

# Innovation Policy and the Transition of Energy System

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## Abstract

Energy systems are deeply embedded in the network of economy, institution and infrastructure. Consequently, a fundamental transition from the present hydrocarbon energy system to a low-carbon energy system will require radical innovation processes. In turn, innovation policy should take into account the systemic character of innovation. This paper provides a brief overview of the current energy system and market development. By using the approach of innovation system theory we analyze the dynamics of several emerging systems, and identify the key activities with main system failures. We will develop a more systemic innovation policy portfolio that aims to improve innovation performance through greater coordination.

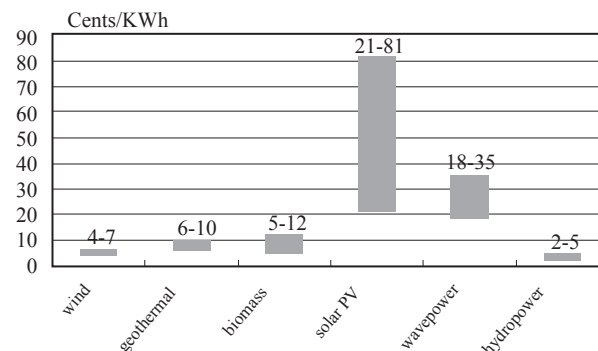
**Keywords:** innovation policy; radical innovation; energy system

## 1. Introduction

Conventional energy sources not only face the risk of depletion, but also give rise to climate change. According to IEA (2010) estimates, growth in global demand for fossil energy is leading to a sustained and rapid growth in carbon dioxide emission, which will not abate at least until the year 2030.

The world's carbon dioxide emission has grown from 20.9 billion tons in 1990 to 28.8 billion tons in 2007, and is expected to grow to 34.5 billion tons in the year 2020, an average annual increase of 1.5%. Although the climate conference in Copenhagen in 2009 did not achieve its intended goals, the development of renewable energy has become a general trend. The world is currently facing a transition from hydrocarbon energy to low-carbon energy.

The main problems are technological innovation and the formation of low-carbon energy industries. So far, renewable energy technology has made great progress and greatly reduced the cost of electricity. Wind power



Source: DOE(2009)

**Figure 1** Price range of renewable electricity by technology (2008)

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began to be competitive with conventional energy sources. Solar photovoltaic power in the near future will also have this capacity.

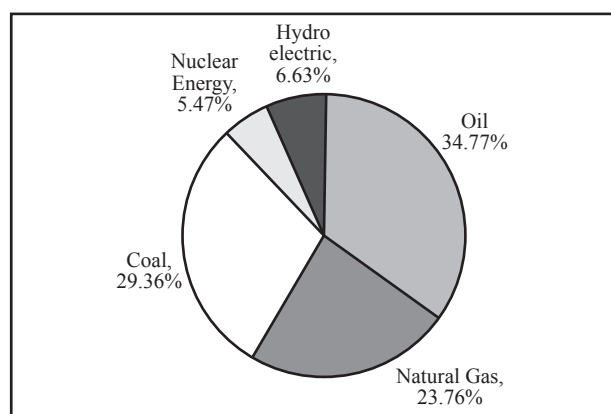
(1) Wind turbines built in recent years typically generate 1.5-2.5 megawatts and even up to 5MW. The per-kilowatt-hour cost of generating electricity from wind has fallen from an industry average of 30 cents in the early 1980s to approximately 10 cents in 2007.

(2) Earlier this decade, the solar energy industry as a whole, which includes solar thermal and photovoltaic (PV) technologies, in both grid-connected and stand-alone applications experienced average annual growth rates in excess of 40 percent (DOE, 2009). Installed PV capacity, most of it grid-connected, grew especially quickly to a cumulative global total of more than 16 gigawatts (peak capacity) by the end of 2008. Meanwhile, the best commercially available PV cells now achieve conversion efficiencies above 23 percent, well above the current industry average of 12–18 percent. Even higher efficiencies have been achieved in the laboratory. Silicon-based solar power efficiency increased from less than 10% in the 1990's to 18% now, and 40% in the lab.

(3) United States, Brazil and other countries' bio-fuel technology has made remarkable progress, but energy and environmental requirements of bio-fuels remain for the most part in the pre-commercial and RD&D phase of development.

(4) Civil nuclear power experienced a relatively period of substantial commercial investment from the 1970s to the mid-1980s, and is now experiencing a second expansion. Various countries have increased subsidies for nuclear power, which is currently in its fourth generation and the period of collaborative research is underway.

So far, there is no energy but civilian nuclear power can change the rules of the energy industry. The energy system is dominated by conventional fossil energy sources. Global primary energy consumption reached 11,164.33 Mtoe (million tons of oil equivalent) in 2009, among them, the total consumption of oil, coal and natural gas reached 9,813.5 Mtoe, accounting for 87.90%. Meanwhile, in the energy field, markets for new technologies have usually emerged when one (or more) of the following occurs: (a) prices



**Figure 2** World energy consumption ratio by fuel (2009)

for conventional resources rise as a result of rising demand and stagnant or falling supply or production capacity; (b) technological possibilities arise that more effectively meet energy demands; and (c) government imposes new policies or regulations that affect market conditions for energy technologies.

From a systemic perspective, the current status of the energy system is quite normal. The transformation of the energy system model contains a number of radical innovations, mainly zero-emission technologies that offer an alternative to the hydrocarbon system: nuclear fusion, hydrogen energy, solar energy, etc. These will minimize the environmental burden of the entire energy cycle and change the generic technology of the energy industry. They will also change the mode of energy production, storage, distribution and usage. To adopt these zero-emission technologies, we need to develop production, transmission and storage systems, construct new infrastructure and adjust industry regulations. Radical innovation shows the complexity of an overall change of “technological regime”. Thus, we are “locked in” to a large-scale hydrocarbon energy system.

This also highlights the need to develop more systemic policies towards the innovation of low-carbon energy.

The structural arrangement of this paper is as follows: Part II gives a short review of innovation systems theory, and provides an analytical framework. Part III takes the German bio-gas industry as an example to analyze the key activities and

**Table 1** Three types of innovations related to climate change<sup>1)</sup>

Modes of innovation	Incremental change	Disruptive change	Radical change
Climate control technologies without emission reduction	Reduced deforestation	Sulphate emissions in atmosphere Carbon sinks	
Emission reducing innovation	Enhanced engine efficiency; District heating and cooling; Gas baseload power	Carbon sequestration/clean coal; Advanced motor fuels; Bioenergy; Fluidised bed; Efficient combustion Technologies; Advanced materials for transportation	
Low or zero emissions technologies	Heat pumping technologies for buildings	Geothermal energy Solar panels Wind energy systems Smart grid	Fusion power; Hydrogen; Hydropower; Ocean energy; Photovoltaic power systems; Concentrated solar Power; Advanced fuel cells; Advanced energy storage technologies (batteries, capacitors, compressed gas storage)

system failure in innovation systems. Part IV takes the Chinese photovoltaic industry as an example to analyze system failure in the development of new emerging industries and energy system transition. Part V presents some short policy suggestions.

## 2. Analytical Framework

### 2.1 Literature Review

At present, innovation is no longer seen as an autonomous process comprised of scientists and firms but rather an undertaking that involves many actors. Most scholars think that innovation is a systemic process.

Carlsson and Stankiewicz (1991) argued that innovation system is comprised of a network of agents interacting in a specific economic/industrial area through a particular institutional infrastructure.

Freeman (1987) defined an innovation system as “the network of institutions in the public and private sector whose activities and interconnections initiate, import and diffuse new technologies”.

Lundvall (1992) opined that the structures and systems of production are two main dimensions in the common definition of innovation systems. Nelson (1993) held that the organization of knowledge development and diffusion are the main factors. In this sense, they all define the innovation system by the key factors in the innovation process. Thus, it can be argued that a definition in a broader sense should encompass all the factors that can influence the development, diffusion and use of innovation, such as economic, social, political, organic and institutional factors as well as other factors (Edquist, 1997).

In the theory of innovation system, scholars always focus on a specific aspect for the convenience of analysis. The national innovation systems approach uses the country as the unit of analysis, and the sector innovation system focuses on the innovative activities of a sector or industry. However, they differ strongly depending on country or technology.

From this point of view, innovation systems are taken to be static. However, innovation systems are inherently dynamic and unstable and the dynamics can be viewed as the nature of actors, networks

1) See Smith (2009). Technological regimes comprise production systems and methods, scientific and engineering knowledge organization, infrastructures, and social patterns of technology use. The author identifies three modes of innovation: incremental innovation, disruptive innovation and radical innovation.

and institutions. Any change in a component in the system may trigger a set of actions and reactions.

In order to describe the dynamics, scholars began to study innovation system from the perspective of functions and key activities. For example, Liu and White (2001) maintained that the innovation system is the explanatory factor in the system. They focused on the activities related to the creation, diffusion and development of technological innovation in the system, and settled on five basic activities: R&D, deployment, end-use, education and linkage.

Those activities can be deemed as the functions of an innovation system. Other scholars like Johnson emphasizes that a system must undertake/commit some functions in order to sustain the growth of an industry, for example to provide resources. He suggests that the innovation system of a technology or a product should be described and analyzed in modes of function. He also provides five functions.

Certainly, as almost all explanations focus on multi-factors in the innovation process, researchers are left to highlight the relative importance of these factors.

## 2.2 Framework

How can it be confirmed whether the innovation system is well-functioning or not? We suggest using the method of system function as we believe that it is important to study the activities (causes, key factors) in innovation systems more systematically.

Through a review of the innovation system literature, we suggest that there are nine basic functions that need to be performed by an innovation system. The following list is categorized with the behavior of firm and government.

### *Function 1: entrepreneurial activities*

Firms are embedded in the innovation system and entrepreneurial activity in innovation systems is of prime importance.

### *Function 2: organization of innovation*

Creation and change of organizations for innovation is very important and mainly includes creating new firms that constitute important channels for the transfer

of both tacit and explicit knowledge.

### *Function 3: resource input and mobilization*

Financial and human capital inputs are the most basic inputs in innovation activities. Resource input is the key factor to the success of new technology.

Human resource capability-building includes education, creation of human resources and personal learning.

### *Function 4: research and development*

Knowledge development is at the heart of any innovation process, but is especially true in the fields of engineering and natural sciences.

### *Function 5: guidance of research*

This activity affects the visibility and clarity of specific needs among technology users. A relevant example is technological guidance provided by the government and the announcement of targets for a certain percentage of renewable energy by a specific time in the future.

### *Function 6: design or transition of institutions*

These activities include legislation intellectual property and tax law, criteria and research input. These influence the creative organization and innovation process by either encouraging or blocking innovation.

### *Function 7: commercialization*

These activities include infrastructure provision, management support and other activities for commercialization.

### *Function 8: market formation*

These activities include niche market creation through various policies. Another option is to create competitive advantages by introducing favorable tax regimes.

### *Function 9: Advocacy coalition*

Parties with vested interests in existing technology invariably oppose new technologies. A league of supporters growing in terms of size and influence will effectively promote “creative destruction.”

Of course, the list above will be adjusted in line with our research into key innovation process factors. Some activities are very important in most innovation systems but others may be relevant only to particular innovation systems, such as the primary importance of technological criteria in the mobile communication industry.

According to the framework above, we could analyze an innovation system of a country or technology by applying the functions of innovation systems to identify the resulting motors of change. When functional patterns are insufficient to sustain innovation system growth and technological progress, it is important that the causes of failure be identified. In many cases these causes can be found within the innovation system structure. Often the necessary components are not in place, the components fail to function in the way they are supposed to or the components do not interact constructively. These types of problems in the structure of the innovation system are labeled as “system failures”. To indicate this, we preceded the name of particular functions with a negative sign “-”.

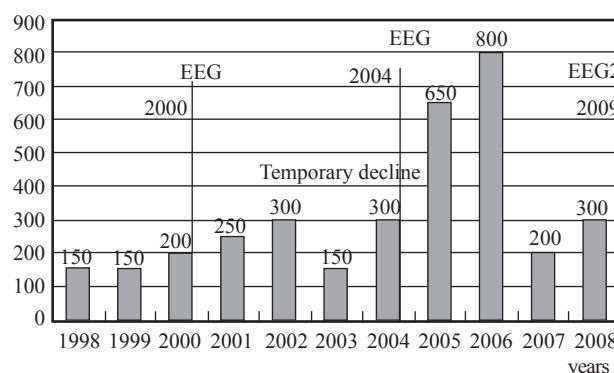
Presently, policy instrument portfolios based on a linear model are insufficient to sustain innovation, necessitating a more accurate framework to account for the systemic character of innovation processes. We should develop a framework that aims to improve the performance of innovation system subsets in a more coordinated fashion.

The method we use does not mean that we could design and plan independently. In fact, a reasonable and systematic policy of innovation could promote the development of an innovation system.

### 3. The Case of Biogas in Germany from 1998 to 2009

In this decade, the German biogas industry has made considerable progress. As of 2008, Germany had about 4,000 biogas plants, of which 300 were built in 2008 alone. The number of installed electric power was only 50MW in 1999 but by 2005 it had increased to 650MW, growing at an average annual rate of 53.34%. After two years, the installed capacity of biogas increased to 1,271MW. In 2008, biogas generating capacity reached 1400MW.

Since 1993, Germany has launched research projects for renewable energy and renewable raw materials, and allocated substantial funding each year for biogas R&D, demonstration and deployment (Function resource input and mobilization). For fiscal year 2000, 51,000,000 DM. was appropriated for R&D and utilization of



**Figure 3** Biogas plants construction in Germany

renewable raw materials, including biogas (Function guidance of research). Many universities, firms and research institutes received federal funding for biogas development, and new organizations were founded (Function organization of innovation). Consequently, German biogas technology and equipment greatly progressed, especially in the area of biogas power generation engineering and technology services, Germany became the leading country (Function R&D).

In Germany, the most important policy document has been the “Renewable Energy Act” (EEG) (Function design or transition of institutions). Between 1990 and 1997, innovation activities occurred that were driven by the introduction of the “Electricity Feed Act” (EFA) for renewable energy and the taxing of fossil fuels. Due to the introduction of these regulations expectations rose among engineers and entrepreneurs that biogas technology could become a promising energy technology for electricity production (function guidance of research). In 1992, the German Biogas Association was established and came to play a role in knowledge diffusion and the formation of interest groups. It began to exert influence on the government (Function Advocacy coalition; Function entrepreneurial activities). We have identified four distinct phases of biogas development.

#### *Period 1: 1998-2001*

This period was characterized by major changes in the institutional environment, i.e. change in government, increase of feed-in rates and liberalization of the energy market (Function design or transition of

institutions) (Negro and Hekkert, 2008). However, in this period, the price of renewable electricity was still too high, averaging 15 cents/KWh, while the electricity market price was only 9 cents/KWh.

To support this form of renewable energy, the Federal Ministry of Economics and Technology, having initiated the “Market Stimulation Program for Renewable Energy,” allocated 150 million Euros, of which 36 million Euros annually was reserved for bio-energy technology, and each biogas plant was eligible to receive 19,000–153,000 Euros in funding (Function resource input and mobilization).

The government, expecting that by increasing feed-in rates energy companies would produce more renewable energy, replaced the “Electricity Feed Act” with the “Act on Sale of Electricity to the Grid” (Negro and Hekkert, 2008).

The new high feed-in rates heightened expectations for the energy companies and agriculture sector as they were to remain stable for 20 years. Furthermore, the “Ordinance on Generation of Electricity from Biomass” (‘Ordinance’) was introduced with the aim of optimizing the availability of biomass (Function design or transition of institutions).

Due to the various programs and the alternation of regulations resulted in continued growth of the biogas sector; 150 biogas plants were built in 1998 and another 150 in 1999 (Function entrepreneurial activities).

#### *Period 2: 2002–2003*

During this period, government policy fluctuated. In 2002, the Federal Ministry of Economics and Technology announced a reduction from 150 million Euros to 86 million Euros in investment support

for biogas plants within the “Market Stimulation Program” (–Function resource input and mobilization). Thus, plants under 200 kW became economically unprofitable, and many farmers halted their construction (–Function entrepreneurial activities).

To boost entrepreneurial activities the Green Party wrote a proposal to support biogas industry and inform farmers of the advantages of biogas.

#### *Period 3: 2004–2006*

In 2003, the Ministry for the Environment initiated an amendment of the EEG. At the same time, the Green Party organized a conference to influence the amendment (Function advocacy coalition). Finally, on 1 August 2004, the amendment of the Act (EEG) entered into force (Function design or transition of institutions). The new EEG provided additional subsidies under the given conditions (Function market formation). Naturally, the higher feed-in rates provided a market for biogas technology and attracted more entrepreneurs to set up biogas plants (Function Advocacy coalition). The act also included a commitment to raise the percentage of renewable energy in electricity supply to at least 12.5% by 2010, and to at least 20% by 2020 (Function guidance of research).

#### *Period 4: 2007–2009*

EEG revisions in 2007 included disincentives that made the biogas industry decline during 2007 to 2008, which in turn led to yet further amendment in 2009. This new EEG version increased the proportion of renewable energy in the national electricity supply to 30% by 2020, while raising the percentage of renewable heat power to 14% by 2020 (Function

**Table 2** Biogas compensation under the EEG (Cents/KWh)

Installed capacity	EFA (1991–1998)	EEG2000 compensation	EEG2000 bonus	EEG2004 compensation	EEG2004 bonus
≤150KW	7.5	-	-	11.5	-
150–500KW		10.2	2.5	9.9	6
500KW–5MW		9.2	-	8.9	4
5–20MW		8.7	-	8.4	-



guidance of research). The act also aimed to introduce new renewable energy technologies (Function guidance of research).

Compared to the EEG as it stood in 2004, this amendment again raised the basic compensation of biogas, increasing the range of additional subsidies, and the decreasing rate was cut from 1.5% to 1%.

In addition to Federal policies, each of Germany's 15 states had its own policies to support the development and utilization of renewable energy. In Germany, both government and biogas plants are very concerned about project quality control, standards, etc (Function commercialization). The German agency TÜV, the national quality inspection institution and its two subordinate divisions, is responsible for Germany's biogas project quality evaluation and inspection.

#### 4. The Case of Photovoltaic in China

Coal contributes about 70% of total primary energy consumption in China, so carbon dioxide emission has become a great challenge for the Chinese government. As a result, the Chinese government has made great efforts to promote energy system transition. We will take Photovoltaic industry as an example to illustrate the current status of renewable energy industries. The development of this industry can be subdivided into two distinct periods.

##### *Period 1: 1986-2004*

China began developing the Photovoltaic industry in 1986 and has placed the photovoltaic industry on the list of the national plans since 1991 (Function guidance of research). The Ministry of Science and Technology and National Development

and the Reform Commission launched many government-funding programs to support photovoltaic technological development to gain patents (Function resource input and mobilization; Function research and development). Among them, the “rural electricity program in western area” launched by National Development and Reform Commission greatly promoted the development of energy technology. The “Bright Movement” and the “Ancient Silk Road Program” were subsequently launched (Function commercialization). The gap between Chinese and international research on solar cells was reduced through years of steady persistence.

##### *Period 2: 2005-2009*

The Chinese government decreed the Renewable Energy Law and related policies commencing in 2005 to develop the photovoltaic industry still further (Function design or transition of institutions). The Renewable Energy Law stipulates regulations of renewable energy exploration, planning, research, development, investment, pricing and tax. Of particular importance is the implementation of the On-Grid Price, which has three main characteristics: (1) guaranteed full acquisition of renewable energy grid-connected electricity; (2) reasonable prices in accordance with the principle of cost plus reasonable profit; (3) deficit between renewable on-grid price and conventional energy on-grid price shared among the whole grid. China also established special funds to support renewable energy technology research and development (Function resource input and mobilization).

“Regulation on Sale of electricity to Grid” in 2007 also mandated that grid utility companies must follow the principles of renewable energy priority to

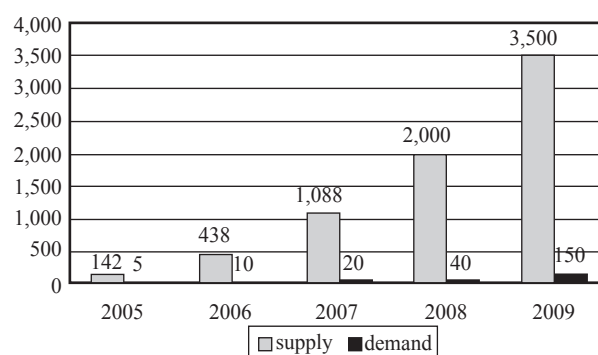
**Table 3** World solar cell production (MW)

Country/ region	1999	2000	2001	2002	2003	2004	2005	2006	2007
U.S.	17.5	20	23	36	66	107	189	337	663
China	2.5	3	4.6	6	12	50	146	438	1,088
Europe	40	61	74	122	200	312	473	680	1,063
Japan	80	129	172	253	365	604	833	927	920
world	201	288	374	537	747	1,201	1,793	2,561	4,000

purchase renewable energy power and provide services to facilitate electricity grid access. Access costs were included in surcharges assessed by the national power grid (Function market formation).

Due to European demand, Chinese Photovoltaic industry has shown explosive growth from 2006. According to incomplete statistics, there are more than ten provinces and cities proposed to promote the photovoltaic industry as new pillar industries (Function resource input and mobilization). As of March 2009, the built and on-building silicon projects in China exceeded 50. According to preliminary estimates, China Photovoltaic industry investment exceeded 100 billion Yuan from 2007 to 2008, while the investment in 2010 is estimated at more than 150 billion Yuan. China has become the biggest country in producing PV cells (Function resource input and mobilization). Already, China PV cell production reached 2 million kilowatts in 2008, and the global market share rose from 1.07% in 2002 to 30% in 2008. Meanwhile, China's solar power prices have fallen rapidly. The national solar electricity price was 4 Yuan/kwh and in March 2009, the bid price of solar power dropped to 1.09 Yuan / kwh in Dunhuang, Gansu Province (Function research and development).

In spite of having the greatest PV cell production in the world, China has such a weak domestic demand that almost all PV cells need to be exported. This is partly because China's renewable energy policy has not been well implemented (–Function design or transition of institutions). Meanwhile, the electricity sector has not really accepted PV power and there is still a lot of resistance in the photovoltaic development. In 2007 the cumulative installation in China was only 100MW. In 2009, the installation rose to 150MW (–Function



**Figure 4** PV cell demand/production in China (MW)

market formation).

Over-investment in the PV industry has led to over-capacity because the Chinese local government has a special preference for investing in huge projects and the cost of resources and the environment have not yet been included in the cost of solar power. Moreover, the financial crisis in 2009 had a great impact on the photovoltaic industry in China.

Overall, China has not established a new industrial innovation system and there is still a deficiency in basic research, key technology and equipment. The overall investment in renewable energy R&D is far from sufficient (–Function research and development). The percentage of China's Energy R&D investment is only one-seventieth of Japan's (–Function resource input and mobilization). China has to introduce technologies from other countries, given the lack of basic core technology of renewable energy, and most of the technology routes are improvements upon Siemens. China also needs to further develop relevant standards, public R&D platforms for innovation and other key organizations (–Function commercialization).

**Table 4** China's PV industry by capacity/production (MW)

	2005		2006		2007		2008		On-building capacity
	capacity	Production	capacity	Production	capacity	Production	capacity	Production	
Si	44	9	367	33	506	122	2,222	500	4,444
Si wafer	-	280	-	630	2,222	1,311	3,333	2,222	3,333
Solar cell	-	200	-	400	2,000	1,088	3,000	2,300	3,000
PV system	-	-	-	709	3,000	1,725	5,000	3,000	3,000



The Chinese government will provide PV industry with subsidies according to two regulations decreed separately by the Ministry of Finance in March and July in 2009, the “Implementation Opinion on Accelerating the Applications of Solar PV Building” and “Financial Assistance Fund Management of Golden Sun Demonstration Project,” respectively (Function market formation). Also, the “Plan of Strategic Emerging Industries” and the “Twelfth Five-year Plan” will give strong support to the solar PV industry (Function guidance of research).

## 5. Conclusions and Policy Suggestions

Through the above case analyses, we can draw the following conclusions:

First, German biogas innovation system performs all key activities, and system functions interact positively with each other.

Secondly, both Germany and China lack policy continuity and broadly shared and long-term vision. Innovation policies are vulnerable to fluctuate.

Thirdly, there are several system failures in China’s renewable energy innovation system.

There are no actors in the system that can yet take the lead in the coordination of a new innovation system. China’s government did not fulfill adequately the task of building a new innovation system or way. Furthermore, China’s renewable energy innovation policy has not been effectively implemented. As a result too few niche markets have been formed.

An adequate infrastructure for renewable power (smart grid, effective access to the electricity grid, large-scale storage facilities, etc) remains lacking.

A necessary long-term financial support for R&D is also absent. Consequently, China has not yet mastered the key technology in the renewable energy field.

Finally, too few actors play their roles effectively and efficiently.

To eliminate these system failures, China need to develop a more systemic policy aiming to support the development of renewable energy innovation systems.

1. The Chinese government should increase investment in renewable energy technology R&D. At the same time, advocacy coalition and more actors should be created. For example, more industry-university-research institute alliances should be established to encourage enterprises to participate in R&D. China also needs to develop a national energy technology research center and related platform. The next step is to assist actors in developing visions, strategies and plans.

2. Renewable energy target should be delineated in the 12th National Economic and Social Development Plan and other related economic development plans.

3. China should amend the Renewable Energy Act as necessary and improve the implementation of the renewable energy innovation policy portfolio. Through technology incentives (like the tax credit), we should increase the demand for renewable energy technologies and promote market formation.

4. The Government should impose new policies or regulations that affect market conditions for renewable energy technologies. Examples include pollution control requirements, access standards, technology standards, technology inspection and quality supervision, etc. The government, power plants and power equipment manufacturers should cooperate to develop renewable energy grid-connection standards,

5. China should develop power grid and other supporting facilities to overcome coordination failure within the innovation system. In Beijing, Shanghai and other metropolises, we should promote the construction of smart distribution networks. At the same time, the development of storage facilities should be undertaken to manage volatility of renewable electricity supply.

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