008 (KWp)

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Cumulative	6630	8800	11100	13300	16300	19000	24700	45000	55000	65000	70000	80000	100000	140000
Annual	1550	2200	2300	2200	3000	3300	5700	20300	10000	10000	5000	10000	20000	40000

Source: New Materials Report, April, 2006; data of 06-08 is from Analysis Report of PV subsidy (2009-03-27)

Figure 2-1 is derived directly from Table 2-1, which makes the tendencies of changing easier to read. The reference mode in the whole time horizon appears exponential - like, but the growth rate is still very low - thus producing a sluggish growth.

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[1] It is calculated by reference to Table 1-1.

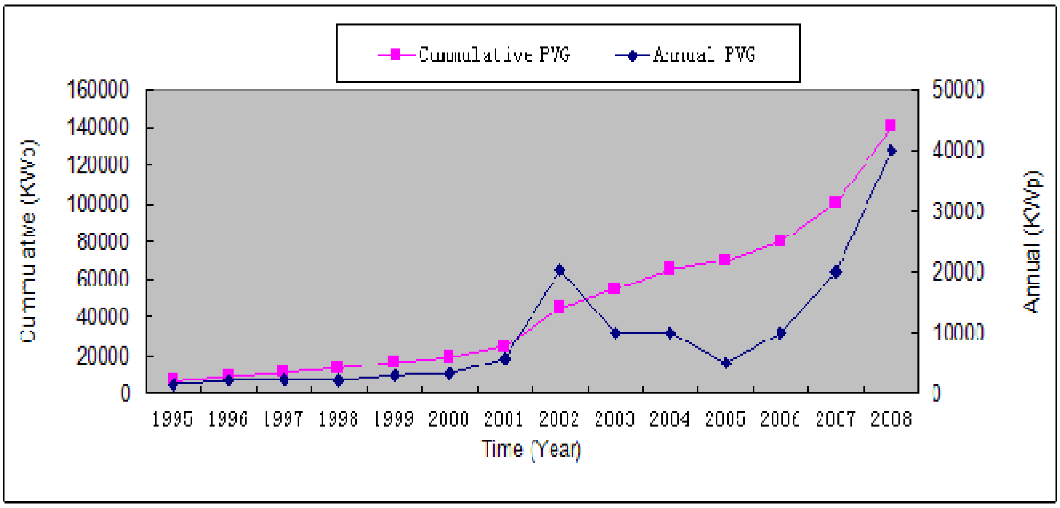

Figure 2-1. Annual and cumulative PVG in China

Based on the Plan of National Solar PV Development (1996-2000) compiled by the Power Ministry，the goal for PVG in China was 66MWp in 2000 and 300MWp in 2020. The goal was revised in the State Plans for Medium and Long-term Development of Renewable Energy in 2007, where 300MWp is planned to be achieved in 2010 and a new goal for 2020 is 1800MWp. Figure 2-2 portrays the development of government goals on China's PV capacity from 1995 to 2020.

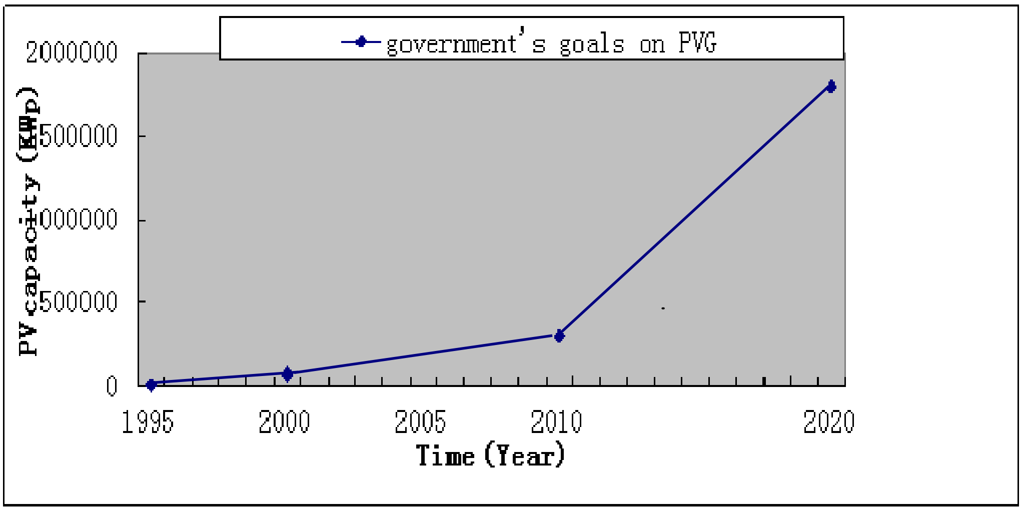

Figure 2-2. Government's goals on PVG in China

Source: (State Plans on PV, 2007)

Let's assume that the PV installed capacity will develop along with its historical trend and forecast the volumes in 2010 and 2020 by simple curve-fitting. Figure 2-2 shows the difference between government's goals and the forecasted values. We can see the gap between the goals and the forecasted values. Besides, the Action Plan of New Energy is going to be introduced by the National Energy Bureau, which might expand the development scale of PV installed capacity in China to 100000MWp in 2020, five times bigger than the original goal (New Jing, 2009).

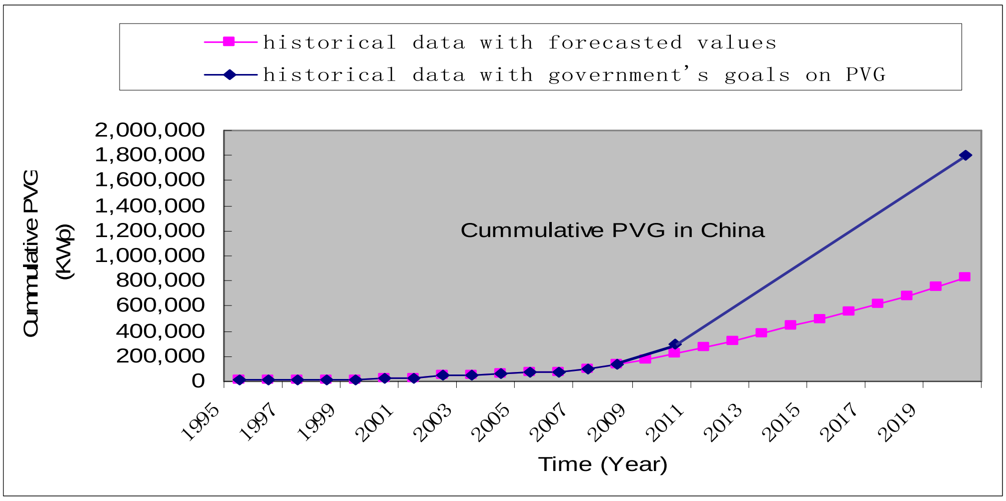

Figure 2-3. Comparison between government's goals and forecasted values of PVG in China

From the above compare, we can deduce that the cumulative PVG in China will be much lower than the government's goals in 2020 if the unfolding of PVG is with its original growth rate. The focus for this research is firstly to build the basic structure to find out the reasons for the sluggish development of PVG in China from 1995 to 2008 in terms of the current operating mechanism. Then the model is used to forecast the future development trend of PVG to 2020 under the trial subsidy policy and see the viability of the government's goals. Policy options are designed and tested for increasing PVG in China in the coming decade.

3. Literature review

There has been much research addressing the PV market issues. In terms of the factors that accelerate PV market, relevant literatures can be divided into three categories: methodologies used in the study of PV market diffusion, factors that determine the cost of PV system, and subsidy policies or programs implemented in different countries. The following parts will be displayed according to the above sequence.

3.1 Methodologies used in studying PV market diffusion

The wide use of PV generating system is still in its infancy in China. Research on PV market development remains the level of qualitative analysis and uptrend forecasting. Zhang (2007) analyzes the current status of China's PV industry and forecasts the PV market share from 2010 to 2050. Several PV industry reports (2006, 2007, 2008) deduce the possible PV market size for the next decades both worldwide and China. All these research address the desirable PVG in the future, but lack quantitative analysis and practical measures. Although Chen (2008) explored the effect of enterprise strategy on the performance of PV system using value chain theory, it is only from theoretical and qualitative perspective.

With respect to the international research on this field, modeling and empirical study are the major methods. Fayssal (1989) presents a probabilistic approach based on Markov Chain Theory to model stand-alone PV power system and predict their long-term service performance. Stijin etc. (2009) undertake an empirical study of the solar photovoltaic (PV) industry using evolutionary economic concepts. They identify the innovation and selection forces that drive the changes in the solar PV industry. A quantitative analysis using diversity indexes is performed at four levels of the solar PV industry: countries, technologies, applications and companies. Paul D. Maycock (1994) obtained the forecasting of international photovoltaic markets and developments to 2010.

Though the above research uses quantitative methods in predicting the development of PV market, what is shown to us is the specific future or a blueprint, which is static and discrete. PV market itself is a complex and dynamic system, certain internal mechanism is driving its unfolding which needs to study. That's why we are going to use system dynamics in this research.

3.2 Factors that determine the cost in the field of PV system

The global PV market nearly quadrupled from 1995 to 2000 due to a combination of technical improvements and supportive policies (Maycock, 2001). Several close observers of the PV industry argue that a virtuous circle of increased demand, expanding production facilities, improved performance and falling costs are pushing PVs ever closer towards convergence with mainstream grid-connected electricity sources (Jackson etc., 2000). Still expensive by comparison with conventional generation technologies, grid-connected PV applications have been slower to emerge both internationally and internally. So, it is necessary to find out factors that determine the cost.

Paul (1997) concluded that: significant cost reduction; several new thin film plants are being built with greatly reduced costs; government subsidized volume orders for PV in grid-connected houses; environmental benefits for PV are being applied in Europe and Japan permitting “early adopters” to enter the market; government and commercial acceptance of PV building integrated products. The combination of these forces lead to the “accelerated” market mode could start in 2000.

SEMI PV Group (2009) takes that future cost reductions will come from process cost reductions, including economics of scale, materials, automation, and improved cell efficiency, involving cell structure and process and materials innovation. It also forecasted the future cost reduction trend under these considerations (Figure 3-1).

Turkenburg (2000) forecasted that given the opportunities for further technological improvement and market expansion, the cost of PV systems could fall to some targets. If these cost targets are met, PV power would become economical in a much wider range of applications. (Geller, 2003)

All the above research can be concluded that technology improvement and economics of scale are the main forces in driving the cost reduction in PV system.

Just as Schaeffer et al. (2004) projected, for large scale PV, 46% of the cost reduction comes from scale and 31% from efficiency improvements.

Because the aim of this paper is to design subsidy policies, which mainly relates to cost, and we are not going to address the production sector of PV products. What we suppose to do is to find out reasonable empirical research and applied the cost decline trend into the model.

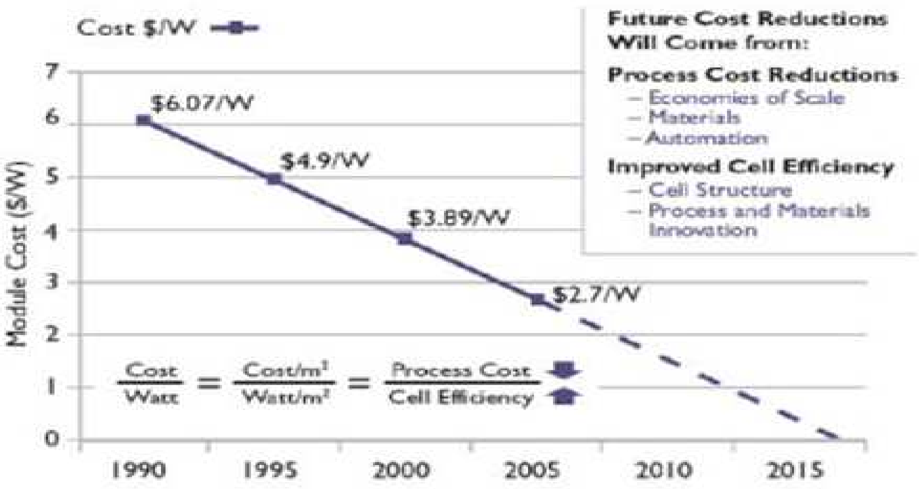

Figure 3-1: The estimated cost reduction of PV system

Source: (SEMI PV Group, 2009)

Madonald and Schrattenlolzer (2001) argue that for most products and services, it is the accumulation of experience that leads to cost reduction. Therefore, learning curves can be contributed to interpret the cost decline trend. Zheng and Liu (2005) studied the linear relation of bottom prices and learning rates and estimate the learing rate of China's PV system is between 22%-34%. There is already much estimation from international scholars. IEA's estimated learning rate is 21% in EU countries. Madonald and Schrattenlolzer (2001) postulated that the post-volatility period corresponds to the stability stage of the IEA/BCG model, a learning rate of 17% would be more appropriate in long-term energy models.

Clayton Handleman (2005) also concluded that in a relatively stable market, average wholesale PV module costs will drop 17% for every doubling of cumulative production. Harmon's estimated PV industry learning rate is 20%; Maycock and

Wakefield estimated the learning rate in the US is 22%, and both of their achievements are under the assumption that the minimum price is zero (Zheng and Liu, 2005). Nemet (2006) used empirical data to populate a cost model and gauged the plausibility of future cost targets by different scenarios (Figure 3-2). Because of the existed learning curve rule, we can tell the public and government that they can accelerate cost reduction by stimulating demand.

The average cost of PV system is relatively the same all over the world, so the learning curve rule also suits China.

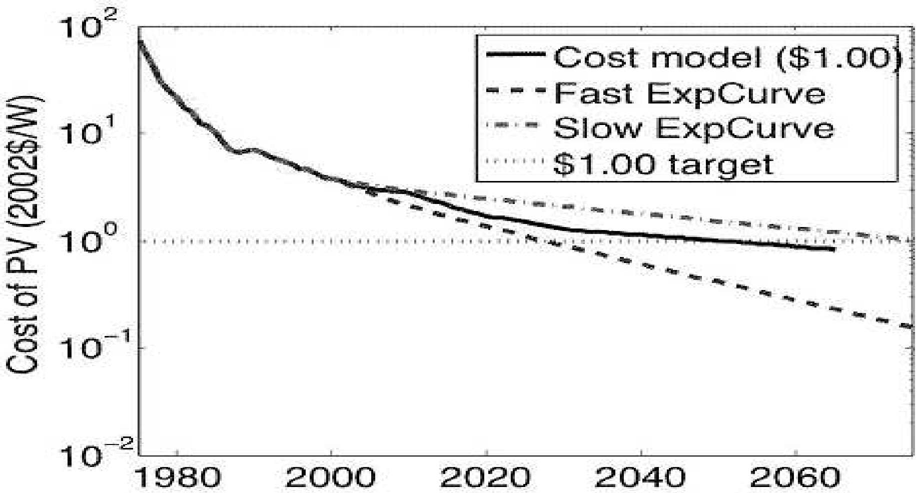

Figure 3-2: Scenarios comparing cost model, experience curves, and $1.00/W target price (Nemet, 2006)

3.3 Subsidy policies or programs implemented in different countries

Along with the rising prices for conventional energy and a major concern on environmental climate problems, great attention has been given to PV by governments of all countries, especially developed countries. Varieties of policy incentives implemented by the governments contribute to the fast development of PVG. China can learn from these subsidy policies or programs to improve its domestic PVG.

In terms of the necessity of subsidies on PV industry, Sanden (2005) takes that infant technologies, such as solar photovoltaic (PV), are normally inferior to entrenched technologies with respect to cost and performance. It is a Catch-22 situation since the diffusion on larger market that would be needed to reduce cost is hindered by the high cost. Therefore a conventional policy option is to subsidize PV to increase sales, which would increase experience and induce investments in larger factories, which in turn would drive down costs and the subsidies needed.

A market support program is likely to create not only economic virtuous circles that reduce costs, but also institutional virtuous circles that work for the survival and expansion of the program itself. The current growth of the PV market is dependent on subsidy programs, mainly in Japan and Germany.

Liu (2009) sums up the three main subsidy patterns implemented currently in the world: setting the on-grid price, construction project subsidy and the combination of both.

The first pattern is to design the on-grid price by the government, which has driven the PV market in Germany and Spain developing rapidly. Renewable Energies Sources Act (EEG in German) mandates that owners of PV equipment, such as solar systems, be paid a "feed-in tariff" for solar energy that is sold into the public grid. The tariff remains the same for 20 years, thus making it profitable for homeowners, businesses, and other institutions to own solar panels and add to the share of renewable energies in Germany's power grid (SEMI, 2008).

The EEG calls for the "feed-in tariff" to fall every year, to encourage the industry to find efficiencies and cost reductions. The reformed EEG, recently approved by both houses of Germany's legislature, has set the annual reduction at between eight and ten percent in 2009 and 2010 and nine percent annually for 2011 and onwards.

The other pattern is like what Japan is doing to give subsidy to the construction of PV projects directly. The Science &Technology Policy in Japan planed to invest 180 billion US dollars in the following 5 years to boost up its global competitiveness. A major part of the money has been used to subsidy PV projects.

The US combines these two patterns by giving the small PV system construction subsidy or designing on-grid price; those big PV systems can be applied certain on-grid price. The initial on-grid price is $0.39 per KWh, which keeps for 5 years and decreases year by year (Jie, 2009).

China's development of PVG is mainly the action of the government. During the 6th Five-year Plan (1981-1985) and the 7th Five-year Plan (1986-1990), Chinese government have been the major investor to sustain the development of PV industry, where enterprise investment only accounted for about 20% of the total. The main supported programs started from 2002 by the former State Planning Commission for the government to invest PV market in rural areas. The promulgated of Renewable Energy Promotion Law in early 2006, gives PV the priority development area in the national energy strategy (Huang, 2007).

Because of the sluggish development of PVG in China, the government started to provide subsidy incentives to enterprises to accelerate the PVG. According to the experience of developed countries, the large application of PV is stimulated by instituting on-grid PV price. The attempt became active in China after 2006 when the government started to give construction subsidy to enterprise investment on PVG at a fixed subsidy percentage, currently is 60%. And the generated electricity is planed to connect to the state grid by negotiated price. It is a trial policy, which is used by the government to see the reaction of enterprises. The validity of the policy should be subject to the test of practice.

From the above review of relative literatures, we can conclude that there is rare quantitative research on the development of China’s PVG. So we introduce a system dynamics model to analyze this issue, which will address the dynamic problem. Cost reduction trend in PV is recognized globally with technology improvement and economies of scale. We will take the cost reduction trend in the model to see its effect on the average installation cost. Subsidy polices will also be tested in the policy analysis section.

4. Dynamic hypothesis and model description

The main pattern in the reference mode appears exponential-like, but with the very slow growth rate, thus it is sluggish growth in the development of China's PVG from 1995 to 2008. It is obvious that there exists problematic gap between the government's goals and the extrapolated trend line (Figure 2-3). A system dynamics model will be built to represent the hypothesis for the historical pattern and then project to see the gap between the model's expected behavior and the government's goals.

A diagram showing the interaction among subsystem is illustrated in Figure 4-1. The model can be divided into four sectors. Capacity construction sector links the external factors – government’s goals and the internal budget source sector by using available investment in constructing capacity. This sector together with the cost sector decides the budget sector. Available funds are from the surcharge of total electricity demand. Total electricity demand is from external factors, GDP and electricity intensity. The diagram shows us the conceptual framework of the model.

Causal loop diagrams will be displayed to show the feedback processes, which might account for the problematic behavior at Figure 2-2. After illustrating model boundaries and assumptions, model structures will be shown by stock and flow diagrams with the same logic as the subsystem diagram. Model formulation follows thereafter.

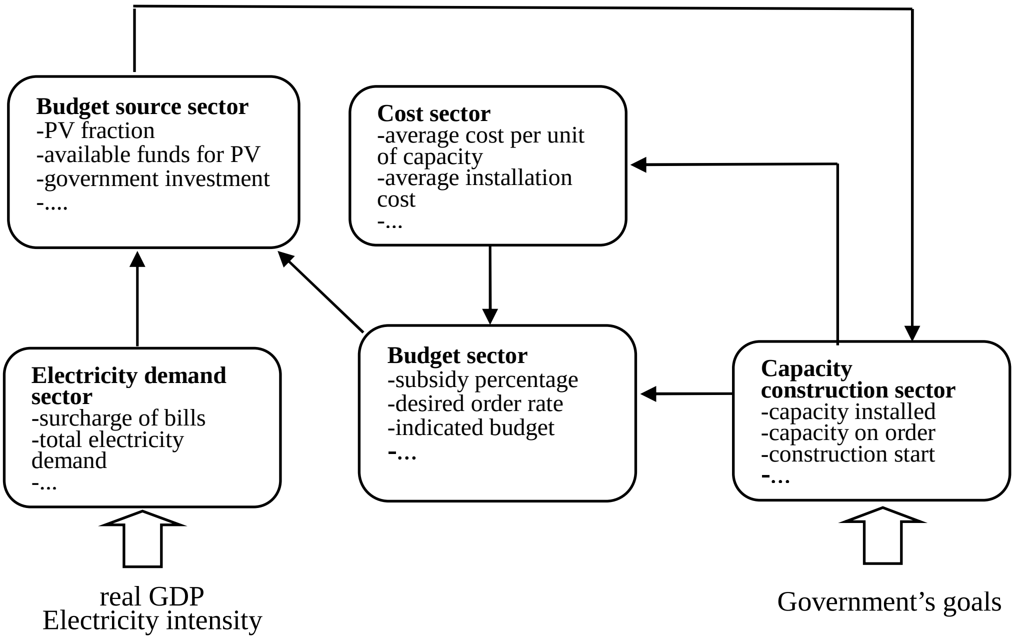

Figure 4-1. Subsystem diagram

4.1 Causal loop diagram

The development of domestic PVG is characterized by the accumulation of Capacity Installed[1]. Firstly let's look at the process of how Capacity Installed is accumulated.

Reinforcing feedback loop R1: Improving Capacity Installed by cost reduction

Figure 4-2 shows a simple loop which reflects the process. The lower the avg installation cost, the more Capacity Installed will be constructed.

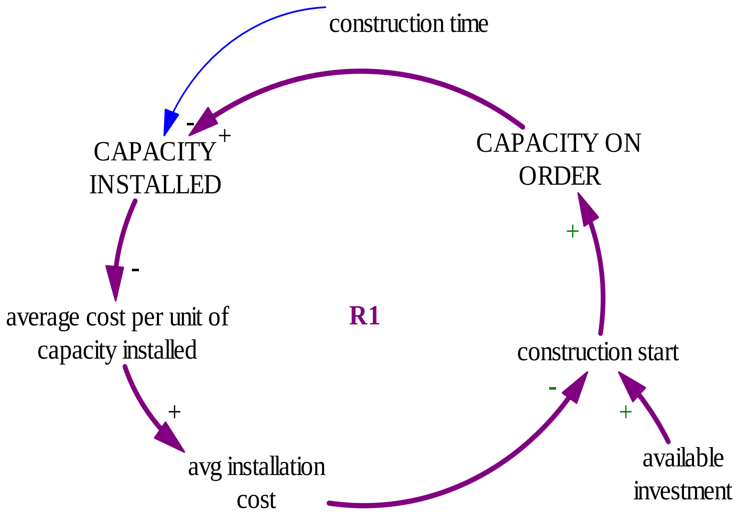

Figure 4-2. Causal loop diagram: Reinforcing feedback loop R1

Because the unit cost of newly installed capacity is much lower than ever, the newly adding capacity can dilutes the the average installation cost. Assuming available investment stays constant, lower avg installation cost will produce higher construction start, which will eventually increase Capacity Installed, say Capacity on Order. Thus the reinforcing loop R1 will drive the system growth exponentially.

Reinforcing feedback loop R2: Cost reduction increasing enterprise profitability

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[1] Capacity Installed is also used to stand for installed PV-based electricity generating capacity. PVG and Capacity Installed are used interchangeably in the paper.

In fact, available investment is not constant at all, which comes from government investment and enterprise investment. Another feedback loop R2 is added to the reinforcing loop R1 in Figure 4-3, which affects the amount of enterprise investment. Government investment will be discussed soon.

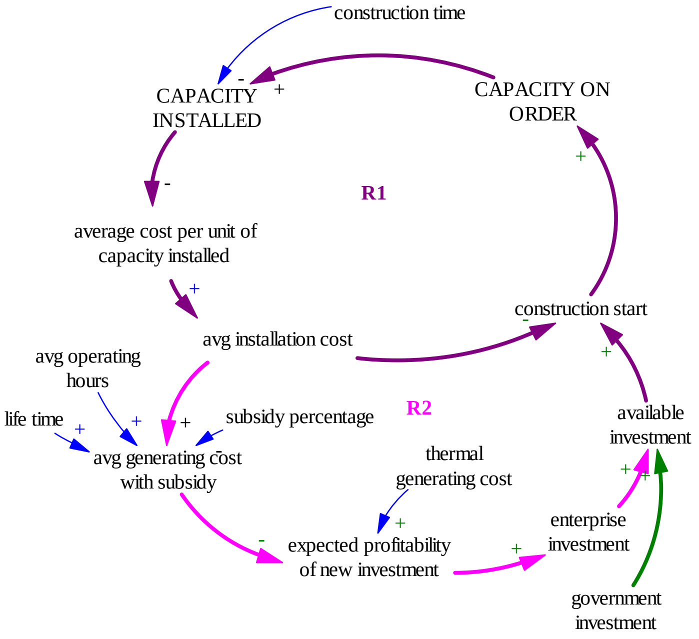


Figure 4-3. Causal loop diagram: reinforcing feedback loop R1 and R2

As discussed before, the government instead of enterprises has been the major investor of China's PVG. Enterprise investment was previously a small percentage of the total. We just assume that enterprises were on their breakeven point, so there was no intention to expand investment. Avg generating cost with subsidy is converted from avg installation cost by considering avg operating hours, life time of installed capacity and subsidy percentage. Subsidy percentage is set by the decision makers to cover part of the PV installation cost and increase the profitability of enterprises.

Compared with the thermal generating cost, which serves as the on-grid PV price at present (Currently, the on-grid PV price is not determined in large scale, only negotiated price is handled case by case. But at least the state grid can buy PV generated electricity as the same price as the thermal electricity. That's why we use thermal generating cost here.). Under a certain on-grid price, lower avg generating cost with subsidy leads to higher profitability, which will improve enterprise investment. The reinforcing feedback loop R2 further drives up Capacity Installed together with the feedback loop R1. That's also one of the reasons why the government has the intention to encourage enterprise investment.

Counteracting feedback loop C1: Cost reduction cutting short desired budget

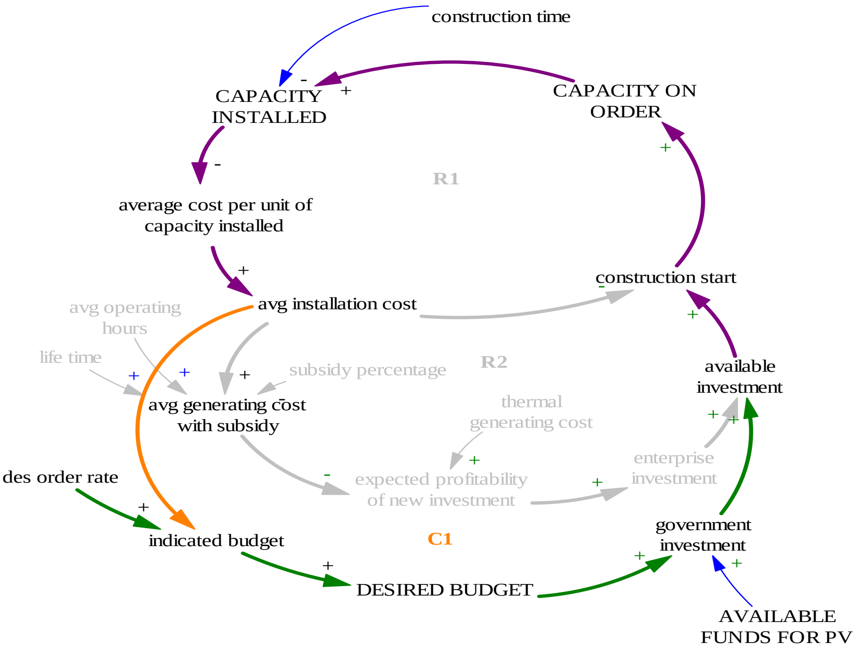


Figure 4-4. Causal loop diagram: Counteracting feedback loop C1

With the above logic, Capacity Installed will keep on growing without any limit, which is obviously not the truth. Available investment will be one of the constraint. Total sustainable funds are collected from total electricity demand, which is used to support the development of renewable energy, including wind, bio-fuels, etc. Available Funds For PV is a fraction of the total amount. Desired Budget is supposed to be the decision makers' perception, which is adjusted by the change of indicated budget. Indicated budget is the money needed to fill up the desired order rate under the certain installation cost. At this stage, we just assume the desired order rate is constant.

As we discussed before, average installation cost is decreasing with the increasing of Capacity Installed, but the mitigated average cost will also shrink the amount of indicated budget. At the same time, Desired Budget is decreasing as well, which means it needs lower government investment deriving from Available Funds For PV. The less available investment, the less construction start occurs, which will reduce Capacity Installed in return. Thus the counteracting loop C1 (Figure 4-4) limits the growth of reinforcing loop R1 and R2. Another possibility is that available funds for PV might be a constraint which limits government investment when available fund is less then desired budget. At that time, government investment will be determined by available funds instead of desired budget.

Counteracting feedback loop C2: Capacity gap adjustment

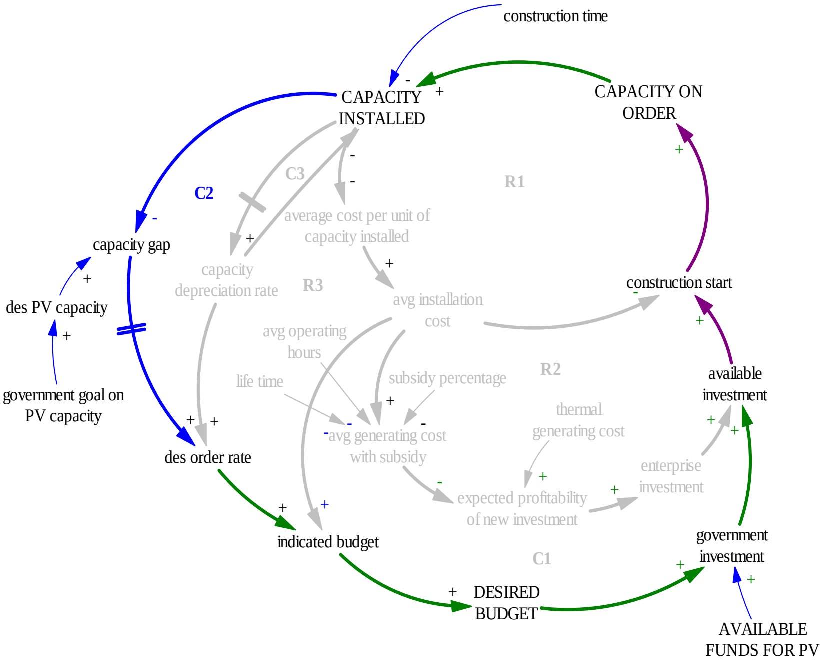


Figure 4-5. Causal loop diagram: Counteracting feedback loop C2

In the previous discussion, we assume that desired order rate is constant. Now we start to address what determines desired order rate in the system.

The bigger the gap is, the higher desired order rate and finally the more government investment will be available. With increased Capacity Installed, capacity gap will be reduced in return, where there is no need to order as much as before. The same decline goes to desired order rate, so it constitutes the counteracting loop C2 (Figure 4-5). It will push the system approaching the goal gradually by adjusting the gap. Because there are significant delays in the loop, it may cause oscillations.

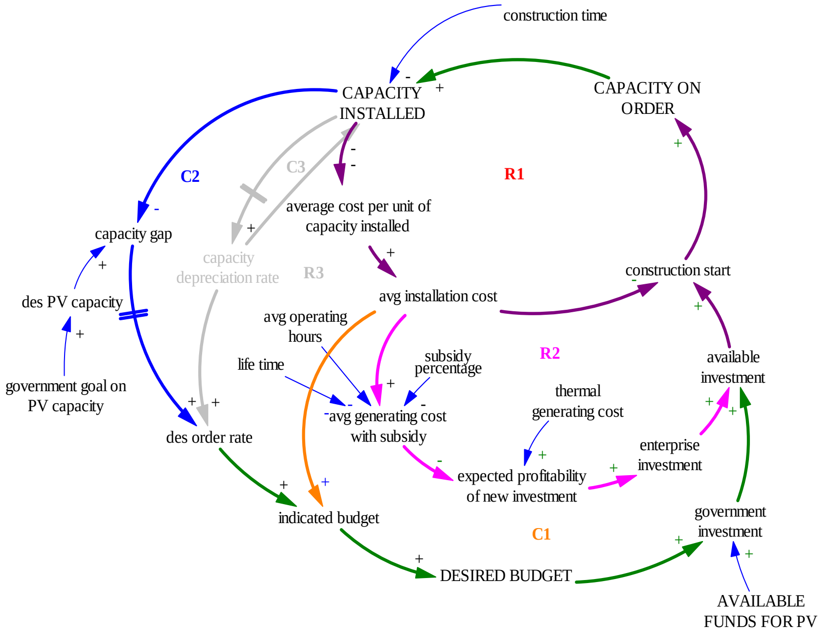


Figure 4-6. Causal loop diagram: reinforcing feedback loop R1, R2 and counteracting loop C1, C2

We add the counteracting feedback loop C2 to the previous discussed loops to form the picture at Figure 4-6. But is the desired order rate determined only by that capacity gap adjustment? Actually, when the government starts to close the capacity gap, not only the functioning capacity, but also the capacity depreciation is taken into consideration. So there will be another loop available as well.

Reinforcing feedback loop R2 and counteracting feedback loop C3: Capacity depreciation added to desired order rate

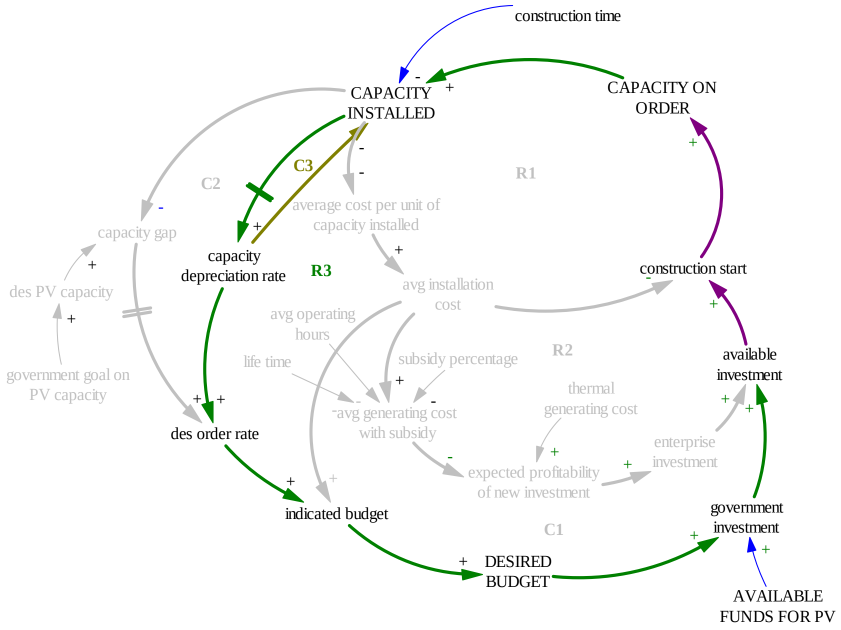


Figure 4-7. Causal loop diagram: reinforcing feedback loop R3 and counteracting loop C3

We can see from Figure 4-7 that the more Capacity Installed is cumulated, the more deprecation occurs, which adds up desired order rate. The multiplication of avg installation cost and desired order rate constitutes indicated budget. It goes to Desired Budget with an information delay. More budget is needed when there is more desired order rate. Construction start will be increased when there is more available investment. And finally Capacity Installed will be improved. Thus, it constitutes the positive feedback loop R3, which drives the system growth.

At the same time, there is another counteracting feedback loop C3, which will slow down the growth of loop R3. With the higher Capacity Installed, the more depreciation occurs, which will also excavate Capacity Installed. This counteracting feedback loop itself will drain Capacity Installed when there are no other active loops.

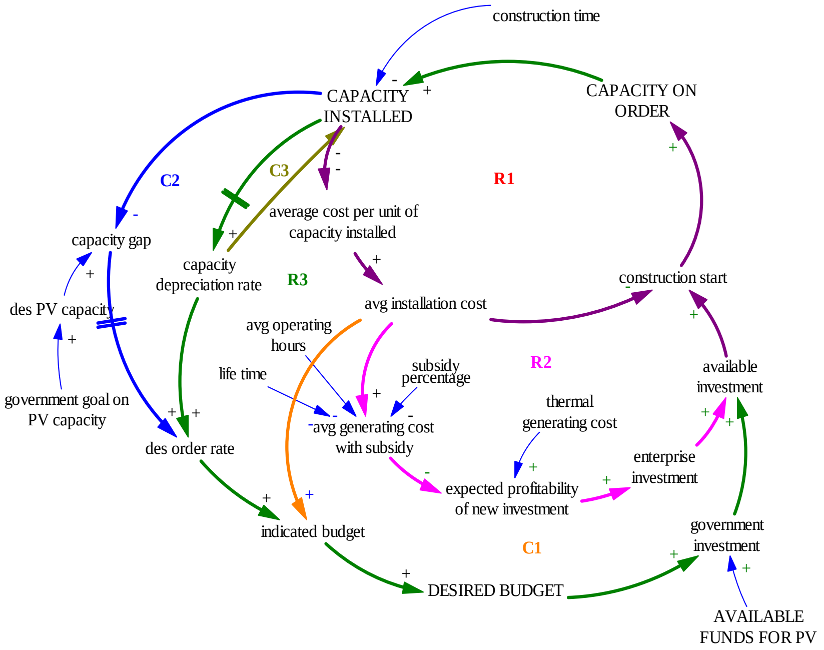


Figure 4-8. Causal loop diagram: reinforcing feedback loop R1, R2,R3 and counteracting loop C1, C2, C3

Figure 4-8 shows the structure of adding reinforcing loop R3 and counteracting loop C3 to the picture at Figure 4-7. Now we can get a relatively clear outlook that desired order rate is the sum of capacity depreciation and capacity gap adjustment.

As we know, government provides subsidy to encourage enterprises investing on PV power station. The total amount of enterprise investment is determined by profitability and government investment.

Counteracting feedback loop C4: decreased government investment reduces enterprise investment

We can see from Figure 4-9 that enterprise investment varies to the same direction with government investment. Under certain profitability, the higher the government investment, the higher enterprise investment is achieved, which will increase construction start. The improved Capacity Installed will drive down average cost, which reduces government investment and enterprise investment in return. Thus it is the effect of counteracting feedback loop C4.

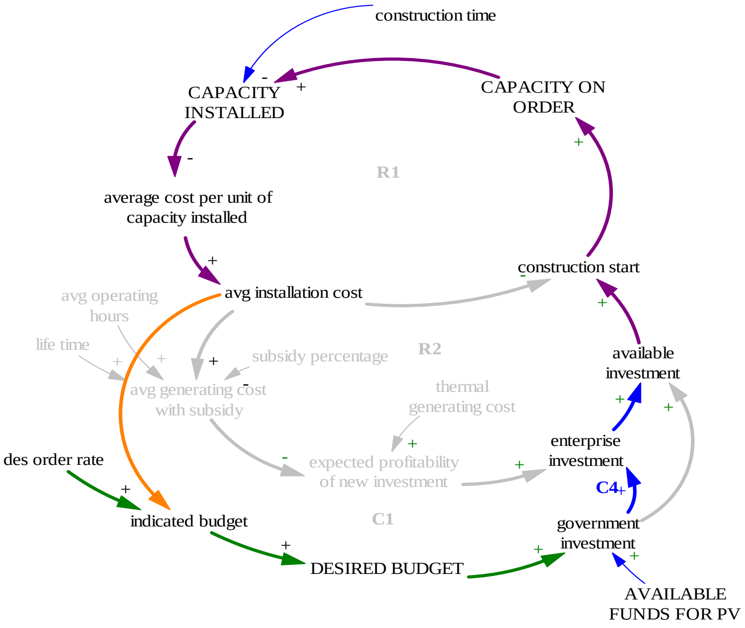


Figure 4-9. Causal loop diagram: counteracting feedback loop C4

Counteracting feedback loop C5: capacity adjustment through enterprise investment

Besides the cost factor, enterprise investment is also affected by capacity gap adjustment. Counteracting feedback loop C5 illustrates the process (Figure 4-10).

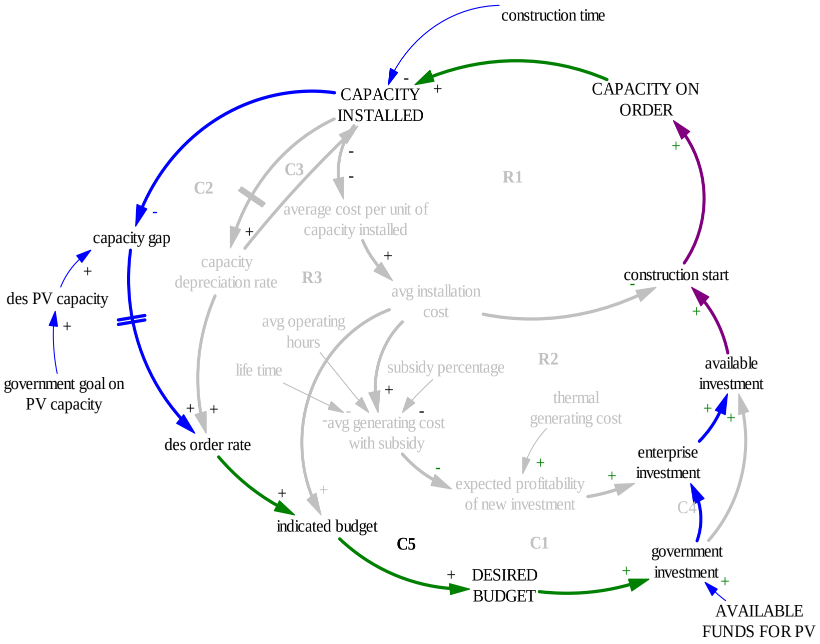


Figure 4-10. Causal loop diagram: counteracting feedback loop C5

When desired order rate is increasing by adjusting the gap, it adds up government investment and enterprise investment as well, which enhance construction start. The improved Capacity Installed will reduce the capacity gap, which lowers desired order rate again. With less budget and government investment, enterprise investment will be decreasing as well.

Reinforcing feedback loop R4: capacity depreciation adding up enterprise investment

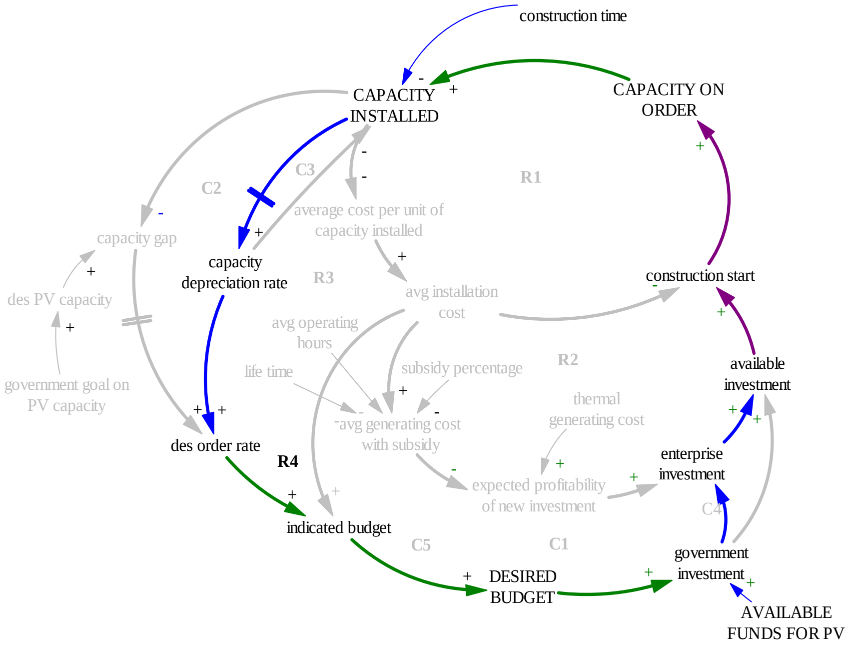


Figure 4-11. Causal loop diagram: reinforcing feedback loop R4

Because capacity depreciation also affects desired order rate, it has the same effect to enterprise investment. The more depreciation rate, the more enterprise investment is needed in terms of the higher desired order rate.

Figure 4-11 shows another reinforcing feedback loop R4, which indicates that capacity depreciation adds up des order rate and government investment. The same increase goes to enterprise investment. Both of them contribute to the increase of Capacity Installed, which will also increase the depreciation rate. Thus the reinforcing feedback loop R4 drives Capacity Installed growing.

We add loop C4, C5 and R4 to the picture in Figure 4-8 and show those loops in

Figure 4-12. Now we have four reinforcing feedback loops and five counteracting feedback loops here.

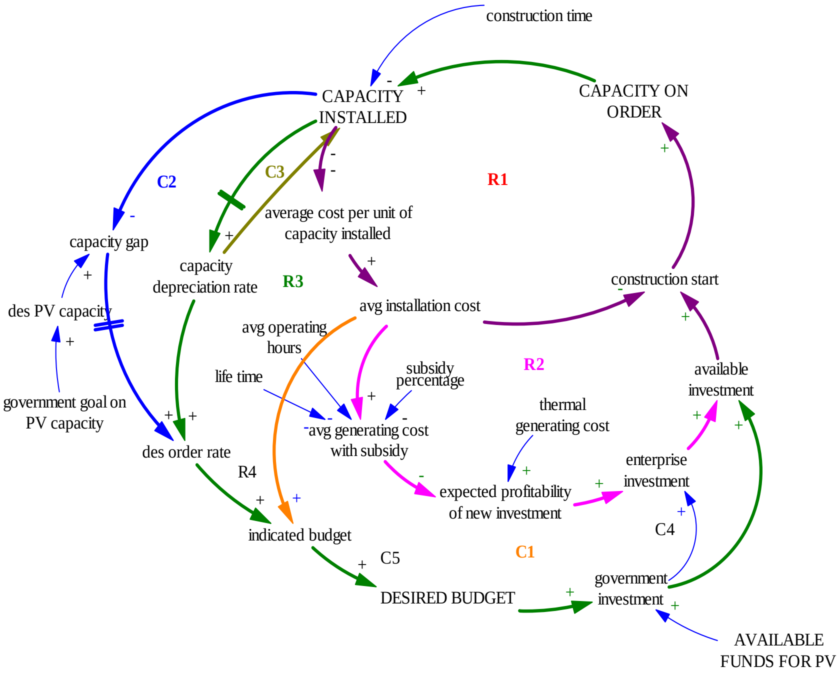


Figure 4-12. Causal loop diagram: adding loop C4, C5 and R4

So far, we all assume that Available funds for PV is constant. In reality, it is driven by total electricity demand. By recruiting a surcharge from the total electricity bill, the money is accumulated to form the funds in order to support the renewable energy generation. Total electricity demand will increase with the real GDP growth multiplied by electricity intensity.

We can assume that there could be another exogenous positive feedback loop driving GDP, which is marked as loop R5 (Figure 4-13). We can deduce that the exponential growth in GDP must be driven by a positive feedback loop. Exponential growth in GDP causes exponential growth in total electricity demand, which finally contributes to exponential growth in Available Funds for PV. It might be another force to contribute to the growth of Capacity Installed.

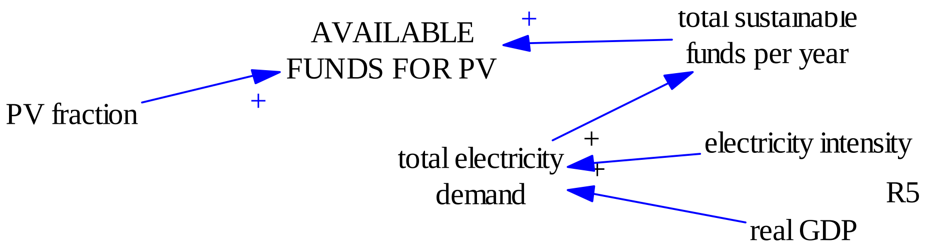


Figure 4-13. Causal diagram: Exogenous feedback loop R5

Now we get the whole picture of the system we are going to model (Figure 4-14). Besides the above discussion, there are many significant delays existed in the counteracting loops. One of the big delays is construction delay, where Capacity on order accumulates the capacity which has been started but not installed. The other delay is the time it takes when the government perceives the gap to the adjustment of gap. There are other information delays lying in the adjustment of funds, cost and budget.

The counteracting loop C2 and C5 are always driving Capacity Installed to catch up with the development of desired capacity, the goal of the system. These two counteracting loops might be the major forces which contribute to the goal-seeking behaviour. Other reinforcing feedback loops like R1, R2 and R3 may drive the system an exponential growth trend. While counteracting loop C1 and C4 might result in the constrain of money and limit the growth of those loops. It might be the reason of sluggish adjustment as mentioned in the problematic behaviour. Because of the delays existed in the loops, the corrective actions will constantly overshoots its goal, or reverses, then undershoots, and so on. Thus, there should be some oscillations in the system besides the growth.

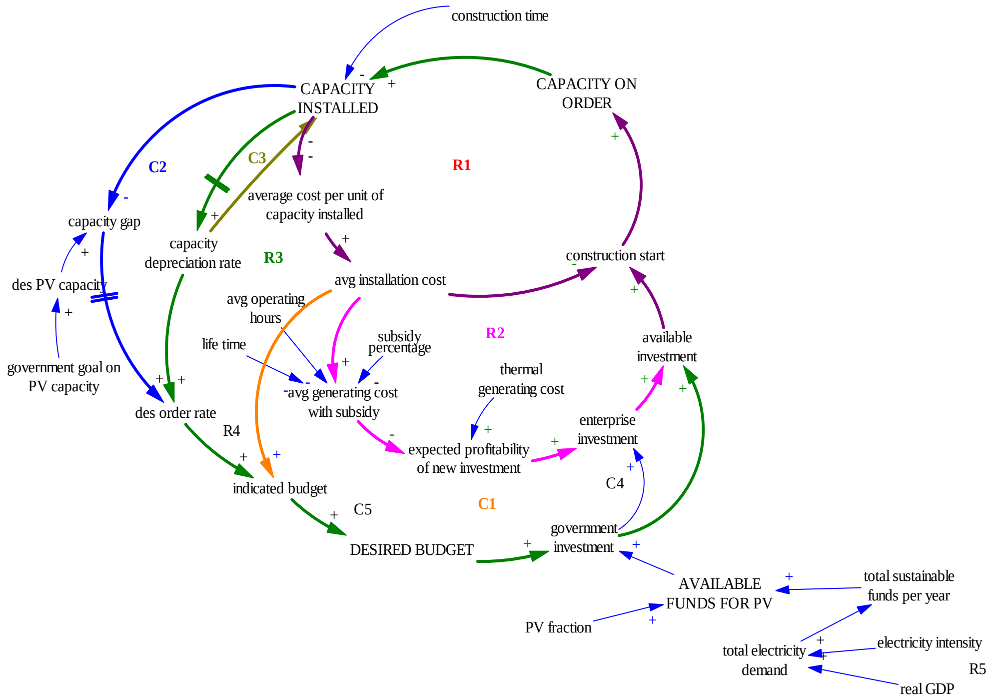


Figure 4-14. Major causal loop diagram

As government's goals of PV capacity are taken exogenous as well, which directly determine the trend of desired PV capacity and will push Capacity Installed exhibit the same behavior as itself. As we can see from the data of government's goals, it shows exponential growth pattern. And the goal of the government does have great effect to the installed capacity according to the historical data, referring the sharp increase of annual installed capacity in the year 2002 and 2006 in figure 2-1. They were just the time when the government set the goals on PV system and started several programs then.

4.2 Major Model Assumptions and boundaries

Several assumptions are adopted for this particular model.

Major model assumptions:

1) The output of PV cells and modules China is with adequacy to fill up with the demand of PC capacity.

2) Only PV system in use is addressed without taking production sector in China

into consideration.

3) The specific application fields of PV system are not distinguished. In another words, PV capacity installed serves as the indicator of PV market development, no matter they are used for on-grid or off-grid generation.

4) Total cost per unit of capacity is assumed exogenous by using the learning curve theory and the industry data. Taking the specific case in China into consideration, average generation cost is determined by average cost per unit of capacity which varies with the development of installed capacity.

5) Subsidy percentage is assumed constant at 60% after 2007. It was a newly adopted trial policy from 2007 when the Chinese Treasury department reviewed its solar program with the introduction of a new solar PV subsidy program, which will be granted for both urban BIPV applications and for photovoltaic building systems in rural and remote areas (AHK, 2009).

6) The construction of PV power station is invested mainly by the government and enterprises investment only accounts for about 20% before 2006. With the introduction of incentive policy, the percentage of enterprise investment might be largely increased due to bigger profitability.

7) Total electricity demand is resting with real GDP and electricity intensity.

Model boundaries:

A model boundary chart is used to communicate the boundary of the model and represent its causal structure. It summarizes the scope of the model by listing and classifying key variables into three categories. See the following chart for details (Figure 4-15).

GDP growth rate and electricity intensity are affected by many factors which are beyond the boundary of this study. Government goal on PV capacity is set by the corresponding government sectors in China. Subsidy percentage is relative stable according to the programs implemented and their investment.

Endogenous	**Exogenous**	**Excluded**
-Capacity Installed -Capacity on Order -Average installation Cost -Desired Budget -Available Funds for PV -Construction start -Desired PV capacity ……	-Electricity intensity growth rate -GDP growth rate -Government goal on PV capacity -Subsidy percentage -PV fraction -thermal generating cost	-PV cells production -Types of PV application -Energy substitution ......

Figure 4-15. Boundary chart of the system under study

With respected to the variables that out of boundary, PV cells production is left aside from the model because it is assumed big enough to meet the PV market diffusion, which is exactly the same case in reality. Currently what the government has been doing is to give subsidy to the construction of PV generation system. The amount of subsidy needed is roughly estimated by the government to compensate about 60% of the generating cost. Because the major subsidy programs in China belong to construction subsidy, it has nothing to do with the specific types of PV application. PV generation is already with high priority in energy area in China which substitution may not be so quickly. That’s why energy substitution in this case is excluded.

4.3 Stock & Flow Diagram

Stock and flow diagram will be discussed for each individual sector in the model, capacity construction sector, subsidy needed sector, subsidy source sector, electricity demand sector, and cost sector.

4.3.1 Capacity construction sector

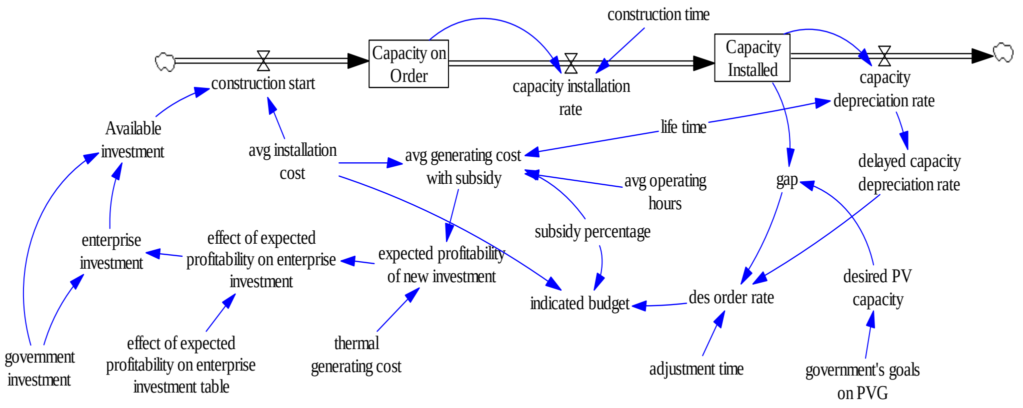


Figure 4-16. Stock and Flow Diagram: Capacity construction sector

Two stocks exist at the top part of Figure 4-16. Capacity Installed is equivalent to an accumulation of generators which is conceptualized as a stock here with Kilowatt at its unit. Capacity Installed here means the capacity has been finished and ready to generate electricity, like functioning capacity. Capacity Installed is built up by capacity installation rate and depreciated by capacity depreciation rate at the same time. We have the hypothesis that decision makers take the depreciated capacity into consideration when deciding desired order rate.

Because it takes time to install capacity, all the capacity being started is accumulated into Capacity on Order. Construction start is assumed to be determined by available investment and avg installation cost, which will be discussed in the followed sectors.

When the goals on PV capacity are set by the government, decision makers are assumed to compare the installed capacity with the desired one and calculate the discrepancy. Adjustment time represents how quickly decision makers try to correct the shortfall. If decision makers seek to correct the shortfall quickly, the adjustment time would be small and vice versa. Desired order rate, together with average installation cost and subsidy percentage determine indicated budget, which will be discussed later. Construction will start to build the capacity when available investment is decided. Equations for each variable will be explained later.

4.3.2 Budget sector

Figure 4-17 shows the stock and flow diagram of budget sector. Desired budget is determined by the change of indicated budget, which is desired order rate multiplied by avg installation cost and subsidy percentage.

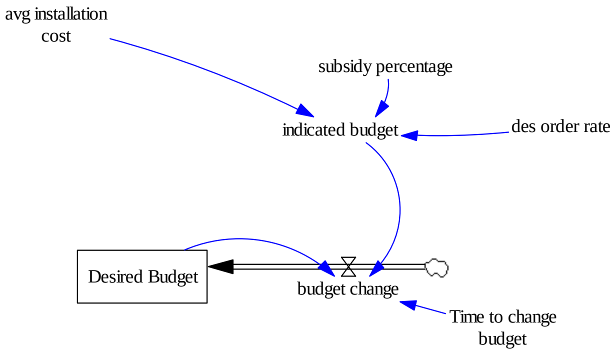


Figure 4-17. Stock and Flow Diagram: Budget sector

Subsidy percentage is a constant value which is set by the government to compensate the high cost of PVG and encourage enterprise investment. It is the decision made by decision makers on how much they'd like to spend to subsidy PVG. Avg installation cost will be discussed at cost sector.

4.4.4 Budget source sector

In order to support the development of renewable energy, the government started to establish the Sustainable Funds which is the surcharge collected by the government from total electricity demand. Currently the surcharge rate is average 0.002 CNY/KWp. It can also be changed if the decision makers want to increase the total amount of the funds.

PV fraction is a percentage of total sustainable funds collected into Available funds for PV. Because there are several support fields by using the total sustainable funds. PV is only one of them. Currently the fraction is around 25%, which means 25% of total sustainable funds will be availalbe to form the funds for PV. Utilization of funds is the same as government investment which is determined in the capacity construction sector.

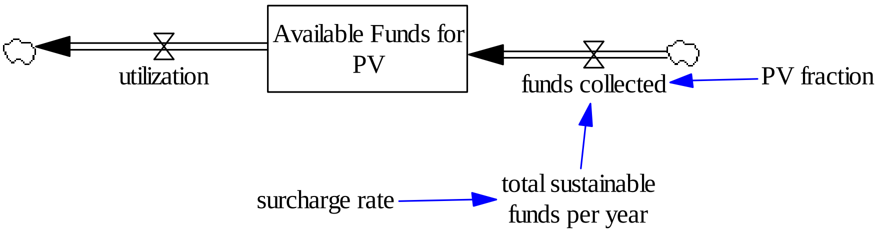


Figure 4-18. Stock and Flow Diagram: Budget source sector

4.3.4 Electricity demand sector

Total electricity demand varies with real GDP and electricity intensity (Figure 4-19). For the unit consistency, there is a convertor (billion convertor) for total electricity demand. By using the individual growth rate of GDP and intensity, it is easy to simulate the value of real GDP and electricity intensity. Electricity intensity is electricity demand per real GDP which can be a proper way in forecasting the electricity demand.

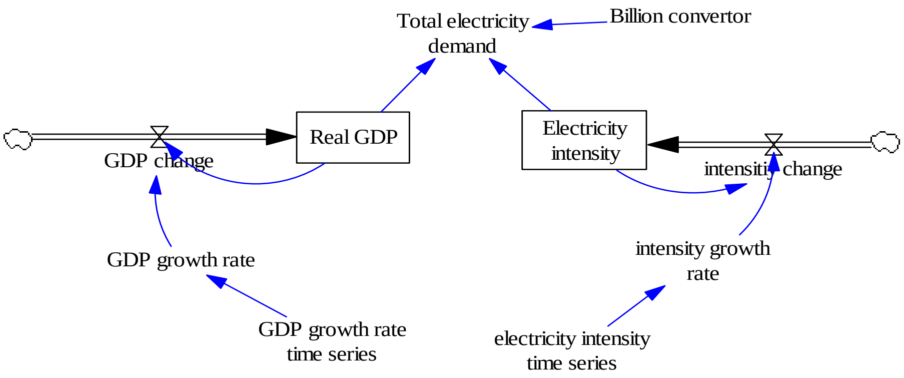
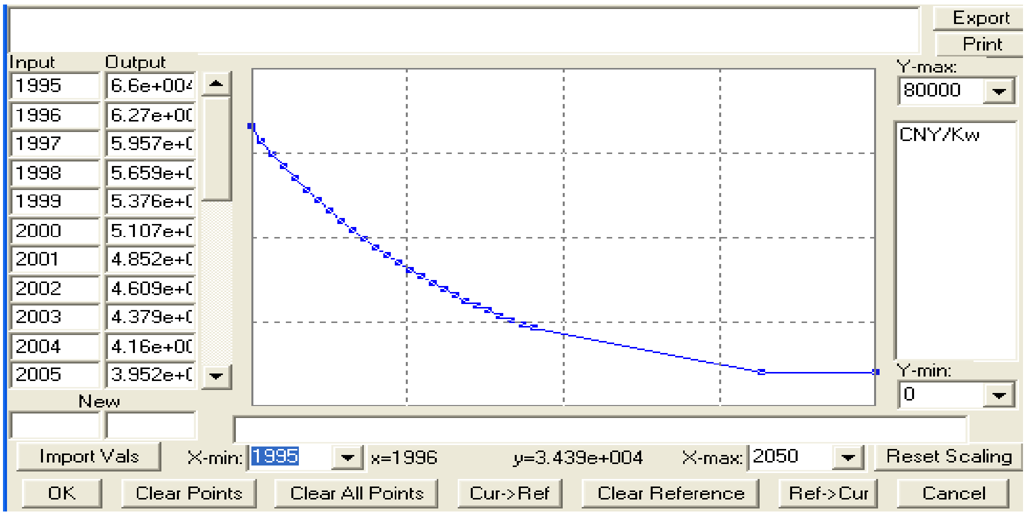


Figure 4-19. Stock and Flow Diagram: Electricity demand sector

4.3.5 Cost sector

As we discussed before, total cost per unit of capacity is assumed by the learning curve theory which has taken consideration with the technology improvement and scale economy. Figure 4-20 shows us the cost data imported into the model.



Input	Output
1995	6.6e+00
1996	6.27e+00
1997	5.957e+
1998	5.659e+
1999	5.376e+
2000	5.107e+
2001	4.852e+
2002	4.609e+
2003	4.379e+
2004	4.16e+00
2005	3.952e+

Y-max: 80000

CNY/Kw

Y-min: 0

X-min: 1995

x=1996

y=3.439e+004

X-max: 2050

Figure 4-20. Cost data

Source: (PV industry, 2007 and Nemet, 2006)

Each unit of capacity is built up; the associated cost will be delivered along with the accumulation. The same goes to the depreciation of capacity. So the avg cost per unit of Capacity Installed will be the average unit installation cost in the year so far. Figure 4-21 shows us the stock and flow diagram for the cost sector.

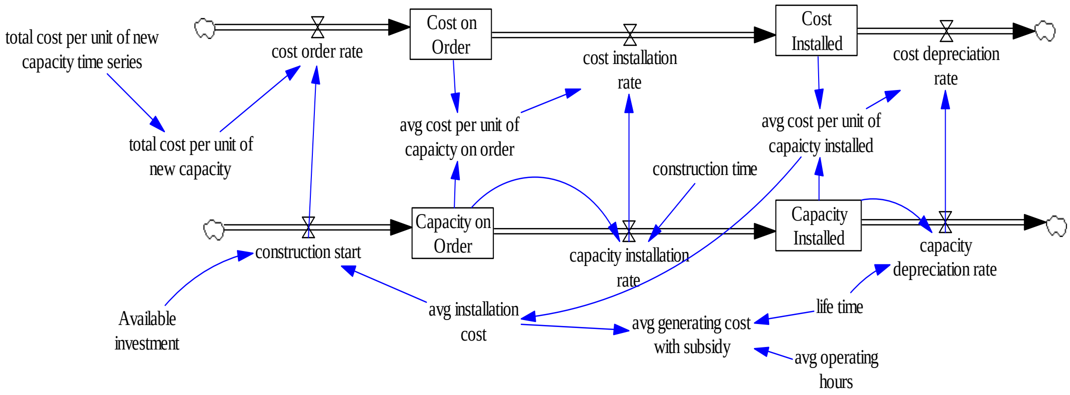


Figure 4-21. Stock and Flow Diagram: Cost sector

4.4 Model Formulation

The model will be formulated in the same sequence as displayed in stock and flow diagram sections.

4.4.1 Capacity construction sector

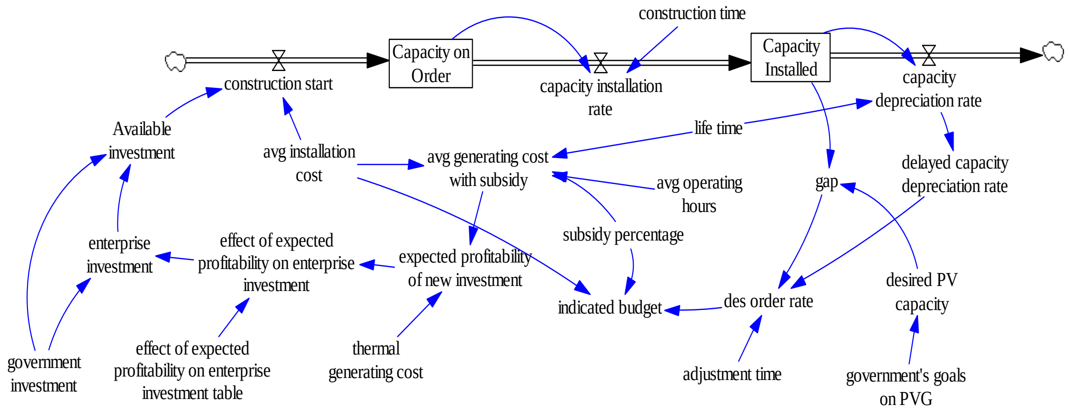


Table 4-1 Equations for Capacity construction sector

	Variable	**Equation**	**Units**
1	Adjustment time	= 1	Year
2	Available investment	= government investment + enterprise investment	CNY/year
3	Avg generating cost with subsidy	Cost sector	
4	Avg installation cost	Cost sector	
5	Avg operating hours	= 1200	Hours/year
6	Capacity on Order	= INTEG (+construction start-capacity installation rate) INIT= initial capacity on order	Kw
7	Capacity Installed	= INTEG (+capacity installation rate-capacity depreciation rate) INIT= initial Capacity Installed	Kw

8	Capacity installation rate	= Capacity on Order/construction time	Kw/year
9	Capacity depreciation rate	= Capacity Installed/life time	Kw/year
10	Construction start	= Available investment/avg installation cost	Kw/year
11	Construction time	=1.5	year
12	Delayed depreciation rate	= SMOOTH(capacity depreciation rate, 1)	Kw/year
13	Des order rate	= gap/AT+ delayed capacity depreciation rate	Kw/year
14	Desired PV capacity	= government's goals on PV capacity	Kw
15	effect of expected profit on enterprise investment	= effect of expected profitability on enterprise investment table(expected profitability of new investment)	Dmnl
16	effect of expected profit on enterprise investment table	= [(-1,0)-(1,5)],(-1,0),(-0.504587,0.372807),(-0.223242,0.657895),(-0.0152905,1.11842),(0.149847,1.95175),(0.149847,1.92982),(0.155963,1.99561),(0.327217,2.91667),(0.541284,3.79386),(0.749235,4.40789),(1,4.73684)	Dmnl
17	expected profitability of new investment	= (thermal generating cost-avg generating cost with subsidy)/thermal generating cost	Dmnl
18	Enterprise investment	= IF THEN ELSE (Time<2006, government investment*0.25,government investment*0.25*effect of expected profitability on enterprise investment)	CNY/year
19	Gap	= desired PV capacity-Capacity Installed	Kw
20	Government's	= Government's goals on PVG time series (time)	Kw

	goals on PVG		
21	Government investment	= min(Desired Budget,Available Funds for PV)	CNY/year
22	Indicated budget	Budget sector	
23	Life time	= 20	year
24	Subsidy percentage	Budget sector	
25	Thermal generating cost	= thermail generating cost table(Time)	CNY/(Kw* hours)

Table 4-1 shows the equations for the capacity construction sector. Here in the equations, some values for the parameters are estimated or from the result of field research. For example, construction time is taken as an average value. It takes 0.5 to 1 year to build a small solar PV power station in rural district and. The construction time will be 1.5 to 2 years for a bigger one. At this stage in the model, an average value, 1.5 years are applied and will be tested in the model validation section. Life time is according to the field research with the PV power station in Neimeng, China.

4.4.2 Budget sector

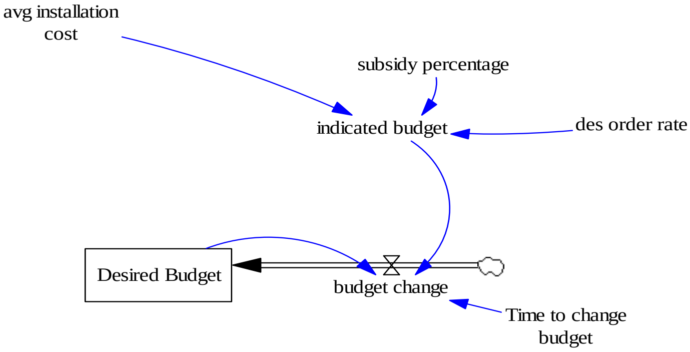


Table 4-2 Equations for budget sector

	Variable	**Equation**	**Units**
1	Avg installation	Capacity construction sector	

	cost		
2	Budget change	=(indicated budget-Desired Budget)/Time to change budget	CNY/year/year
3	Des order rate	Capacity construction sector	
4	Desired budget	=INTEG (+budget change) INIT=initial desired budget	CNY/Year
5	Indicated budget	= des order rate*avg installation cost	CNY/year
6	subsidy percentage	= 0.6	Dmnl
7	Time to change budget	=1	year

Equations for budget sector are shown in Table 4-2. There are some estimated values for the parameters here as well. Subsidy percentage is set by the government to compensate the cost of construction investment and increase the profitability of enterprise investment. The policy was announce in the year 2006 and government started to implement it then. Before the specific subsidy policy is introduced, almost all investment on PVG was by the government. The public data we got so far is that the government plans to spend 2.6 billion CNY in 2001. (National PV Plan, 1996-2000). Another program implemented in 2006 stated to invest 2.8 billion CNY on the construction of PVG.

Time to change budget is estimated because the government will adjust the budget every year by looking at the spending in the previous year. The same estimation applied to other parameters as time to change funds and time to change cost. All of these estimated parameters will be tested in the next section.

4.4.3 Budget source sector

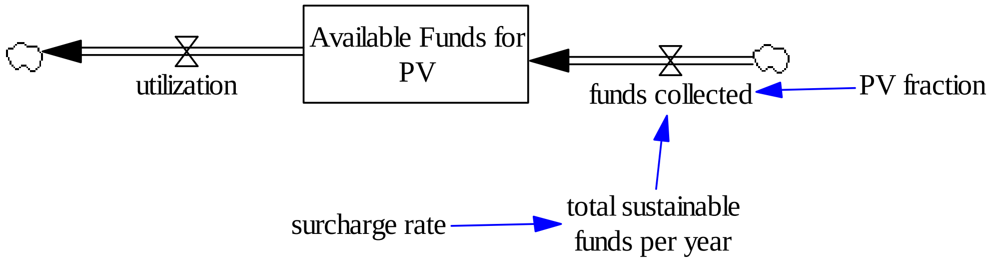


Table 4-3 Equations for budget source sector

	Variable	**Equation**	**Units**
1	Available funds for PV	= INTEG(funds collected-utilization) INIT=equi available funds for PV	CNY
2	Funds collected	= total sustainable funds per year*PV fraction	CNY/year
3	PV fraction	=0.25	Dmnl
4	Surcharge rate	= 0.002	CNY/(Kw *hours)
5	Total sustainable funds per year	=Total electricity demand*surcharge rate	CNY/Year
6	Utilization	= government investment	CNY/year

4.4.4 Electricity demand sector

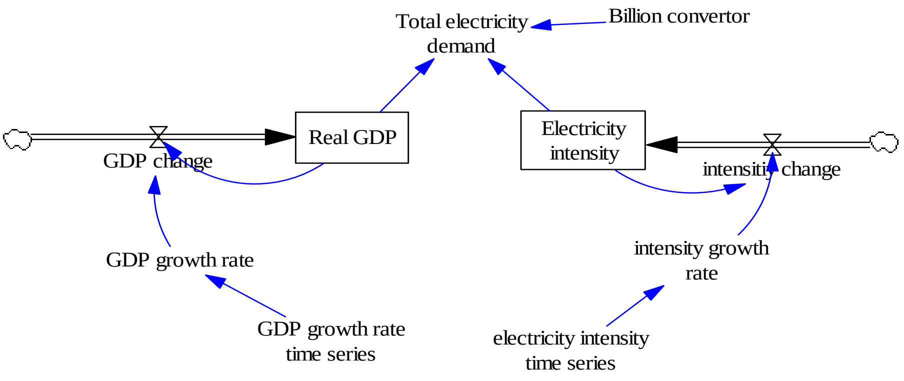


Table 4-4 Equations for electricity demand sector

	Variable	**Equation**	**Units**
1	Billion convertor	= 1e+009	Dmnl/billion
2	Electricity intensity	= INTEG (+intensity change) INIT=initial electricity intensity	(Kw*hours)/ CNY
3	GDP change	= Real GDP*GDP growth rate	Billion*CNY /year/year
4	GDP growth rate	= electricity intensity time series(Time)	%/year
5	GDP growth rate time series	=[(1995,0)-(2020,1)],(1995,0.11447),(1996,0.105382),(1997,0.100529),(1998,0.101125),(1999,0.0808981),(2000,0.096024),(2001,0.0923283),(2002,0.0996699),(2003,0.106595),(2004,0.107016),(2005,0.107252),(2006,0.120555),(2007,0.114),(2008,0.098)	%/year
6	Intensity change	= Electricity intensity*intensity growth rate	(Kw*hours)/ CNY/year
7	Intensity growth rate time series	=[(1995,-0.2)-(2100,0.4)],(1995,-0.0255153),(1996,-0.0487537),(1997,-0.0329965),(1998,-0.0635566),(1999,-0.0178041),(2000,0.0130022),(2001,-0.00760589),(2002,0.0130764),(2003,0.0396902),(2004,0.0398172),(2005,0.0256788),(2006,0.026757),(2007,-0.135284),(2008,-0.00802499),(2020,0)	%/year
8	Real GDP	= INTEG (+GDP change) INIT=initial real GDP	Billion*CNY /year
8	Total electricity demand	=real GDP *electricity intensity*Billion convertor	(Kw*hours)/ Year

4.4.5 Cost sector

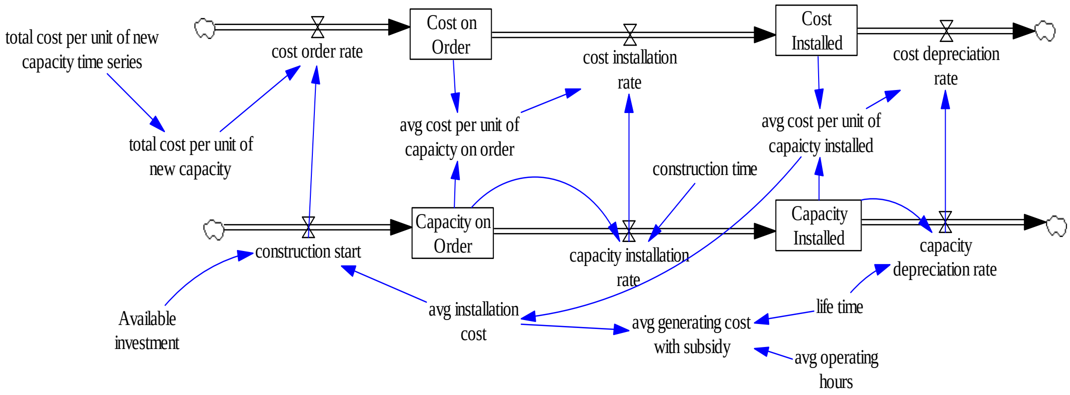


Table 4-5 Equations for cost sector

	Variable	**Equation**	**Units**
1	Avg cost per unit of capacity on order	= Cost on Order/Capacity on Order	CNY/Kw
2	Avg cost per unit of capacity installed	= Cost Installed/Capacity Installed	CNY/Kw
3	Avg generating cost with subsidy	= IF THEN ELSE(Time<=2006, avg installation cost/life time/avg working hours, avg installation cost*(1-subsidy percentage)/life time/avg working hours)	CNY/(Kw *hours)
4	Avg installation cost	= avg cost per unit of capaicty installed	CNY/Kw
5	Cost installation rate	= capacity installation rate*avg cost per unit of capacity on order	CNY/year
6	Cost depreciation rate	= avg cost per unit of capacity installed*capacity depreciation rate	CNY/Kw
7	Cost on order	= INTEG(+cost order rate-cost installation rate) INIT=8e+007	CNY
8	Cost installed	= INTEG(+cost installation rate-cost depreciation rate) INIT=8e+008	CNY

9	Total cost per unit of new capacity	= total cost per unit of new capacity time series(Time)	CNY/Kw
10	Total cost per unit of new capacity time series	=[(1995,0)-(2020,80000)],(1995,66000),(1996,62700),(1997,59565),(1998,56586.8),(1999,53757.4),(2000,51069.5),(2001,48516.1),(2002,46090.3),(2003,43785.8),(2004,41596.5),(2005,39516.6),(2006,37540.8),(2007,35663.8),(2008,33880.6),(2009,32190),(2010,30577.2),(2011,29048.4),(2012,27595.9),(2013,26216.1),(2014,24905.3),(2015,23660.1),(2016,22477.1),(2017,21353.2),(2018,20285.6),(2019,19271.3),(2020,18310),(2040,8000),(2050,8000)	

5 Model validations

This section presents model validations. The purpose of model validation is to develop justifiable confidence in the model.

Firstly structure and behavior tests in different model sectors will be conducted to ensure that the individual model sector reproduces the behavior predicted by the corresponding hypothesis. Then, a series of extreme condition tests will be applied to the entire model. After that, behavior reproduction tests will analyze the behavior of the model for the time between 1995 and 2008 and the possible gap generated under the current policy. These tests examine whether the model is capable of reproducing the reference mode in this case. The last part of this sector is sensitivity tests to investigate how the model behavior reacts to changes in parameter values.

Before the testing, the model will be initialized to equilibrium. Submitting the model to step increase and decrease in parameter values allows identifying the range of behavior mode that the model generate.

5.1 Structure and behavior test

The entire model is divided into two individual sectors (submodel sector I and submodel sector II) in order to ensure each part of the model is reflecting the reasonable behavior.

5.1.1 Submodel I structure and behavior test

As the hypotheses we made in the last section, loop R1, R2 might drive the system exponential growth and loop C1, C3, C4 limit its growth. In order to test the hypothesis, firstly, submodel sector I (including Loop R1, R2 and Loop C1, C3, C4) is initialized to equilibrium and stars simulating in the year 1995. Structure and behavior tests will start by subjecting the model a 10% step increase in desired order rate from the year 1998 (in this case, the original desired order rate is exogenous and equals to its equilibrium value 3300, and then it is increased to 3630). The base run result is shown in Figure 5-1 (in order to show the behavior clearly, we run the model to the year 2035).

The figure illustrates the behavior of Capacity Installed in this submodel I is like an S-shape growth. Initially when the system is shocked, Capacity Installed increases quickly, which drives down avg installation cost that accelerates construction start through the reinforcing loop R1. (Theoretically, the lower installation cost brings higher enterprise profitability, which should contribute to construction start through the reinforcing loop R2. But here in the test, the model is in equilibrium, the table function effect of profitability on enterprise investment is set to 1, which means there would be no any effect to enterprise investment even with very high profitability. Loop R2 does not work in this case.) However, the growth of Capacity Installed will be slowed down because the decreased installation cost also reduces indicated budget and available investment, finally the model stabilized to a new state under the effect of counteracting loop C1 and C4. Thus, it produces the S-shape behavior.

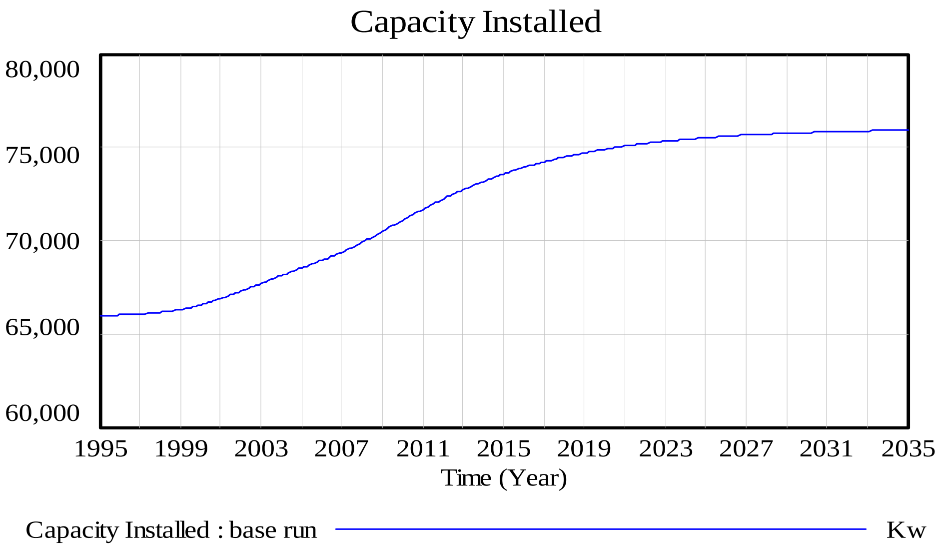


Figure5-1. Base run for submodel I structure and behavior test

In order to test that the behavior is produced by the corresponding structure, firstly all the other loops are cut by setting a constant indicated budget (3.33e+007) from the year 1998, which means there is no effect between avg installation cost and indicated budget. Then government investment and enterprise investment are constant as well. There is only one operating loop, reinforcing loop R1. We can see from Figure 5-2 that the system shows exponential growth, which means loop R1 contributes to the rapid growth of installed capacity.

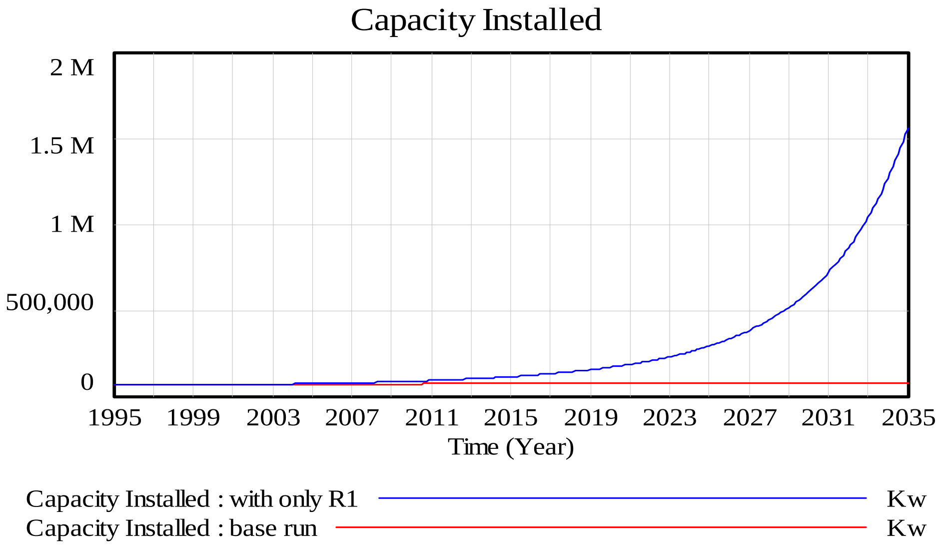


Figure 5-2. Submodel I Structure and Behavior Test: With and without all other loops except for loop R1

Counteracting feedback loop C4 is cut by setting a constant enterprise investment (6.666M). The active feedback loops are loop R1 and C4. We can see from Figure 5-3 that Capacity Installed behaves like an exponential growth trend, but the growth rate is less than that when there is only loop R1 active, which means loop C1 limits the growth of the system.

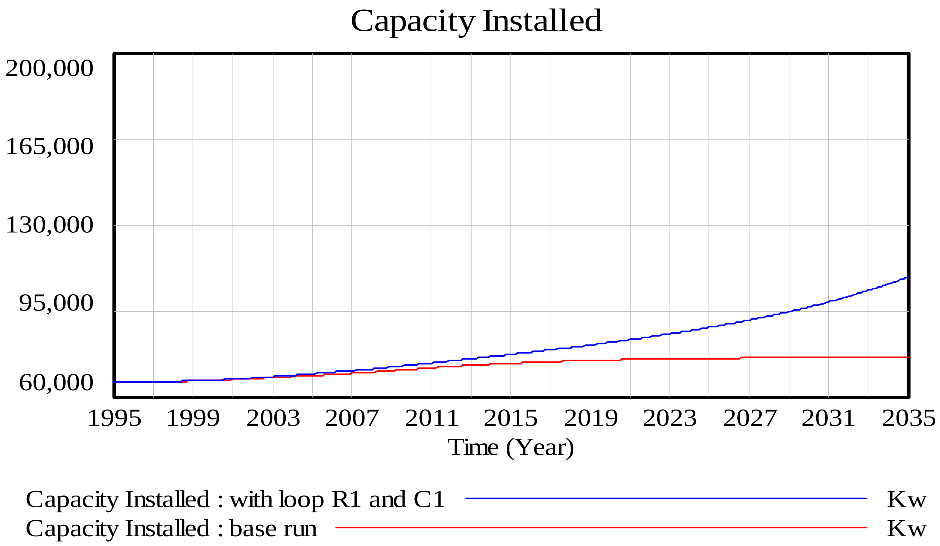


Figure 5-3. Submodel I Structure and Behavior Test: With and without loop R1 and C1

Figure 5-4 shows the behavior when loop R1 is cut by setting avg installation cost constant at its initial value 12121, which indicates construction start is determined by the change of available investment. Available investment varies with enterprise investment and government investment, which are driven by loop C4 and loop C1 respectively. Compared with the base run, it stabilizes in a lower level, which means that reinforcing loop R1 is the major force in driving the system growth.

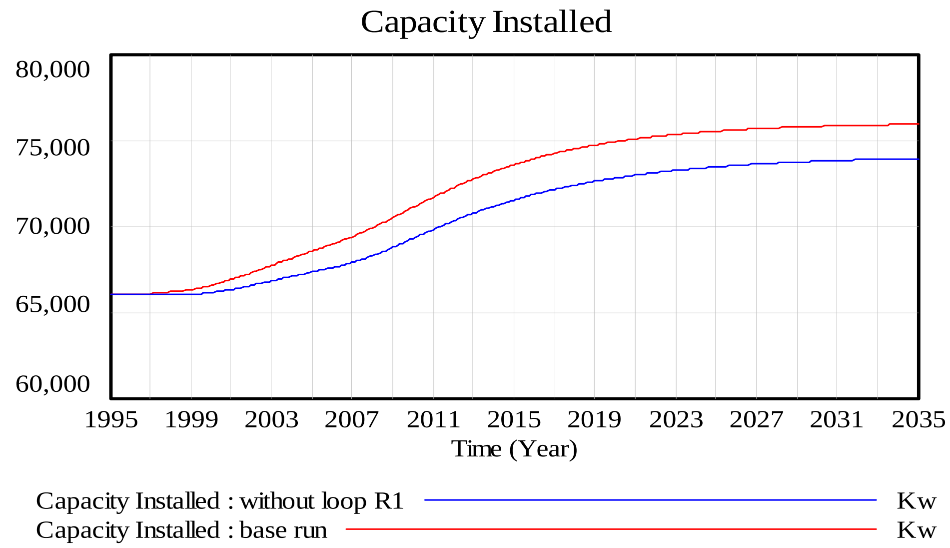


Figure 5-5. Submodel I Structure and Behavior Test: With and without loop R1

Figure 5-6 shows the behavior when counteracting feedback loop C3 is cut by setting a constant depreciation rate (3300). It behaves like an exponential growth initially and a slightly trend of goal seeking in the end, which means loop C3 is the major force limiting the growth of the system.

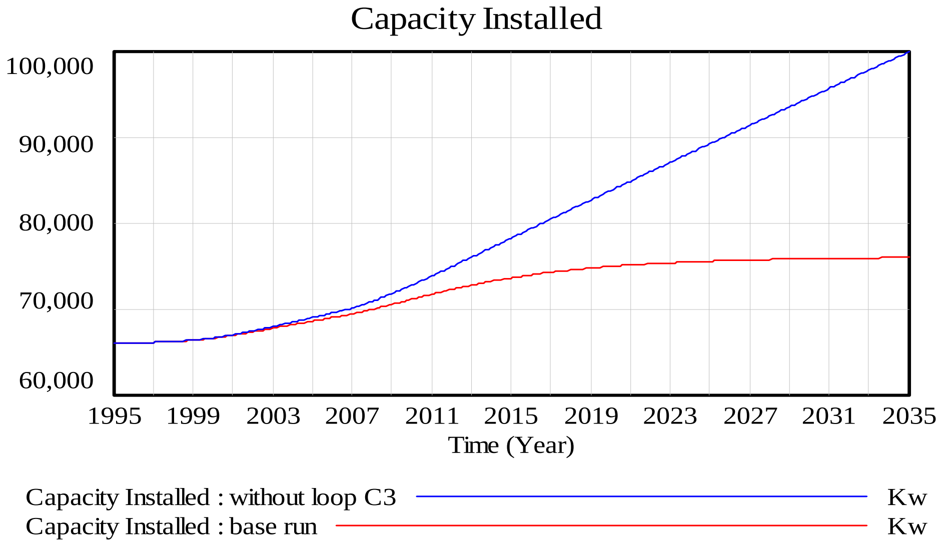


Figure 5-6. Submodel I Structure and Behavior Test: With and without loop C3

We can conclude from the above submodel I structure and behavior tests that the reinforcing feedback loop R1 and R2 contribute to an exponential growth and other counteracting feedback loops limit the growth and drive the system an S-shape behavior.

5.1.2 Submodel II structure and behavior test

We take the hypothesis that counteracting loop C2 and C5 contribute to the goal-seeking behavior, which drive the system approaching the government's goals on PVG. In this part, submodel II (including Loop R3, R4, C2, C3 and C5) is initialized to equilibrium and stars to simulate in the year 1995. Structure and behavior tests will start by subjecting the model a 10% step decrease in government's goals on PVG in the year 1998. The base run result is shown in Figure 5-11 (in order to show the behavior clearly, the model is run to the year 2035).

The figure illustrates the behavior of Capacity Installed in this submodel II. As government's goals on PV increase, capacity gap is enlarged, more desired order rate is needed to fill up the gap. The increased Desired budget brings more government and enterprise investment. Then Capacity Installed increases as the result of more construction start. The more Capacity Installed, the more depreciation rate occurs, which increases desired order rate as well. Desired order rate will affect both government investment and enterprise investment through loop R3, R4, which accelerate the increasing trend of Capacity Installed. That's why the system shows a rapid increasing trend initially. With the increasing of Capacity Installed , capacity gap shrinks gradually, the counteracting loops constrain growth to act swiftly as the goal is approached. There are significant time delays in the counteracting loops. Time delays lead to the possibility that the state of the system will overshoot and oscillate around the goal. These feedback loops contribute to the S-shape growth with overshoot. (Figure 5-11).

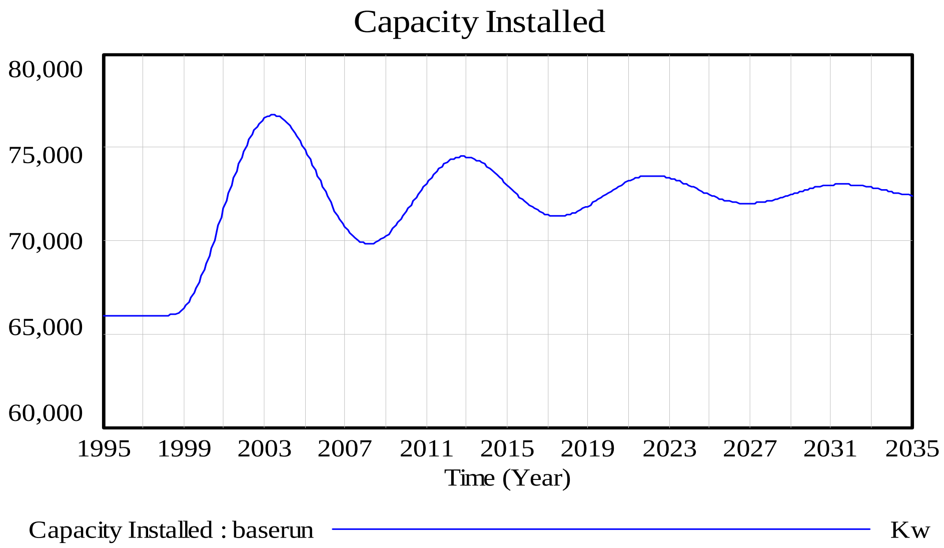


Figure 5-11. Base Run for Submodel II Structure and Behavior Test

In order to see the behavior of loop C2 and C5, we remove depreciation rate from desired order rate from the year 1998, which means loop R3 and R4 have been cut then. Figure 5-12 shows the behavior when only loop C2 and C5 operate. We can see that Capacity Installed shows almost the same S-shape growth with oscillations and finally has the trend of stabilization at a lower level. It indicates that the counteracting loops are the major force in driving the system approaching its goal by the capacity gap adjustment process. Because of the delays existed in the counteracting loops, the state of the system shows overshoot and oscillate. We can also see from figure 5-12 that there is steady state error when depreciation rate is not considered to desired order rate. The goal will not be achieved then. That also indicates the necessarity to take depreciation rate into consideration when deciding the equation of desired order rate.

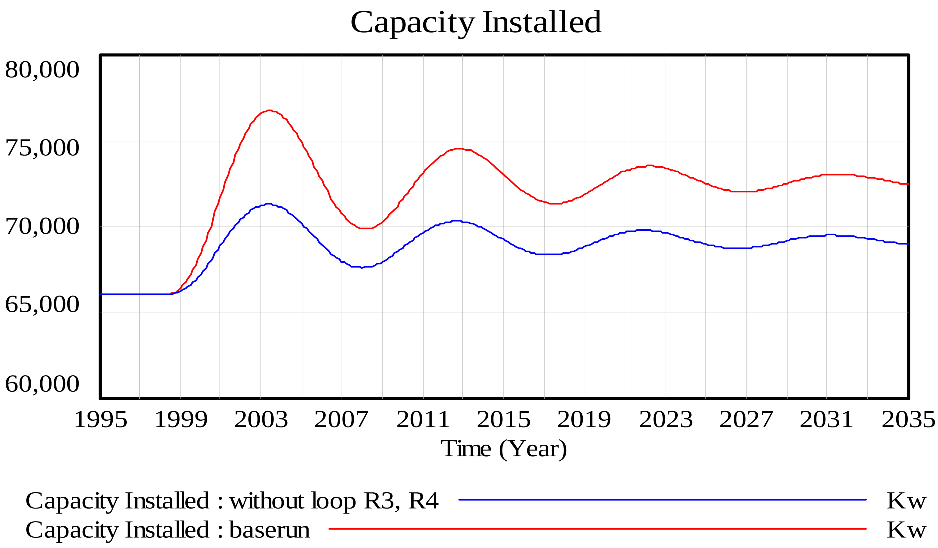


Figure 5-12. Submodel II Structure and Behavior Test: With and without loop R3 and R4

The above structure and behavior tests validate some of the hypothesis put forward in the previous section. The major counteracting feedback loops C2 and C5 drive the state of the system approaching the external goal. It also can be deduced that the trend of the external goal will have great effect on the system. In this case, government's goals show exponential growth trend, which means one of the characteristic behavior - exponential growth may be the result of it. Counteracting feedback loops C1 and C4 will limit the growth of other reinforcing loops because of the available funds constrain, which also give us some hints that money constrain will be an important factor determining the development of PVG in reality. So the incentive of enterprise investment may be a effective way for the PVG improvement in China.

5.2 Extreme condition test:

A "good" model will generate the right behavior for the right reasons. This is true not only under ordinary model conditions, but also under extreme conditions. Extreme condition test consists of running the model under various extreme conditions that may not or rarely happen in reality, so as to investigate whether the model behavior is reasonable under such situations.

In order to conduct the extreme condition test, the entire model is initiallized in equilibrium and starts simulate from 1995 to 2035. Figure 5-13 shows the base run behavior.

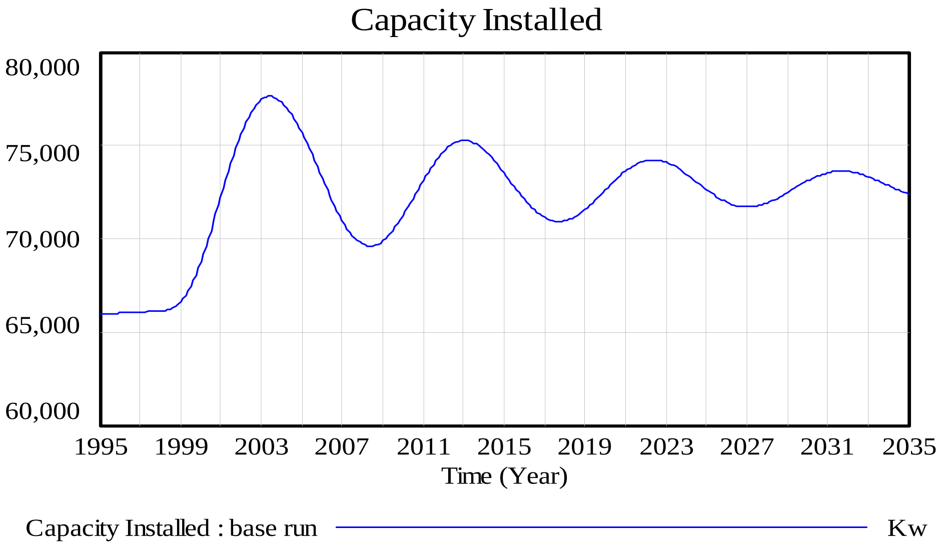


Figure 5-13. Base run for extreme Condition Test

If there is no electricity demand, what will happen to the system? Total sustainable funds are collected from surcharge of electricity bills. When total electricity demand goes to zero, there should be no money flowed to the funds. Available funds for PV should be zero as well. There would be no government and enterprise investment contributing to construction start. In order to test the hypothesis, we assume that total electricity demand goes to zero from the year 1998 and see the behavior of installed capacity.

When there is no available investment, there would no inflow in the system, what only happens should be the depreciation of the existing capacity. From the diagram in Figure 5-14 we can see that construction start goes to zero from the year 1998 when there is no money available then.

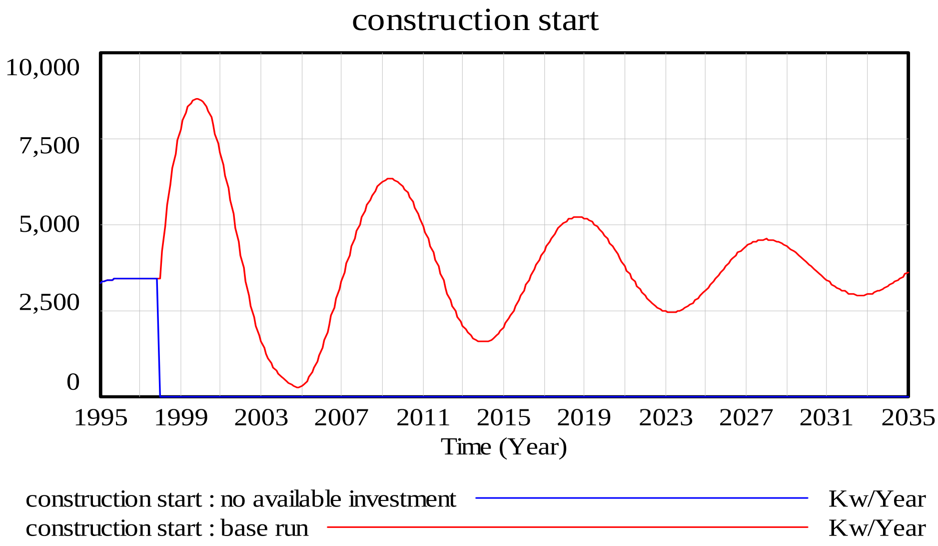


Figure 5-14. Extreme Condition Test: construction start: no investment available

The decrease of capacity installation rate is not as suddenly as construction start because the existed Capacity on Order needs to be delivered to Capacity Installed through the 1.5 years construction time (Figure 5-15).

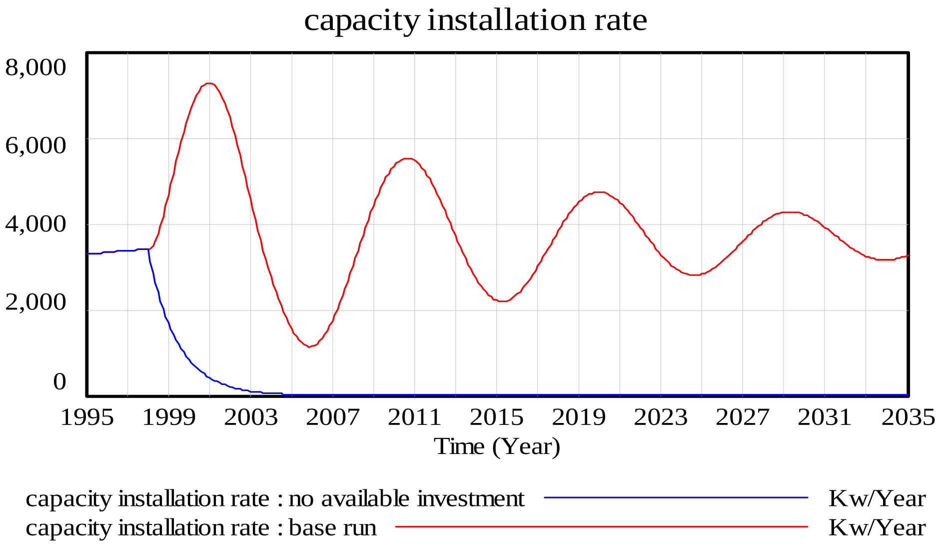


Figure 5-15. Extreme Condition Test: capacity installation rate: no investment available

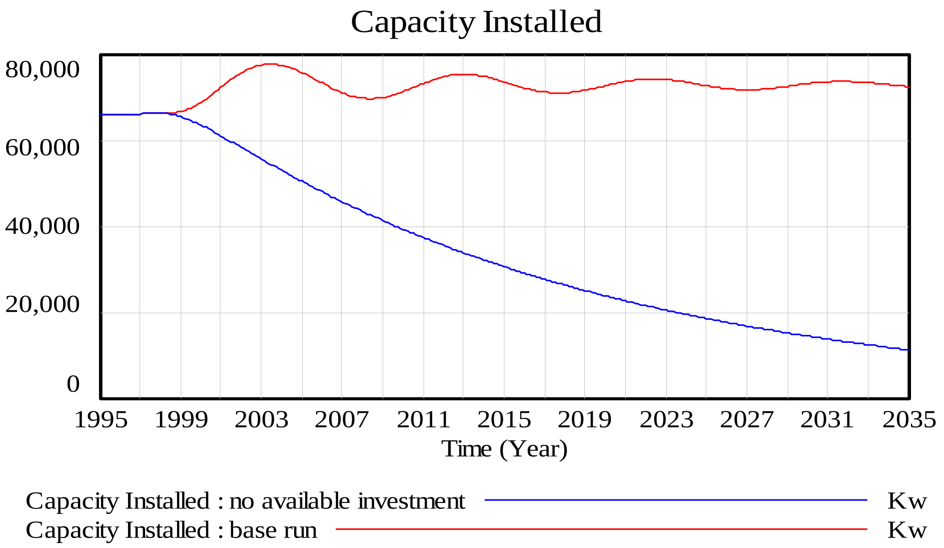


Figure 5-16. Extreme Condition Test: Capacity Installed: no investment available

Capacity Installed starts an exponential decay when capacity installation rate decreases to zero, where there is no inflow to Capacity Installed and only depreciation occurs since then (Figure 5-16).

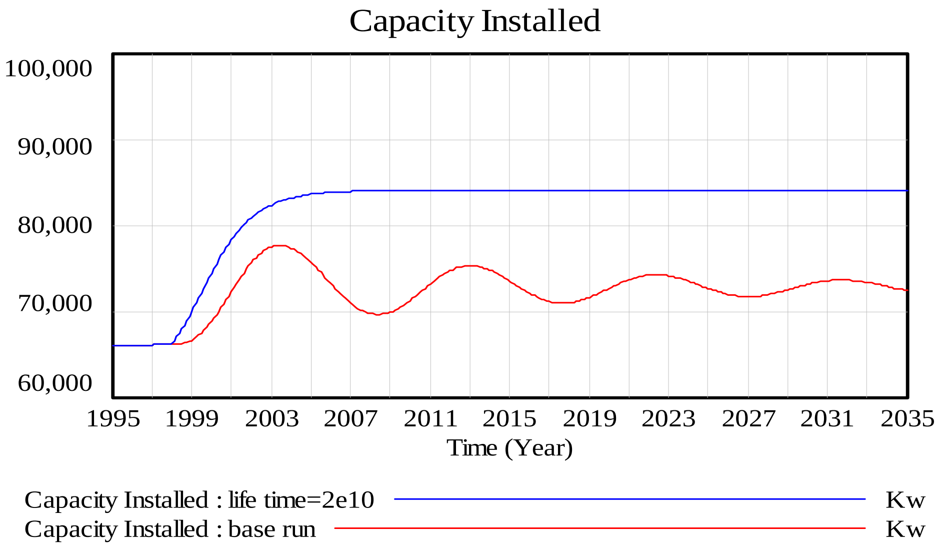


Figure 5-17. Extreme Condition Test: Capacity Installed: life time=2e10

Another extreme condition test is done by assuming a very long life time of installed capacity (life time=2e+10). There will be no depreciation as the life time is extremely long and Capacity Installed should be increase rapidly. But from figure

5-17 we can see that Capacity Installed does increase initially, it then stabilizes even there is no depreciation rate. Figure 5-18 tells us that desired order rate goes to zero around the year of 2000, which leads to the zero construction start in 2005. Because the real installed capacity is bigger than desired capacity and there is no depreciation, capacity gap becomes negative and no desired order rate is needed any more.

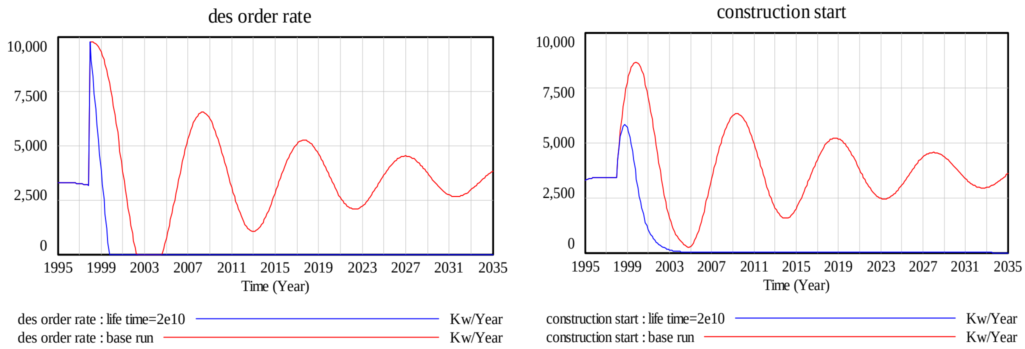


Figure 5-17. Extreme Condition Test: construction start and des order rate: life time=2e10

The above results of structure and behavior tests and extreme condition tests give us confidence in the model itself. We can say that the model shows reasonable behavior under specific structures and extreme conditions.

5.3 Reference mode replication test

In this section, all initial values and exogenous data are applied in the model. By running the model, the behavior of variables of interest will be shown and compared with the reference mode.

As shown in Figure 5-18, the simulated value of the model can roughly replicate the reference mode, especially the growth trend in Capacity Installed from 1995 to 2008.

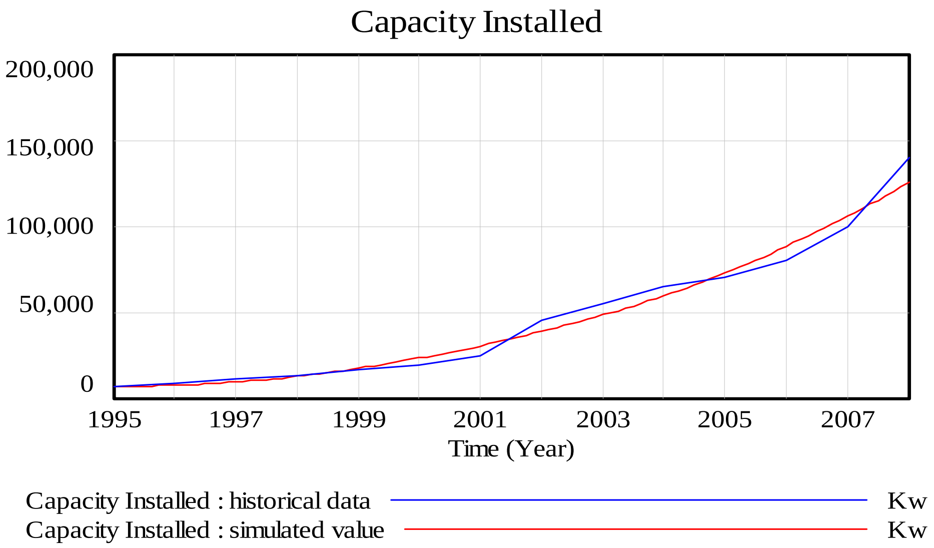


Figure 5-18. Reference mode replication test: Capacity Installed

In order to compare the government's goals with the forecasted values before we design the model, we just assumed it is with a linear growth trend of government's goal from 2010 to 2020 in depicting the reference mode (as shown in Figure 2-3 in session 2). But the PV capacity may not develop linearly in reality, an exponential growth trend might be more realistic. So we assume an exponential growth rate for the government's goals as the desired capacity in the model and it serves as the goal of the system. Then we start to simulate the model from the year 2009 to 2020 under the current trial subsidy policy and see the gap between the government's goals and simulated values. Figure 5-19 portrays the result of comparision. The gap after the year 2009 is obviously, which verifies the supposed viability of government's goals as stated in the reference mode.

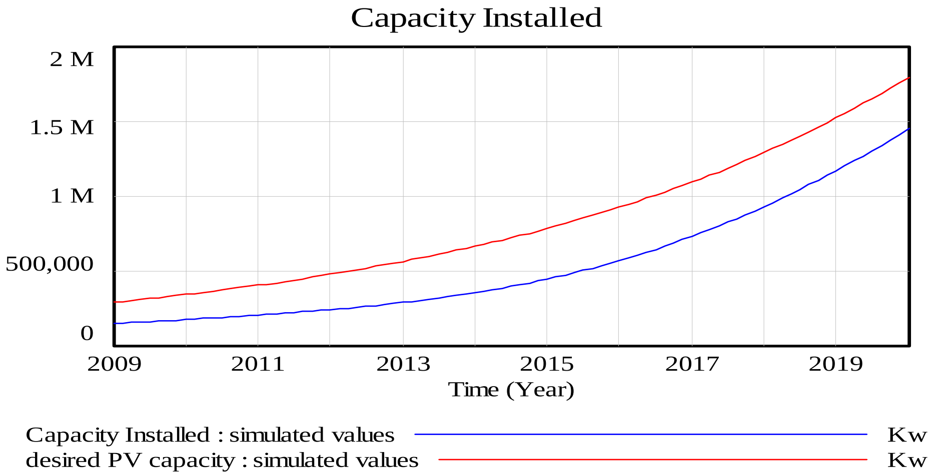


Figure 5-19. Reference mode replication test: Capacity Installed with desired PV capacity

5.4 Parameter sensitivity tests

The model has passed structure and behavior tests and extreme condition tests, which means the logic of the model is reasonable and the equations are robust enough. Then reference mode replication test shows us the model does replicate the characteristic behavior.

This section will test the sensitivity of the parameters with highly uncertain data or with estimated values. These parameters are listed in Table 5-1. Some of them are policy parameters in the model and can be controlled by decision makers, the government in this case.

Tabel 5-1 List of parameters for sensitivity testing

Parameters	Estimated values	Policy parameters
Adjustment time	√	√
Construction time	√	
Subsidy percentage	√	√
Time to change budget	√	√
Life time	√	

PV fraction	√	√
Surcharge rate	√	√

Here for sensitivity analysis, the whole model is initialized to equilibrium and starts simulating in the year 1995. The model is then subjected to a 10% step increase in government goals in the year 1998. The base run result is shown in Figure 5-20.

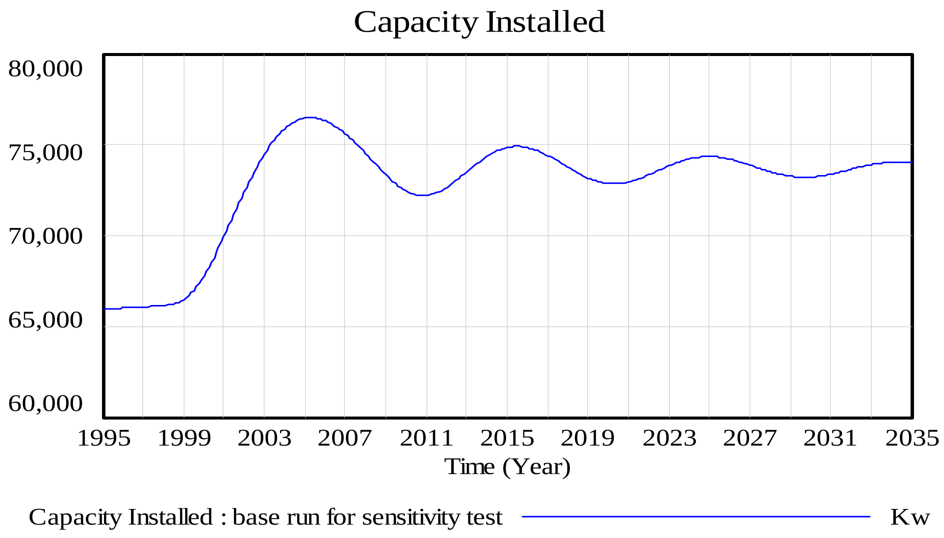


Figure 5-20. Base run for sensitivity tests

The results of sensitivity testing are displayed in terms of confidence bounds. A graph is generated showing confidence bounds for the output variables Capacity Installed and des order rate when the value share was randomly varied around its normal value.

5.4.1 Sensitivity test I: Adjustment time

Adjustment time is estimated according to the government's reactions on the current development of PV market in China. We assume that the government looks at the function capacity each year and compare it with the current goal. We are not sure about the exact value. Firstly we analyze the impact of variations in the value of this parameter by setting the range of adjustment time from 0.5 years to 2.5 years.

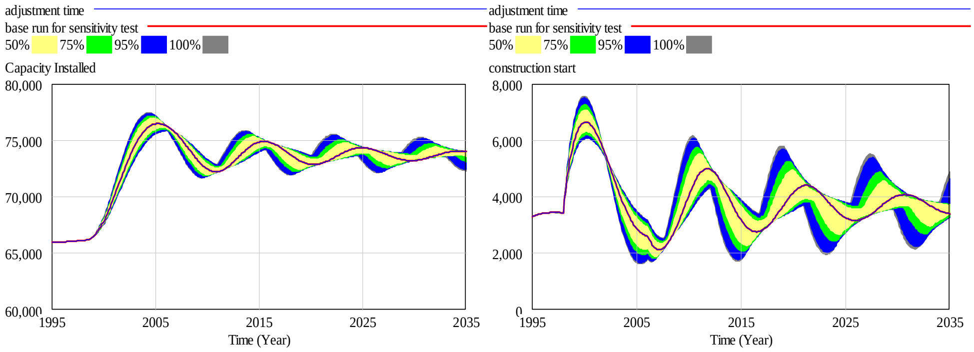


Figure 5-21. Sensitivity test: adjustment time=0.5~2.5

Figure 5-21 shows the reaction of Capacity Installed and construction start to a variation of the parameter value from 0.5 to 2.5 years. Variation leads to an increased variation range but not to a variation in the behavior pattern. As shown in the above figures, both of these two variables are numerically sensitive to adjustment time.

5.4.2 Sensitivity test II: Subsidy percentage

Subsidy percentage is also a policy parameter in the system as discussed in the SFD formulation part.

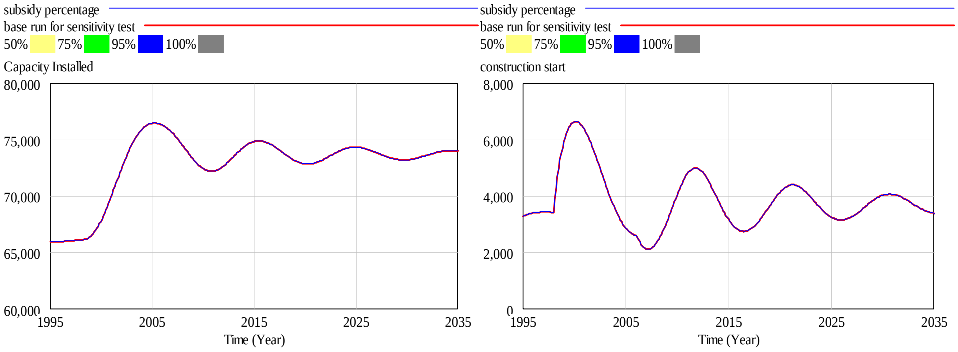


Figure 5-22. Sensitivity test: subsidy percentage=0.1~0.9

Subsidy percentage determines enterprise profitability in reality, which will affect enterprise investment. The model should have been sensitive to the change of subsidy percentage intuitively. As shown in Figure 5-22, the variation of parameters does not lead to any change in the behavior pattern. Both of these two variables are not numerically sensitive to the change of subsidy percentage from 0.1 to 0.9.

5.4.3 Sensitivity test III: Construction time

Construction time is the time needed in constructing a PV power station. The value the this parameter we assumed in the model is 1.5 years, which is according to the average construction time for both big and small PV power stations. Now we will run sensitivity test to see if the model is sensitive to this parameter. Figure 5-23 shows the reaction of Capacity Installed and construction start to a variation of construction time from 0.5 to 2.5 years.

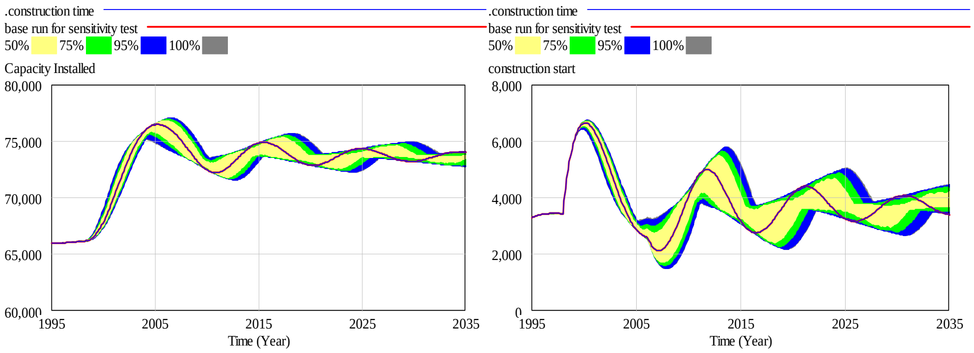


Figure 5-23. Sensitivity test: construction time=0.5~2.5

We can see that Capacity Installed is not very sensitive to the big change range of construction time, which means the uncertain value of construction time does not affect the credibility of the model.

5.4.4 Sensitivity test IV: PV fraction

PV fraction is also a policy parameter in the model. Figure 5-24 indicates that Capacity Installed and construction start are sensitive to the change of PV fraction from 0.1 to 0.5. Because PV fraction in reality is how the government allocates its sustainable funds and the fraction on PV has not been changed for years, that's why we are confident for the value of PV fraction used in the model.

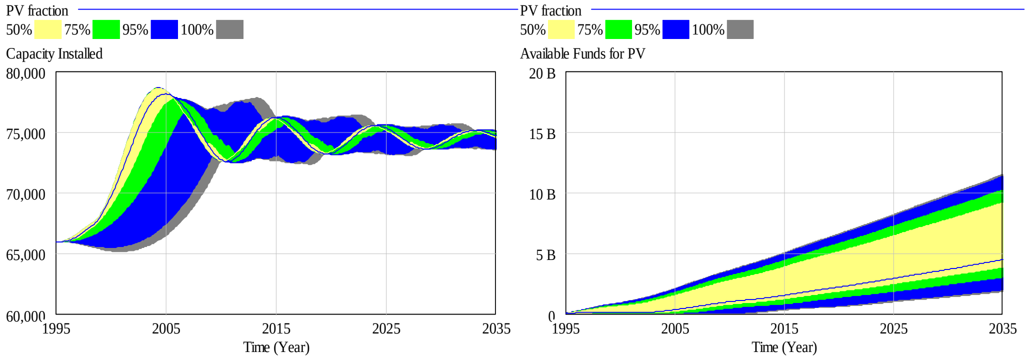


Figure 5-24. Sensitivity test: PV fraction=0.1~0.5

5.4.5 Sensitivity test V: Life time

Life time is set as 20 years in the model, which is an average value in different size of PV stations according to the field research. In order to test the model's reaction to this parameter, we run the sensitivity test by giving life time a variation range from 15 to 25. Figure 5-25 shows the behavior under this sensitivity test.

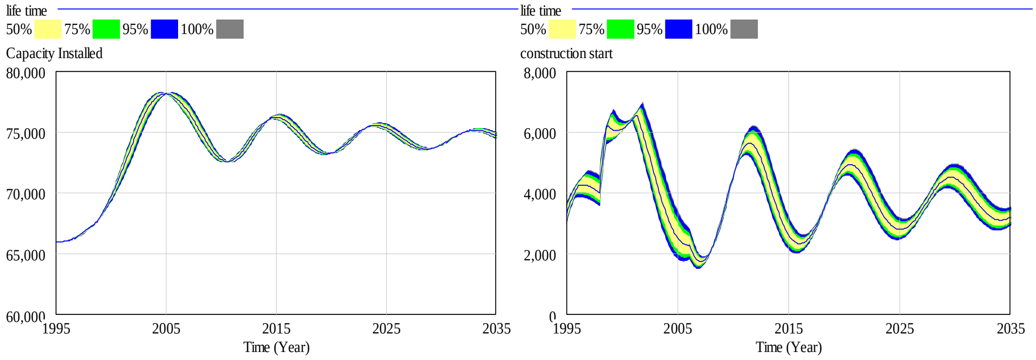


Figure 5-25. Sensitivity test: life time=15~25

We can see from Figure 5-25 that there is quite small change in Capacity Installed under the comparatively big range of change of life time, which means that the model is not much sensitive to life time and the estimated value of life time does not affect the model too much.

5.4.6 Sensitivity test V: Time to change budget

Time to change budget is estimated as 1 year, which means that the government will decide and adjust the desired budget every year. Sensitivity test is run by change the time from 0.5 to 2.5 years to see the reaction of the model.

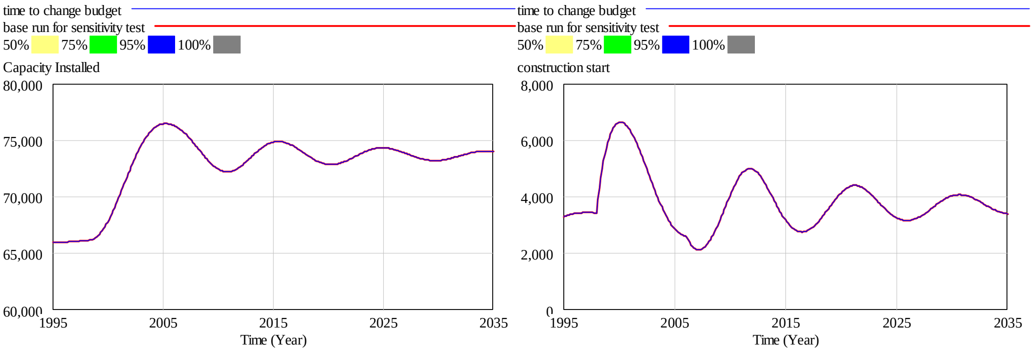


Figure 5-26. Sensitivity test: time to change budget=0.5~2.5

Figure 5-26 tells us that the behaviour of variables of interest has no any changes when time to change budget is given a big variation range, which means the model is not sensitive to the change of time to change budget.

5.4.7 Sensitivity test V: Surcharge rate

Surcharge rate will affect the total sustainable funds per year and also the money collected into available funds for PV, it's change should have big impact on Capacity Installed. Figure 5-27 indicates the big change range of the model when surcharge rate has the variation from 0.001 to 0.003. We can say that both of the two variables of interest are numerically sensitive to surcharge rate. They reveal behavior mode sensitivity. As surcharge rate is set by the government, we are sure about its value so far.

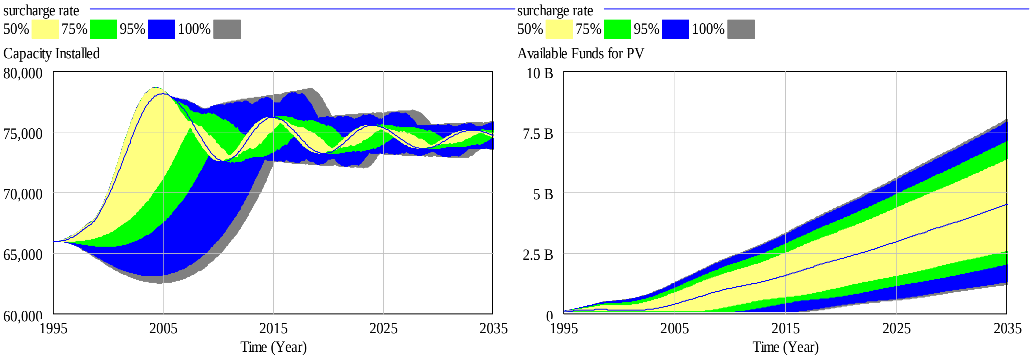


Figure 5-27. Sensitivity test : surcharge rate=0.001~0.003

5.5 Conclusion of sensitivity test

Most of variables with estimated values have no big effect on the behavior of the model by running the sensitivity test. The model is most sensitive to the parameters like adjustment time, surcharge rate, and PV fraction.

There are some policy parameters, which the sensitivity tests can give us some hints on policy testing. The model is not sensitive to two of the policy parameters, subsidy percentage and time to change budget in equilibrium. Because the effect table in the model is set to 1 when the model is in equilibrium, which means table function does not operate even with any change of profitability. That explains why the model is not sensitive to the policy parameter subsidy percentage. So sensitivity tests will be run again when the model is not in equilibrium in the policy test and discussion part.

Besides the estimated value of time to change budget, surcharge rate and subsidy percentage are also under the control of the government. Surcharge rate is from public data and subsidy percentage is confirmed with the newly issued subsidy policy in China. The Chinese Ministry of Finance introduced interim measures for subsidies for “solar photovoltaic building applications” in China. A fixed subsidy has been granted for both urban BIPV and remote areas (AHK, 2007). The fixed subsidy is around 60% of the average generating cost. So we are confident with the value of these parameters in the model so far. Sensitivity tests will also be run in policy analysis section to see the sensitivity of policies.

In terms of the other two policy parameters, adjustment time and PV fraction, the model is sensitive to their changes. Adjustment time reflects how aggressive the government is to make decisions. We assume that the government make decisions once per year to fill up the gap and plan Desired budget. PV fraction is determined by the government according to the current state plan (PV, 2007). The estimated value in the model is also realistic. We can test the efficiency of this policy in the policy discussion section.

6. Policy test and discussion

Policy test and discussion in this section will follow the hints raised from the above sensitivity tests and discuss the possible policy parameters in how to increase China's PVG in the period of the state plan.

6.1 Policy test and discussion

I. Surcharge rate

Surcharge rate is a policy parameter that the model is sensitive to according to the discussion in the sensitivity test part. Therefore, it is recommended that the government could increase this parameter.

In terms of the simulation, the government can raise the surcharge rate to 0.0025 from 2009 to achieve the goals in 2020 as shown in Figure 6-1.

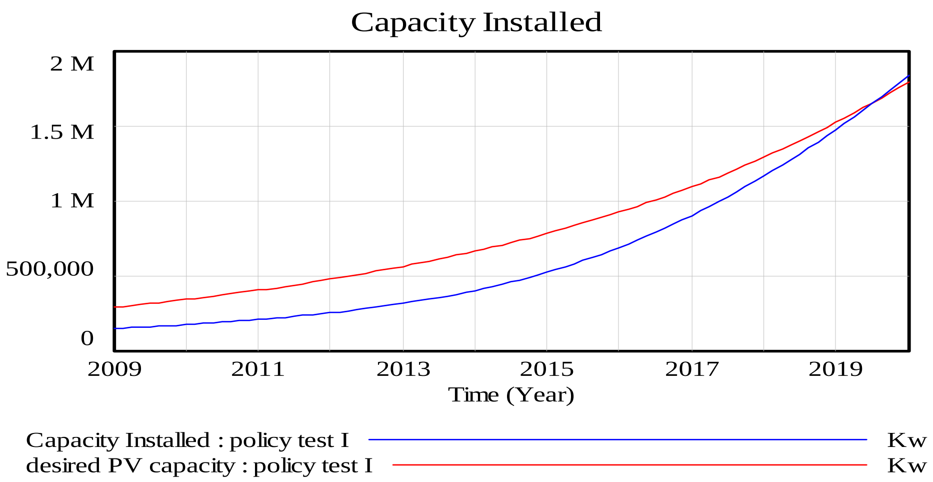


Figure 6-1. Policy test I: surcharge rate=0.002+step(0.0005, 2009)

However, there will be some obstacles to the implementation of this policy, the main of which comes from the heavy electricity intensity users, such as the steel companies, chemical companies etc. An increase of 0.001 CNY for each Kilowatt of electricity can mean a loss of tens of millions of CNY each year for these companies.

Therefore, the first one to oppose to this policy could be them.

Another obstacle comes from all the other ordinary electricity consumers. Due to the policy of Coal-Electricity Tariff Automatic Mechanism that has been adopted twice in the past 5 years, the price of electricity in China has been increased by 0.0536 CNY, which is almost 10 percent of the average electricity price in China and is obviously a big increase. On the other hand, the per capita GDP of China, in reference to the World Bank, was 2460 US dollars in 2008, and ranked 104 in the world, which was largely out of step with China's GDP, which ranked the 3rd and just followed the US and Japan (Juanqiong Li, 2006). Therefore, one can imagine the difficulty of implementing this policy of improving surcharge rate, which is against the will of more than 1.3 Billion people in China.

The last obstacle lies in the government itself, due to the pressure from CPI. As mentioned above, the price of electricity has been increased by nearly 10% in the last few years due to the coal-electricity tariff policy. Actually, according to this tariff policy, the Chinese people would have been subject to another increase in the electricity price last year. However, the government did not let that happen, because they know very well that electricity industry is in nature a public welfare establishment. An increase in electricity price, even very small, can bring up the price increase of a series of goods, thus the CPI in China would go up and threaten the goal that government designed for it. This was why the government did not allow electricity price to increase in 2008. Therefore, we can say that pressure from CPI is also an obstacle to improve the surcharge rate in China.

To sum up, although an increase in the surcharge rate could be an effective policy to increase PVG in China, there are obstacles from three perspectives: high electricity-consuming industries, ordinary people and the government itself for the sake of social welfare. Especially in the times of worldwide economic crisis, and in the presence of already 10 percent increase in electricity price, it might be difficult to improve the surcharge rate in China.

There might be one possible solution to educate both the enterprises and the people in China about the importance of developing PV capacity in China, so that the obstacles to implementing the policy from them can be eliminated. Actually, the development of PVG in Japan is a good example of this way. However, it might not be very realistic to do so in China. Therefore, this could be possible in the future, but there is a long way to go.

II. Subsidy percentage

Although the model is not sensitive to subsidy percentage as discussed before, we are sure it is necessary to run the sensitivity test again when the model is not in equilibrium. Because the model is in equilibrium when conducting the sensitivity tests in section 5, which means the table function in the model is set to 1. No matter how big the subsidy percentage is, it won't affect the profitability and enterprise investment won't change at all. That's the reason why the model is not sensitive to the change of subsidy percentage. While the real values are put into the model, say the model is not in equilibrium, the table function will operate then and subsidy percentage will have effect on profitability. Figure 6-2 shows the result of sensitivity test, which justifies that the model is quite sensitive to the change of subsidy percentage. Subsidy percentage is an effective policy parameter to increase the profitability of enterprise investment.

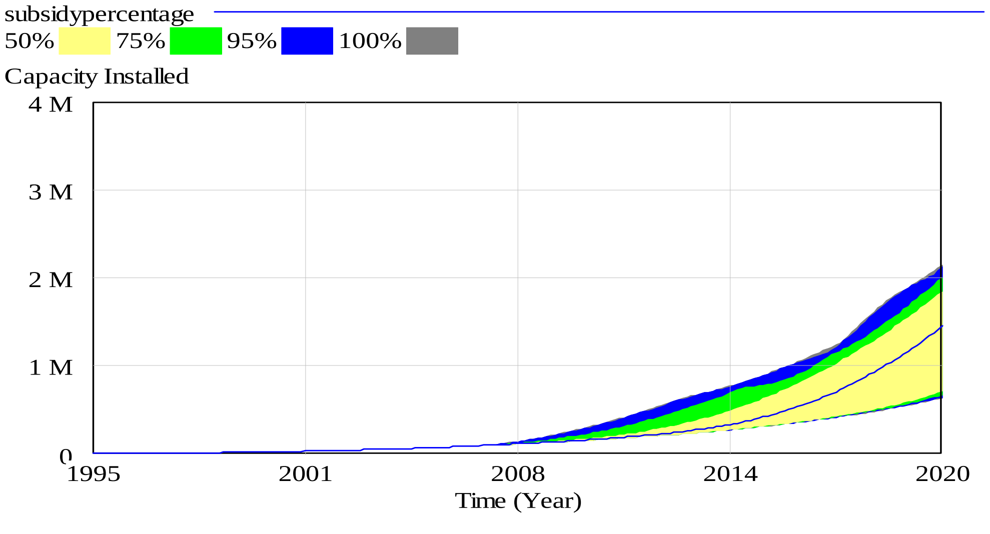


Figure 6-2. Sensitivity test (not in equilibrium): subsidy percentage=0.1~0.9

Therefore, it is recommended that the government increase the subsidy percentage so as to improve the profitability of enterprises to encourage investment.

In fact, this is also a feasible policy which the government has been trying to implement in China. In the past few decades, the government has been giving little subsidy to the enterprises, which led to its reluctance of investing in PVG. Those enterprises that invested in PVG were actually to improve their corporate image, rather than for the sake of earning money. In other words, solar PV capacity turned into image project for these enterprises, which made it impossible for the PVG to really thrive in China.

However, the government established a newly trial policy to grant a fixed 60 percent of cost of each Kilowatt of PVG to enterprises from 2007. It is believed by some experts in PV field that this policy could be effective in terms of encouraging enterprise investment. However, according to this research, 60% subsidy percentage is still not enough to accomplish the goals in 2010 and 2020, as shown in Figure 6-3 (Here we use policy test II-1 to indicate the current policy, say keeping 60% subsidy policy constant to 2020).

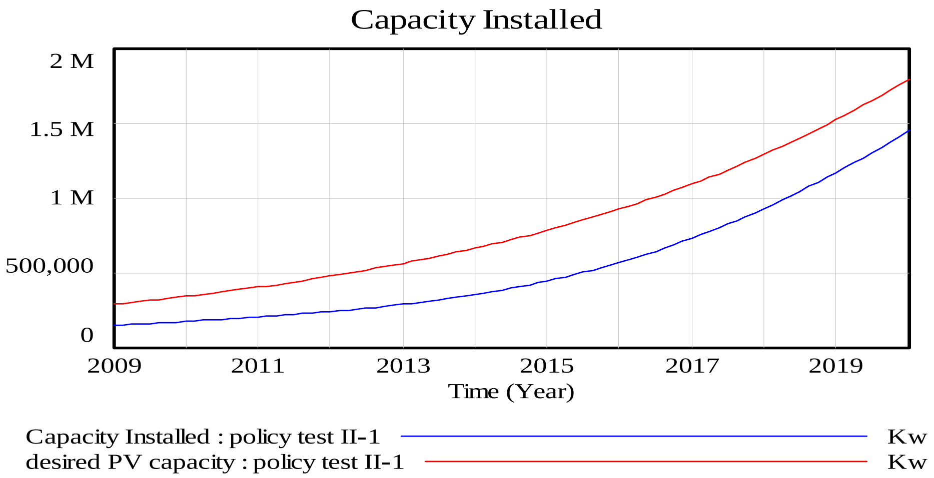


Figure 6-3. Policy test II-1: subsidy percentage=0.6

In order to reach the government's goals of PVG in 2020, the government has to increase the subsidy percentage to 70% from 2009 according to the model (Figure 6-6)

(We labeled this policy option as policy test III-2). Therefore, it is recommended that the government can increase the subsidy percentage to 70% from the year 2009. We can see in Figure 6-4 that the goal in 2020 is achieved, although it still doesn't access to the goal in 2010. Because the new policy starts to operate from the year 2009, it may not be easy to change the sluggish development very soon.

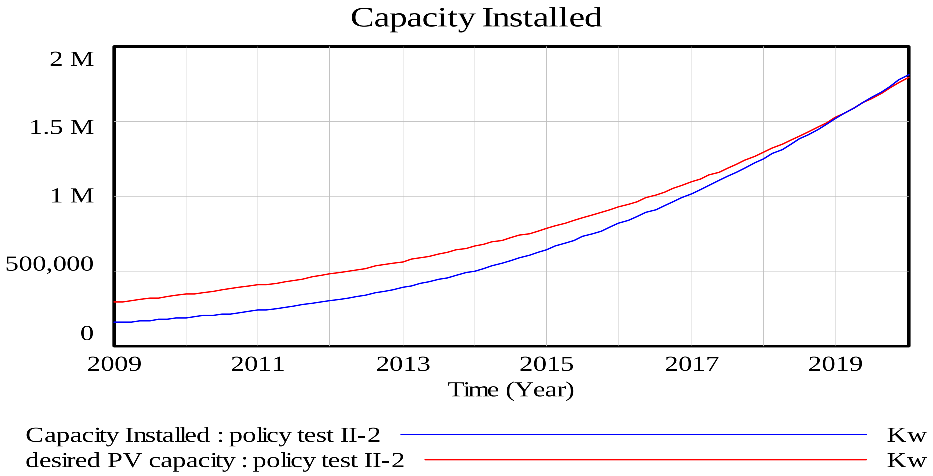


Figure 6-4. Policy test II-2: subsidy percentage=0.6+step(0.1, 2009)

However, by looking at the good examples of countries where the solar PV capacity has been well developed, we can find out that these countries, for instance, Germany and Japan, granted a very big sum of subsidy to PV capacity in the beginning. Then as the PVG developed in their countries, the cost of PVG gradually reduced year by year. Then what these countries did was to reduce the subsidy step by step, till they did not need to give any subsidy for the development of its PV capacity. Therefore, it is recommended that China learn from these countries in this subsidy policy.

Following this mode, it is found that the Chinese government could granted 80% subsidy for the construction of PV capacity from 2009 to 2013, then reduce the subsidy to 65% from 2013 to 2017, and 50% from 2017 to 2020. From the year 2020, the government does not need to grant subsidy to the PVG in China, as shown in Figure 6-5 (this policy option is called policy test II-3).

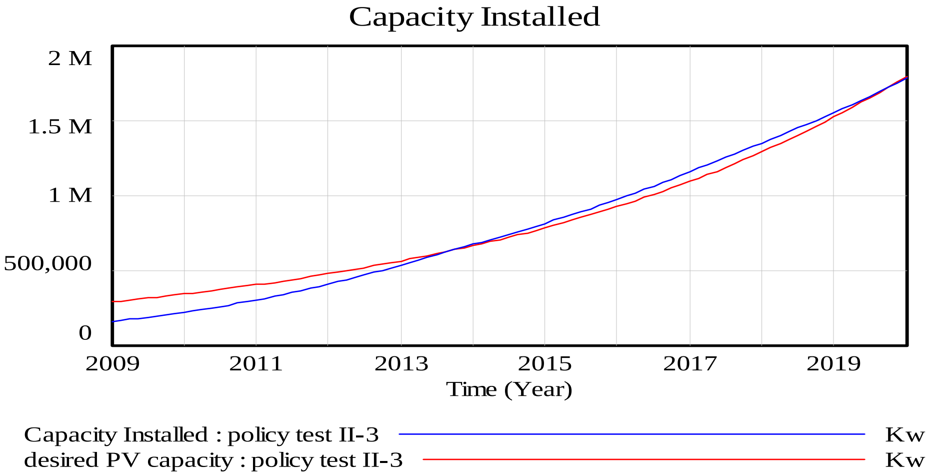


Figure 6-5. Policy test II-3: subsidy percentage=0.8(2009-2013), 0.65(2013-2017), 0.5(2017-2020)

In conclusion, it is recommended that the government increase the subsidy percentage from 60 percent to 70 percent, in order to accomplish the government's goals of PVG in the coming decade. In reference to the experience of some countries where solar PV is well developed, the Chinese government can adopt a "gradually decreasing" subsidy policy, which is to grant 80% from 2009 to 2013, 65% from 2013 to 2017, 50% from 2017 to 2020 and finally no longer grants any subsidy, because by then the cost of solar PV capacity is low enough for its self development.

III. PV fraction

As discussed in the sensitivity test part, the model is sensitive to PV fraction. Due to the fact that PV fraction is in the control of the policy makers in China, as mentioned before, it is justifiable to arrive at the conclusion that PV fraction could be an effective policy parameter to improve PVG in China. As PV fraction is increased, more funds out of the total sustainable funds will be spent on PV construction, thus there will be more Capacity Installed. Therefore, to raise up the PV fraction in China could be an effective way out.

Actually, it is not new to come up with the policy to increase PV fraction so as to solve the problem of PVG dilemma in China. Many experts have called on the government to allocate more money to PVG in China since years ago (Fu, 2007). The difference is that they did not work out quantitative methods to support the suggestions.

The simulation results shown in Figure 6.6 indicate that achievement of the government's goal in 2020 requires a PV fraction closer to 0.30 than 0.25.

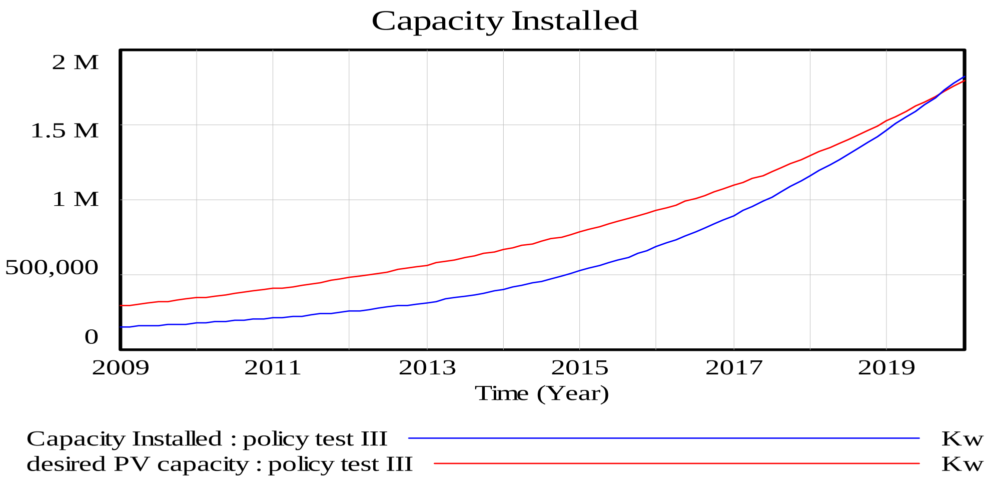


Figure 6-6. Policy test III: PV fraction=0.25+step(0.06, 2009)

If the policy is feasible, why till now no big improvement has been witnessed in the PV fraction in China? According to the analysis of some stockjobbers (Wang & Zheng, 2007), the fact is that the PVG in China failed to win over wind energy, which is also a form of sustainable energy, in terms of its prospect in the eyes of the government. In other words, the unit cost of PV-based electricity is much higher than wind-driven electricity, which is about 2 CNY versus about 0.5 CNY per Kwh. Therefore, a larger share of funds to wind capacity is an obvious outcome.

Therefore, to improve PV fraction could be an effective solution to solve the problem concerning PVG shortage in China. However, till now it has not become a feasible one due to the much higher cost of PV-based electricity.

This led to the PVG dilemma in China: The smaller PV fraction, the less investment into solar PV capacity, the less economy of scale in the PV capacity construction, the less competitive of solar PV energy, thus even smaller PV fraction in return. We can see the vicious feedback concerning PV capacity construction in China below (Figure 6-7):

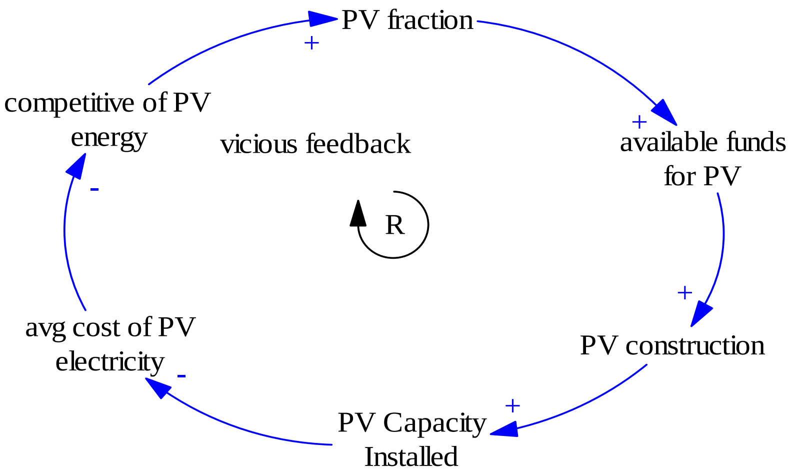


Figure 6-7. Vicious feedback concerning PV capacity construction

Therefore, it is important that the government should be aware of this vicious feedback to keep the disastrous loop from working. Actually, this is also an important aim of this research. Although it is not economically wise, for the time being, to allocate more money into PV capacity, we still hope the government can make the determination to give support to PVG, which has the biggest potential to thrive in the future. The development of PVG in some developed countries, such as Germany, Japan and the US, is a good illustration of that.

Therefore, it is recommended that the Chinese government give support to PVG in spite of the fact that the cost of it is still high compared to other sustainable energy. Actually, this is supposed to be the difference between government and enterprises in the way that the former is public oriented while the latter is benefit oriented. We believe as the government changes the path dependence of the vicious feedback as shown above by improving the PV fraction, the vicious feedback can turn into a virtuous feedback loop.

If that's the case, we can also advise a combination policy by increasing PV fraction to 0.28 and make subsidy percentage 70% from 2009 to 2013, 60% from

2013 to 2017, and 0.5 from 2017 to 2020 as shown in Figure 6-8.

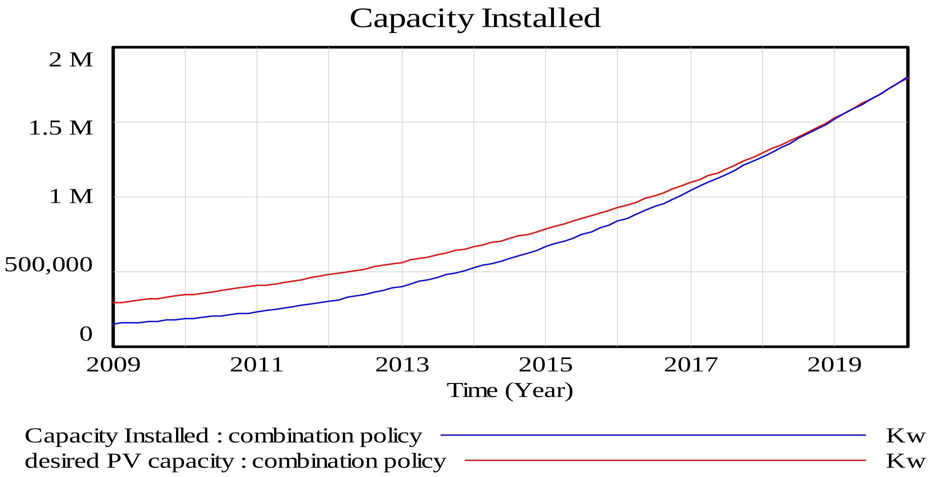


Figure 6-8. Combination policy test: PV fraction=0.25+step(0.3, 2009) and subsidy percentage =0.7(2009-2013), 0.6(2013-2017), 0.5(2017-2020)

IV. Adjustment Time

Adjustment time should be an effective policy parameter based on the sensitivity test results. But it is a bit special as a policy parameter, in terms of the fact that the model is sensitive to it when in equilibrium, but it is not sensitive to it when not in equilibrium as shown in Figure 6-9. The sensitivity test conducted not in equilibrium shows us that the Capacity Installed does not change at all even with the big change range of adjustment time. Therefore, to reduce adjustment time alone might not be an effective policy to improve the PVG in China.

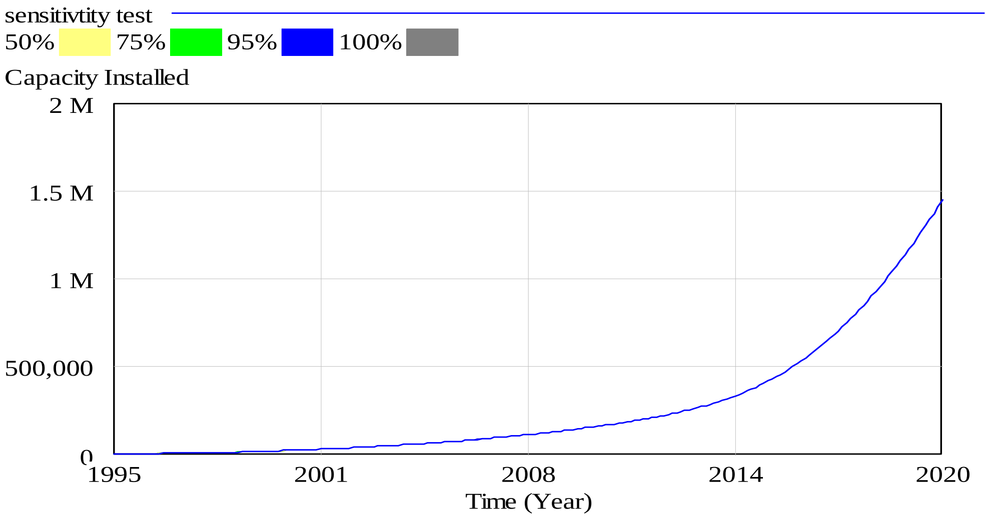


Figure 6-9. Sensitivity test (not in equilibrium): AT=0.5~2.5

However, it could be an effective policy in the presence of other three policies discussed above, or two policies, improving PV fraction and subsidy percentage, due to the somewhat infeasibility of increasing surcharge rate in China. Figure 6-10 shows the results of the sensitivity test of adjustment time, when the PV fraction is 0.31 and subsidy percentage is 0.7 from the year of 2009.

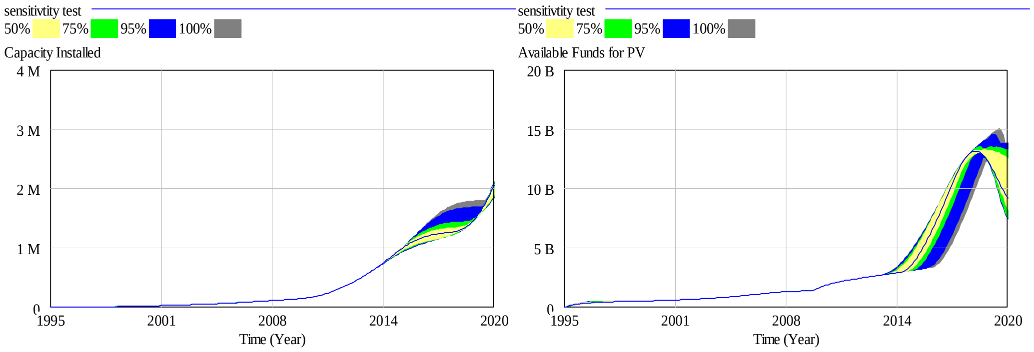


Figure 6-10. Sensitivity test (increasing PV fraction and subsidy percentage): AT=0.5~2.5

Therefore, adjustment time is also an effective policy parameter after the adoption of other two policies, increasing PV fraction and subsidy percentage. Therefore, it is reasonable to say that the policy of increasing PV fraction and subsidy percentage is effective when the model has reached its bottleneck, the constraints of funds. However, after the bottleneck is broken, there can be more policy options, such as reducing adjustment time.

6.2 Policy robustness test

Now the robustness of the policy options discussed above is tested by subjecting the model to changes that are out of the hand of the government, construction time and average life time of PV capacity. In order to do so, the model is run based on three scenarios of GDP. The first scenario is to assume that GDP growth rate will keep the same value as 2008 to 2020 (high GDP growth rate). The second scenario is to set the growth rate linearly drop to 5% in 2020 (medium GDP growth trend). The value of GDP growth rate is supposed to be 2% in 2020 in the third scenario (low GDP growth trend). This is because GDP is an important index of economic status of a country, which in this paper, has big impact on the total sustainable funds, which eventually affect the PV Capacity Installed in China.

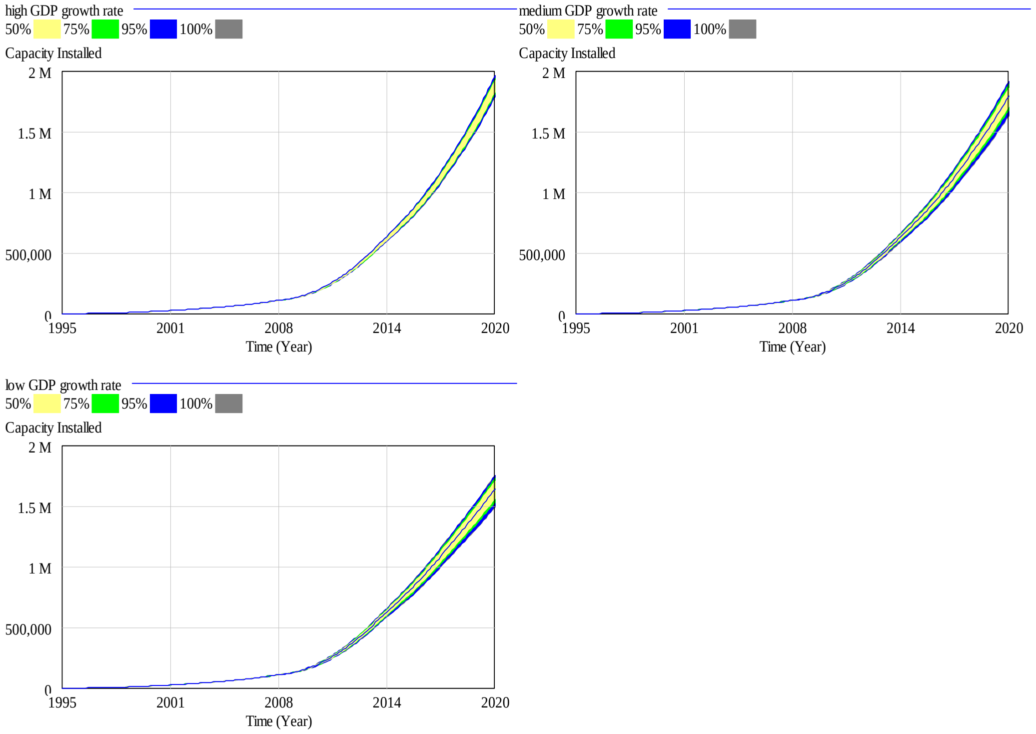


Figure 6-11. Sensitivity test under three GDP growth rate scenarios: Life time=18~22

As shown in the sensitivity tests in Figure 6-11 and Figure 6-12, the model is not sensitive to the two parameters that are out of the control of the government after adopting the policies discussed above, regardless of GDP scenarios in the future. Therefore, according to my knowledge, the policies we recommend for the government are robust.

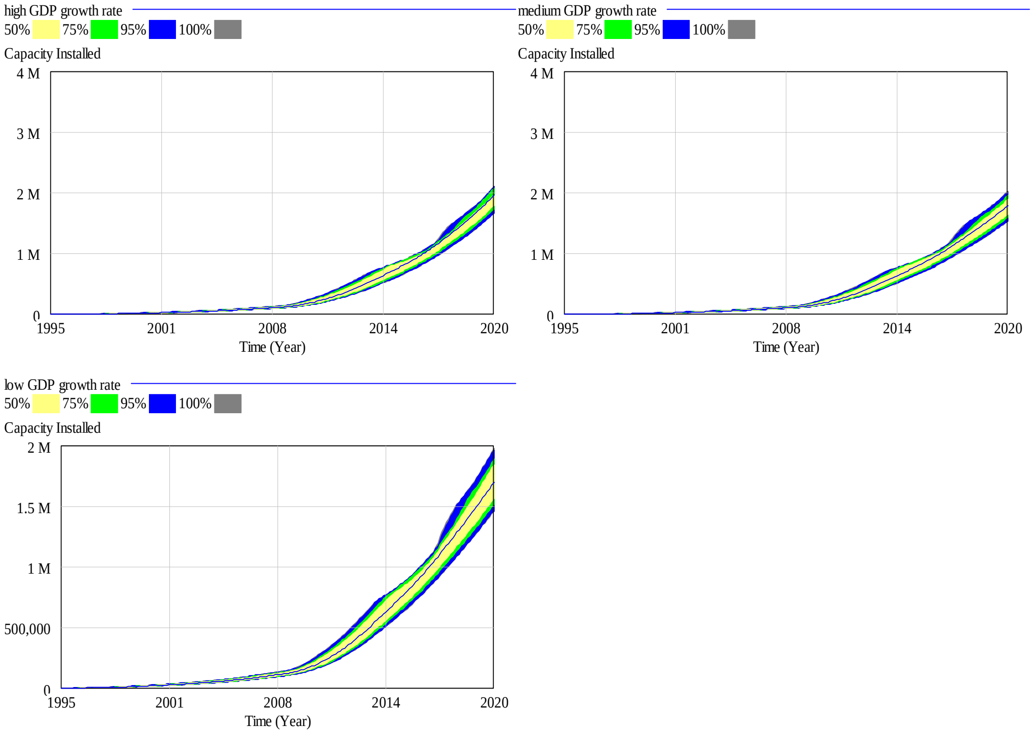


Figure 6-12. Sensitivity test under three GDP growth rate scenarios: Construction time=0.5~2.5

6.3 Conclusion of policy discusstion

To sum up, there are four policy options that are effective in terms of achieving the government's goals of PVG in China: to increase PV fraction, surcharge rate, subsidy percentage and to reduce adjustment time. However, it might not be feasible to increase the surcharge rate due to the obstacles from three perspectives.

To increase subsidy percentage could be the most feasible policy since the government has been trying to implement the policy. However, the current subsidy policy might not be effective enough in order to reach the government's goals. Based on the model analysis, it is recommended the government to increase the subsidy percentage to 70%, or make it 80% from 2009 to 2013, 65% from 2013 to 2017, and 50% from 2017 to 2020, then after that grants no more subsidy.

To increase PV fraction could be feasible if the government has the determination to change the path dependence of the present vicious feedback loop. If so, we suggest the government to raise the PV fraction to around 0.30 from 2009 or to adopt the combination policy to increase PV fraction to 0.28 and make subsidy percentage 70% from 2009 to 2013, 60% from 2013 to 2017, and 0.5 from 2017 to 2020.

Anyway, these three policies proved to be effective when the PVG in China has reached its bottleneck, shortage of funds. After the bottleneck is broken by adopting these three policies, one more policy option becomes available, which is to reduce the adjustment time, i.e. the government adopts more aggressive policy.

7. Conclusions

Through the experience of model building and simulation in the research project, we gained insights into the major problems of the sluggish unfolding of China's PV-based generating capacity. Based on that, policy options have been developed and tested on its effectiveness to achieve the government's goals of PVG in 2020.

7.1 Limitations and future work

Model boundary and assumptions determine the limitations of the work. For example, we have not compare the state energy strategy for alternative new energies, only focusing on PVG; PV cells and modules manufacturing capacity is assumed ample to meet the domestic demand; the average life time and construction time for PV-based electricity generating systems with different scales have not been distinguished.

For the future work, the production sector of PV cells and modules could be introduced to link with the existing cost sector; and the effect of funds re-allocation to the development of other sustainable energies could also be concerned. In terms of the subsidy policy, the major research point could be to investigate the level of on-grid price and its possible effect when implemented in large scale.

7.2 Major findings and contribution

The research discloses the major problems of the sluggish development of China's PV-based generating capacity. One of the reasons lies in the funds constrain on PVG. Because of the high cost of PV generating electricity compared to other sustainable energy, funds allocation to PVG is not big enough to sustain its desired development. Thus there exists the PV dilemma in China: The smaller available PV funds, the less investment into PVG, the less economy of scale in the PVG construction, the less competitive of PV energy, thus even smaller PV funds in return.

The other reason is lack of active enterprise investment. There exists the difference between government and enterprises investment in the way that the former is public oriented while the latter is benefit oriented. Only when a profitable mechanism is established, which benefits enterprises investment, the PVG in China can survive by itself. Both of the above reasons result in the sluggish development in China's PVG, which also raise doubts about the viability of the government's goals in 2020.

The system dynamics model built in the research indicates that the government's goals on PVG can not be achieved under the current trial subsidy policy. We have put forward several options that are effective in terms of realizing the government's goals.

Firstly, the government is recommended to adopt a higher subsidy percentage or to increase the subsidy percentage much higher initially and then decrease it gradually till no more subsidy is needed, which could be a feasible way to encourage enterprise investment and greatly increase PVG in China.

Secondly, the government could reallocate the funds on PV by increasing the PV fraction if the government has the determination to change the path dependence of the present vicious feedback loop, which contributes to the relieve of funds constrain.

The government can be more aggressive in deciding the amount of PVG construction when the above two options are available.

The research findings are the major concerns of the Chinese government when the trial subsidy policy has just been implemented. It can be used to guide the strategic planning.

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Appendix A

A photovoltaic PV generator is the whole assembly of solar cells, connections, protective parts, supports etc (see Figure A).

Figure A. PV industry chain

Since the first silicon solar cell was reported in 1941 with less than 1% energy conversion efficiency, there have been substantial improvements in silicon cell performance, culminating in the 25.0% value reported in the present paper. Since 1983, key results have been independently measured at recognized testing centers (Martin A. Green, 1991). Standardization of past measurements shows there has been a 57% improvement between confirmed results in 1983 and the present result (Martin A. Green, 2009).

With the impelling of technology improvement and progressing statute, the cost of PV module is decreasing gradually from \$100/W in 1970, \$25/W in 1978, \$13/W in 1984 and now around \$3-4/W. Polycrystal silicon takes the major part of the PV modular cost. Table A shows the price and value-added at different production links in 2007.

Table A. 2007 PV Cells Price and value-added at different production links

Production links	Polycrystal silicon material	Wafers	Cells	Modular
Price/\$/Wp	2.05	2.5	3.05	3.65
Value-added/\$/Wp		0.45	0.55	0.60
Percentage/%	56.16	12.33	15.07	16.44

Source: Wang Sicheng (2007)

Appendix B

System dynamics is a methodology for studying and managing complex feedback systems. In fact it has been used to address practically every sort of feedback system. Stock and flows, along with feedback, are the two central concepts of dynamic systems theory (Sterman, 2000). Only the study of the whole system as a feedback system will lead to correct results.

There are several diagramming tools in capturing the structure of systems, including Causal loop diagrams (CLDs) and stock and flow maps. A causal diagram consists of variables connected by arrows denoting the causal influences among the variables. The important feedback loops are also identified in the diagram. Variables are related by causal links, shown by arrows. Each causal link is assigned a polarity, either positive (+) or negative (-) to indicate how the dependent variable changes when the independent variable changes. The important loops are highlighted by a loop identifier with shows whether the loop is a positive (reinforcing) or negative (counteracting) feedback.

Stocks are accumulations. They characterize the state of the system and generate the information upon which decisions and actions are based. Stocks give systems inertia and provide the with memory. Stocks create delays by accumulating the difference between the inflow to a process and its outflow. By decoupling rates of flow, stocks are the source of disequilibrium dynamics in system.

All dynamics arise from the interactions of two types of feedback loops: reinforcing loop and counteracting loop. The basic modes of behaviour in dynamic systems are identified along with the feedback structure generating them. These modes include growth created by positive feedback; goal seeking, created by negative feedback; and oscillations (including damped oscillations, limit cycles and chaos) created by negative feedback with time delays.